

**Recording the Facts: A Generic Recording System for Animal
Palaeopathology**

**Thesis submitted for the degree of
Doctor of Philosophy
at the University of Leicester**

by

Stephanie Louise Vann BSc., MA

School of Archaeology and Ancient History

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‘Recording the Facts: A Generic Recording System for Animal Palaeopathology’
by Stephanie Louise Vann

Abstract

The impact of animal disease on human societies has been highly publicised recently, both as a consequence of diseases that have spread amongst animal populations (*e.g.* foot and mouth), as well as those that have ‘jumped’ from animal to human populations (*e.g.* HIV, bird flu and BSE). Non-disease-related pathologies can also provide much information about human-animal interactions, such as the use of animals for traction or riding. While the human, social and economic effect of such conditions is profound, the study of their impact on past human populations has been widely neglected. This is partly due to the inconsistent manner in which incidences of animal disease (palaeopathology) have been collected, recorded and interpreted which, together with the typically low incidence of specimens per site, has precluded any detailed studies of regional or temporal trends. The aim of this project was to improve the study of animal palaeopathology in order to attain a better appreciation of the potential for such research to resolve archaeological questions. This was to be achieved by designing, developing and implementing a methodology to overcome these problems and enable the past impact of animal disease to be better understood.

The primary objectives were to:

1. Design and develop a generic methodology to facilitate the consistent recognition, recording and description of animal palaeopathological data;
2. Implement the methodology within a database system;
3. Apply and critically evaluate the methodology, using assemblages from the Roman legionary fort at Alchester and the Roman town of Colchester, and demonstrate the benefits of adopting a systematic approach to recording animal palaeopathology.

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Chapter One: Introduction

1.1 What is animal palaeopathology?

This thesis is concerned with animal palaeopathology: the signs of health, disease and injury in past animal populations. While this is a topic that is principally embedded within one sub-discipline of archaeological investigation (archaeozoology: the study of animal bones), it is a field of enquiry that requires integration and co-operation across multiple disciplinary boundaries, including: biology, veterinary science, the history of science and medicine, and ethnography. It is also a subject that can contribute to expanding knowledge in multiple disciplines: archaeology, evolutionary biology, wildlife biology, veterinary medicine, the history of science and medicine and wildlife management.

1.2 Why study animal health?

Disease is a common phenomenon. It has affected both human and animal evolution, and has been culturally formative, whether in determining rituals, impeding armies, or influencing the elaboration of therapeutic practices (Brothwell, 1988a: 276). The information provided by the study of animal health in both wild and domestic taxa can provide helpful insights into human-animal interactions, as well as the environment in which both are living (Vann and Thomas, 2006: 2.0). Palaeopathology, therefore, should be viewed as a significant topic in archaeology (Brothwell, 1988a: 276).

The range of questions that can be pursued through the analysis of palaeopathological data is broad. Amongst wild animals it can tell us about natural levels of disease, environmental conditions and landscape. Such questions include: what were the nutritional planes in that environment? What do injury patterns and prevalence indicate about the terrain? What evidence is there for inter- and intra-species conflict? For at least the last million years, hominids have been hunters, developing tool technologies and hunting techniques in relation to a wide range of fauna (Baker and Brothwell, 1980: 2). It seems unlikely that such prehistoric hunters were unaware of injury and disease in the animals they hunted for food, and through palaeopathological analysis of faunal assemblages their response to such injury and disease, and how that affected hunting strategies and behaviour, can perhaps be addressed: were diseased animals hunted or avoided, for example.

Amongst domestic animal populations, other issues can be addressed: which animals were domesticated? What agricultural systems were practised? What were stocking conditions like? How were animals used? Investigation into the occupational stresses being placed upon the animals can contribute to questions about agricultural practices and the Secondary Products Revolution; the shift from primary (carnivorous) to secondary (milk, wool and traction) products believed to occur during the Neolithic (Greenfield, 2002: 14). Conditions related to nutritional stresses can also help to answer questions related to aspects of animal husbandry. By investigating the seasonality of apparent nutritional deficiencies, for example, it is possible to look at when animals were weaned, general population health during the agricultural year, as well as questions of

diet. Meanwhile, traumatic injuries such as fractures can contribute to examinations of veterinary practice, and the use and abuse of animals. This in turn helps to illuminate how humans perceived animals. Were animals pets worthy of care and attention, were they working animals of value to society or were they simply vermin to be driven away?

Animal palaeopathology can even shed light on the prevalence of disease in human populations. Disease, even as a natural process, is no more without its cultural components than other aspects of archaeology. The circumstances that determine transmission can be as much due to social and cultural factors as to biological imperatives. Zoonotic diseases such as tuberculosis, which may be passed from animals to humans and vice versa, provide insight into issues such as domestication and farming. Closer contact with animals of necessity also involves closer contact with their diseases. Examination of the origin and evolution of such diseases in animals can contribute to similar studies in humans, something that can be of great interest to the medical profession in their quest to understand, prevent and cure illnesses even in modern human populations.

1.3 Research aims and scope

Despite the significance of these topics for research both within archaeology and other disciplines, it is clear that the potential of animal palaeopathological research has never been fully recognised (see chapter two). This has partly been attributed to the inconsistent manner in which incidences of palaeopathology are

collected, recorded and interpreted which, together with the typically low incidence of specimens per site, has precluded detailed studies of regional or temporal trends. The aim of this project is to improve the study of animal palaeopathology in order to achieve a better appreciation of the potential for such research to resolve archaeological questions. This is to be achieved by designing, developing and implementing a methodology to overcome these problems and enable the past impact of animal disease to be better understood.

The primary objectives are to:

1. Design and develop a generic methodology to facilitate the consistent recognition, recording and description of animal palaeopathological data;
2. Implement the methodology within a database system;
3. Apply and critically evaluate the methodology, using assemblages from the Roman legionary fort at Alchester and the Roman town of Colchester, and demonstrate the benefits of adopting a systematic approach to recording animal palaeopathology.

What this project will not do, however, is to provide an automated diagnosis and interpretive tool as this is outside the scope of the current objectives.

1.4 Approach and structure

The development of this methodology, if successful, will represent a breakthrough in studies of past human and animal interactions since it will enable palaeopathological data to be recorded in a consistent and comparable

manner for the first time. However, this study does not exist in isolation and it is firmly embedded within a framework of previous research. For this reason it is necessary to provide a brief outline of the historical development of the discipline and highlight the necessity for the present study (chapter two). From the outset it is also necessary to qualify some of the significant terms used in this thesis – the definition of pathology being key – and these too will be considered in the following chapter.

To understand pathological processes, it is necessary to understand something of the underlying anatomy and physiology of the animal. The relevant biological principles will therefore be explained in order to inform later discussion (chapter three). The systems employed within human osteology, where protocols are already well established, as well as those guidelines that have been established for specific animal pathologies, will then be critically analysed with the intent of defining the current situation in the sub-disciplines and establishing best practice (chapter four).

The conclusions drawn from these chapters will inform the devised methodology. The details of this methodology will be given in chapter five, outlining the details of its development, as well as explaining what pathologies should be recorded, how the methodology should be applied, and how the results should be subsequently analysed and interpreted. The benefits and challenges of a systematic approach to recording animal palaeopathology will then be illustrated using archaeozoological material from two Roman sites in central southern Britain: the Roman legionary fortress at Alchester and Cups

Hotel, Colchester (chapter six). Finally, the conclusion will reflect upon the success of the methodological system devised during the period of this research. Future applications and research agendas will also be considered.

Chapter Two: Research Context

2.1 Introduction

This chapter will contextualise current research within animal palaeopathology by providing an overview of the history of animal palaeopathology, as well as describing the types of questions that researchers in this discipline might be called upon to answer. It will then define key basic terminology and explain the term 'pathology' as this is central to the understanding of the methodology.

2.2 History of animal palaeopathology

Interest in the diseases of animals is not new. The history of veterinary medicine dates back many centuries. Amongst the founding fathers of that discipline were Aristotle (384-322 BC) who conducted dissections of animals, Pliny the Elder (23-79 AD) who described normal and abnormal features of animals and plants, and Galen (130-200 AD) who conducted animal dissections and external examinations of lesions.

Roman authors such as Varro in the first century BC wrote of a world of tiny invisible animals that were carried with the air into the body by way of the mouth and nostrils, giving rise to serious disease, views that may have been a compilation of theories of previous writers, since his works on agriculture have survived where many others have been lost (Wilkinson, 1992: 10-11). Pliny,

meanwhile, in his work a '*Natural History*', describes the behaviour of elephants "when worn out by disease (for even these vast masses are liable to disease) lying on their back, and throwing the grass up into the air, as if deputing the earth to intercede for them with its prayers" (Pliny, *N.H* VIII. 1) and the effects, as well as remedies against, canine madness (Pliny, *N.H* VIII. 63). These, as well as discussions of maladies in other animals such as fish (Pliny, *N.H* IX. 73) demonstrate that, even in the Classical period, individuals were aware of disease in animals and had begun to describe it.

However, it was not until the 18th century that the first case of animal palaeopathology was recorded – authors in the medieval period having followed the Classical line. This first case was a reference made by Esper to a pathology on the femur of a cave bear (*Ursus spelaeus*). Later, in 1820, Cuvier described the skull of a hyena from Gaylenreuth displaying a healed injury to the occipital crest. Contemporaneously, in England, Clift noted inflammatory changes in bovines in a paper on cave fauna (Brothwell, 1969: 310). There was increasing reference to ancient disease through to the mid nineteenth century, initially within palaeontology and later also within human osteology until, by the time of World War I, a number of pioneering physicians and anthropologists had clarified the medical nature of ancient skeletal pathologies (Aufderheide and Rodríguez-Martín, 1998: 2-7).

The first comprehensive work by Moodie in 1923 summarised data on disease in both human and animal palaeopathology (Bartosiewicz, 2002: 30) and, along with Pales (1930), placed animal disease within the context of palaeopathology

as a whole. Other publications (*e.g.* Tasnádi Kubacska, 1960), reviewed the evidence for disease in both invertebrate and vertebrate palaeontology (Bartosiewicz, 2002: 30), however the impact of this latter volume was limited by its publication in Hungarian and German (Baker and Brothwell, 1980: 1). It was also only concerned with pathology which had thus far been found in early skeletal material and did not deal with the future possibilities of finding other conditions, something criticised by later workers (*e.g.* Baker and Brothwell, 1980: 1) who felt that a broader treatment was necessary. For example, Baker and Brothwell (1980: 1) stressed the importance of “giving information relevant to the proper interpretation of vertebrate abnormality as found on archaeological sites, the prospects of finding other as yet undescribed conditions, and the ways in which aspects of veterinary studies are relevant within a maturing science of archaeology.”

It was during the 1960s and early 1970s that a new theoretical approach began to influence the discipline. The ‘New Archaeology’ sprang from a desire to make archaeology more scientific and more anthropological (Johnson, 1999: 20). The theoretical body of thought that evolved from this has become known as processualism, so called because of its stress on cultural processes (Johnson, 1999: 30). However, for many people, it was the development and growth of scientific techniques that was one of the key features of ‘New Archaeology’, with the period after the Second World War seeing an explosion in the number and range of these techniques being used in archaeology (Johnson, 1999: 35). These included the use of computers, the study of environmental remains, and dating techniques such as carbon-14 and dendrochronology (Johnson, 1999: 35).

Archaeozoology, and thus animal palaeopathology, also saw a rise in interest at this time. The uniformitarian assumptions inherent in the 'Middle Range Theory' advocated by Binford, a major component of 'New Archaeology', formed the basis for much of this development. The principle that conditions in the present could inform those in the past (Johnson, 1999: 55) provided a study framework that is still used within the discipline today. In addition, an increase in specialisation saw divisions become more pronounced between the study of disease in animals, humans and fossils (Johnson, 1999: 35).

Palaeopathological studies of animals were still few in number when Brothwell (1969) published his synopsis of the palaeopathology of Pleistocene and more recent mammals. This article stressed the need for precise description and careful diagnosis alongside the potential for animal palaeopathology to contribute to archaeology through the study of the transmission of disease from animals to humans. Another early attempt to conduct a thorough survey of animal palaeopathology published seven years later (Siegel, 1976) expressed surprise at the fact that, despite the antiquity of the interest in disease, palaeopathology was still not seen with great frequency in faunal analyses. Instead workers had taken a cautious, even pessimistic, view of the usefulness of pathological data, stressing the many difficulties involved in this kind of analysis. The problems noted included the infrequency of palaeopathological lesions within archaeozoological assemblages, fragmentation and disarticulation of archaeological faunal remains, conflicting nomenclature and a lack of familiarity with abnormal conditions amongst workers. Despite this pessimism, during the formative period of archaeozoology a growing body of literature was

being built up on diseases in early human populations (*e.g.* Jarcho, 1966; Brothwell and Sandison, 1967; Steinbock, 1976), and it was argued that the same should also be possible for animal disease (Siegel, 1976: 350).

The next major milestone in the development of animal palaeopathology was Baker and Brothwell's, 'Animal Diseases in Archaeology' (1980). This book remains the only major English language synthesis of the subject. Following Siegel's classification, this book considers nine categories of pathology – providing in the process archaeological and veterinary examples:

- Abnormalities of skeletal development (*e.g.* supernumerary digits, additional nutrient foramina and other congenital and hereditary anomalies);
- Diseases of the immature skeleton (*e.g.* rickets, osteopetrosis and other diseases of young animals);
- Inflammation, infection and necrosis (*e.g.* periostitis, osteomyelitis and other signs of bone infection or death);
- Traumatic injury (*e.g.* fractures and other injuries);
- Neoplasia (*e.g.* osteomas and other tumours);
- Arthropathy (*e.g.* osteoarthritis, spavin and other types of joint disease);
- Oral pathology (*e.g.* calculus, abscesses and other diseases of teeth);
- Miscellaneous conditions (*e.g.* hypertrophic pulmonary osteopathy and other conditions which do not fit elsewhere in the classificatory system);
- Non-skeletal evidence of disease (*e.g.* calcified parasitic cysts).

This text has been hugely influential (*e.g.* Bartosiewicz and Bartosiewicz, 2002; Bathurst and Barta, 2004; Fabiš, 1997; Murphy, 2005; Thomas, 2001). Even so, it should be noted that this position of importance has largely come about, not just because of its comprehensive coverage, but because there has been no real alternative, and much of the text is taken up with proposing and describing conditions that might *potentially* be recognised in archaeological material (O'Connor, 2000: 105). Additionally, the over-reliance upon this volume by researchers with few other texts has resulted in its use as an identification manual with cases of pathology being matched with images presented by Baker and Brothwell (1980). This has consequently emphasised the 'interesting specimens' approach to palaeopathology with archaeozoologists typically relegating pathological observations to a brief description, or even just a diagnosis (Thomas and Mainland, 2005: 2).

Despite earlier works (Baker and Brothwell, 1980; Siegel, 1976) calling for more attention to be paid to pathology in archaeozoological samples, there was still a general paucity of publications by the time of Shaffer and Baker's (1997) review of historic and prehistoric animal pathologies in North America. This was in contrast to the situation in human palaeopathology where critical reviews of the 1960s had, it seems, acted as a stimulus towards interdisciplinary scholarship and collaboration (Buikstra and Cook, 1980: 461). There was also an apparent contrast between the Old World and the New World within animal palaeopathology, something that was perhaps a reflection of the Old World emphasis on domestic taxa versus the New World predominance of wild taxa, as

well as the longer span of human occupation in the Old World (Shaffer and Baker, 1997: 256).

In recent years there has been a resurgence in the number of papers that have appeared on animal palaeopathology and efforts have been made to move away from the ‘interesting specimens’ approach and consider the wider archaeological implications (Thomas and Mainland, 2005: 2). Comparative studies have investigated the occurrence and prevalence of specific conditions in modern and archaeological data sets (Bartosiewicz *et al.*, 1997; de Cupere *et al.*, 2000; Levine *et al.*, 2000), new techniques have been developed to record specific pathologies (Dobney and Ervynck, 1998), syntheses of regional and temporal trends in palaeopathology have begun to appear (Murphy, 2005; Shaffer and Baker, 1997) and publications have attempted to collate current research in the field (Davies *et al.*, 2005; Miklikova and Thomas, forthcoming). Particular interest has focused on the evidence for the use of cattle for draught (Bartosiewicz *et al.*, 1997; de Cupere *et al.*, 2000; Fabiš, 2005; Groot, 2005; Higham *et al.*, 1981; Johannsen, 2005; Telldahl, 2005), the use of horses for riding (Daugnora and Thomas, 2005; Levine *et al.*, 2000; 2005) and nutritional deficiency and developmental stress in pigs (Dobney and Ervynck, 1998; 2000; 2002; Ervynck and Dobney, 1999; Teegan, 2005a). New theoretical approaches, such as post-processualism, for example, have also seen some uptake within the discipline (*e.g.* Thomas, 2007a), although this has generally been slow. Nonetheless, almost a quarter of a century after Siegel’s overview, O’Connor (2000: 98) still described the study of animal palaeopathology as, “an inchoate discipline, pursued by a relatively small number of analysts.” Many of the

issues, which he sets out in explanation of this, are similar to those expressed by earlier workers (Shaffer and Baker, 1997; Siegel, 1976). It seems, therefore, that despite being recognised for a number of years, these problems have not yet been fully addressed.

2.3 Current problems in animal palaeopathological research

Several factors appear to have contributed to the neglect of animal palaeopathology, some of which are a matter of perception, while others are methodological issues that require addressing (Albarella, 1995: 699; Shaffer and Baker, 1997: 256; Thomas and Mainland, 2005: 1-2). One of the most frequently cited problems with studying animal palaeopathology is the difficulty of diagnosis (Vann and Thomas, 2006: 1). Animal bone assemblages typically consist of isolated and disarticulated fragments. This poses particular difficulties in attempting diagnosis for two related reasons. Because one pathological process can be expressed on several different elements, diagnosis is sometimes only possible through the analysis of the distribution of lesions across the skeleton. This is compounded by the fact that many different disease processes can manifest themselves on particular skeletal elements in a similar manner. As human osteologists have long recognised (Roberts and Manchester, 1995: 6), it is often only possible to undertake differential diagnosis when the skeleton is very well preserved; only rarely do such circumstances present themselves in faunal assemblages (although see Fabiš, 2005 for an exception). While a number of quantitative and qualitative recording systems have been devised to try to overcome such difficulties (e.g. Bartosiewicz *et al.*, 1997; Dobney and Ervynck, 1998; Levine *et al.*, 2000), they are generally very specific, often

relating to only one pathology, frequently intended for a single species and repeatedly driven by a need to address very specific research questions (Vann and Thomas, 2006: 1).

A further problem is that it is frequently only the 'interesting' pathological specimens that are reported: specimens that exhibit extreme deformation, or those that are most readily identifiable, or that reflect the particular skills and research interests of the archaeozoologist (O'Connor, 2000: 108). Moreover, where such pathologies are noted, emphasis is placed on diagnosis rather than description (Vann and Thomas, 2006: 1). This diagnosis-centric approach is problematic for a number of reasons and has been attributed, at least in part, to an over-reliance upon Baker and Brothwell's (1980) seminal volume, 'Animal Diseases in Archaeology', as a solely diagnostic tool (Thomas and Mainland, 2005: 2). As noted by Thomas and Mainland (2005: 1-7), such an approach not only fails to integrate pathological data with the other faunal evidence, but also fails to consider their wider archaeological relevance. No evidence at a population-level can be gained from merely studying isolated examples (Vann and Thomas, 2006: 1).

There is also a belief that pathological conditions occur too infrequently within most assemblages to provide meaningful data (Vann and Thomas, 2006: 1). It is undoubtedly true that small sample sizes plague palaeopathological studies and, combined with the fragmentary and disarticulated condition of most archaeological collections of animal bone, hamper diagnosis and make it

difficult to draw accurate conclusions regarding their significance. However, where the prevalence of broad categories of palaeopathology have been analysed on a regional basis, (*e.g.* Murphy 2005), the results have been extremely informative (Vann and Thomas, 2006: 1).

Given the multiple aetiologies of pathological anomalies coupled with the fragmentary nature of faunal assemblages and the fact that incidences of pathological bone are often low it is perhaps unsurprising that negative attitudes towards the diagnosis of animal palaeopathology and the study of past animal health and disease have persisted. However, it is argued that an adjustment in approach amongst archaeozoologists could provide the solution to these problems (Vann and Thomas, 2006: 1). The development of a generic methodology would, as has previously been argued (Vann and Thomas, 2006: 1), enable the consistent recognition, recording and description of animal palaeopathological data. Furthermore, the experience of human palaeopathologists can be drawn upon to suggest how animal palaeopathology might be recorded more consistently (Vann and Thomas, 2006: 1). Recording is important because it is only through accurate and consistent recording that questions of wider significance to archaeologists can be addressed. We must never forget that animal palaeopathology, and its ‘big brother’ archaeozoology, are merely branches of a much larger discipline – archaeology – a discipline focused primarily upon the study of humans in the past. To be of value outside the sub-discipline itself, studies must be archaeologically relevant. Animal palaeopathologists should, therefore, ask themselves what their results demonstrate about human-animal relationships and human society generally.

However, issues such as small sample size make it of paramount importance that analysis is conducted, not just at a site-level, but also on a broader level. Population-based studies have a key role to play in bringing animal palaeopathological research to a wider audience.

2.4 Terminology

Having now contextualised this study in light of previous research, it is necessary, before proceeding to consider the ideas upon which the generic methodology was constructed, to define some key aspects of terminology; the most important of which is the definition of pathology itself.

2.4.1 Significant terms used in this study

Whilst key points of the devised methodology were that the protocol should be accessible to a wide audience by keeping it simple and effective and that the terminology used should be understood by all researchers, regardless of academic background or nationality, it was nonetheless necessary to use a number of terms specific to the discipline. These are defined where they are encountered in the text and also in the glossary (appendix 1), and the problems inherent within palaeopathological terminology and nomenclature are discussed in greater detail in section 5.2. However, to aid comprehension, a number of the more important general terms that are encountered within the thesis are defined here.

- **Aetiology:** The study of the cause or origin of disease.
- **Epidemiology:** The study of the incidence (or prevalence), distribution and determinants of disease in populations.
- **Lesion:** A broad term referring to any pathological or traumatic discontinuity of tissue or loss of function of a part; one of the individual points or patches of a multi-focal disease.
- **Prevalence:** The relative frequency of pathological specimens to non-pathological specimens within a population.

2.4.2 *What is pathology?*

Pathology has been defined as “the signs of disease and injury in... hard and soft tissue” (O’Connor, 2000: 98). However, this definition is perhaps too narrow for practical purposes when dealing with archaeological remains as it requires a condition to be diagnosed as due to some type of disease before recording can take place and makes no allowances for those conditions where the underlying cause remains a mystery. Given the unknown aetiology of many conditions, it is perhaps not surprising to find that palaeopathology has often been viewed by archaeozoologists simply as ‘abnormality’. This does, nevertheless, broaden the scope of the field and raises the question of exactly what is ‘normal’ and what is ‘abnormal’ (Vann and Thomas, 2006: 4.2). Periodontal disease, *i.e.* the infection of the alveolar bone surrounding the teeth and the periodontal membrane of each socket, for example, shows the development of porous bone around the margins of one or more alveoli in the mandible and this might be taken as diagnostic. However, close examination of a series of mandibles will demonstrate a range of bone surface porosity. The

ends of that range will define ‘normal’ and ‘pathological’, but numerous specimens will fall somewhere in between (O’Connor, 2000: 107). Furthermore, it is worth remembering that both bone formation and bone destruction are normal cellular processes, and bone will re-model many times during the life of the individual, blurring the boundary between what is pathological and what is non-pathological.

Non-metric variation is also often conflated with palaeopathology (*e.g.* Andrews and Noddle, 1975; Baker, 1984: 255; Baxter, 2002; Brothwell *et al.*, 1996; Manaseryan *et al.*, 1999). Non-metric variation is discontinuous, with traits exhibiting only one of a fixed number of variables. An example of this might be the number of molars in an adult human; the maximum number is twelve and some people may have fewer, however, it is not possible to have 9.3 molars, and thus the range of possible values is discontinuous (O’Connor, 2000: 111). Most individuals would not view the absence of one or more wisdom teeth in a modern human as evidence of disease. Instead, as with many non-metric traits, this would be perceived merely as another example of variation between individuals due to genetic or environmental factors. Should non-metric traits therefore be recorded by palaeopathologists?

Research into the aetiology behind the absence of second permanent premolars in ruminants (Andrews and Noddle, 1975) is one example where non-metric traits have been treated as interesting abnormalities worthy of study, and such studies are seen in both human (*e.g.* Tyrell, 2000) and animal palaeopathology. This is not to suggest that the authors of such papers imply that non-metric traits

are pathological. However, they are treated in much the same way as genuine examples of disease or trauma. It is, therefore, necessary to consider whether a generic methodology should include the ability to record conditions currently viewed as non-metric traits.

Unfortunately, this issue is complicated by that fact that determining whether a condition is truly pathological or congenital is often difficult (Vann and Thomas, 2006: 4.2). Several conditions that might once have been viewed as pathological are now instead considered to be examples of non-metric variation, and there are other conditions where the precise aetiology is still unknown. An example of this debate can be seen in the discussion on the causes of perforations in cattle skulls (Baxter, 2002; Brothwell *et al.*, 1996; Manaseryan *et al.*, 1999). Explanations for these lesions include parasites, tumours, infection and chronic pressure from yoking; congenital factors are now seen as most likely, although the precise reason for the occurrence of these perforations is still not entirely understood.

This example is not isolated and a decision was consequently taken to accept that, at this present time, it would be better for a generic recording system to have the flexibility to permit the recording of those conditions whose aetiologies are currently uncertain. This would then at least permit the consistent recording of these abnormalities and encourage future research to enable the aetiology to be determined, even if that later proved to be non-pathological. This recording protocol thus considers pathologies and related conditions to be “variations from

the typical confirmation observed in an assemblage due to bone formation, bone destruction, or alterations in size or shape” (Vann and Thomas, 2006: 4.2).

Whilst a generic recording system requires the flexibility to cope with all of these conditions, it is also true that all pathologies share common traits and it is upon these that a methodology has been built. This commonality is based upon the biological manifestations of bone reaction. The actions of bone cells result in two basic, non-mutually exclusive, responses to disease:

- bone formation (a blastic response);
- bone destruction (a clastic response);

These in turn can generate two other major categories of pathological alteration: alteration in size and alteration in shape. The precise form these responses take can be diagnostic, especially when considered together with anatomical distribution, and diagnosis is primarily achieved by discerning differences between them. Nevertheless, it is the similarities that provide a starting point for the descriptive recording, which is the aim of the generic methodology, and the biological nature of these will be discussed further in the following chapter.

Chapter Three: Animal Anatomy and Physiology

3.1 Introduction

To understand pathological processes and be able to correctly understand and categorise them, it is necessary to understand something of the underlying anatomy and physiology of the animals and their response to disease and injury. The relevant biological processes will, therefore, now be discussed in order to inform later discussion.

3.2 Gross bone anatomy

Normal bone shows two gross anatomical forms in varying proportions, depending on the particular type of supportive function required of it. These are:

1. Compact bone, seen in the shafts of long bones, where it contributes rigidity and forms the dense outer shell (cortex),
2. Cancellous bone, which (along with marrow) occupies the medullary cavities, where it contributes compressibility and pliability.

Both of these have a lamellar structure. However, they differ in terms of their basic unit and organisation. That of compact bone (Figure 3.1) is the osteon. These are arranged in vertical columns and come in two types: primary and secondary (Haversian systems) (Martiniaková, 2006: 18). The main difference between the two is that primary osteons are not surrounded by a reversal line; lamellae around primary osteons merge smoothly with the surrounding bone (Martiniaková, 2006: 18). Secondary osteons consist of a central (Haversian)

canal, which is surrounded by concentric rings of matrix called lamellae. Between these rings are spaces, or lacunae, in which bone cells called osteocytes are located. Small channels (canaliculi) radiate from the lacunae to the Haversian canal, providing passageways through the hard matrix (Martiniaková, 2006: 18).

The Haversian canal is 30 – 70 μm in diameter and contains nutrient vessels, nerves and connective tissue (Martiniaková, 2006: 18). Volkmann's canals, running obliquely through this system, enable communication between the Haversian canals, as well as the periosteum and bone marrow (Martiniaková, 2006: 18). They can be differentiated from Haversian canals by their lack of concentric lamellae (Martiniaková, 2006: 18).

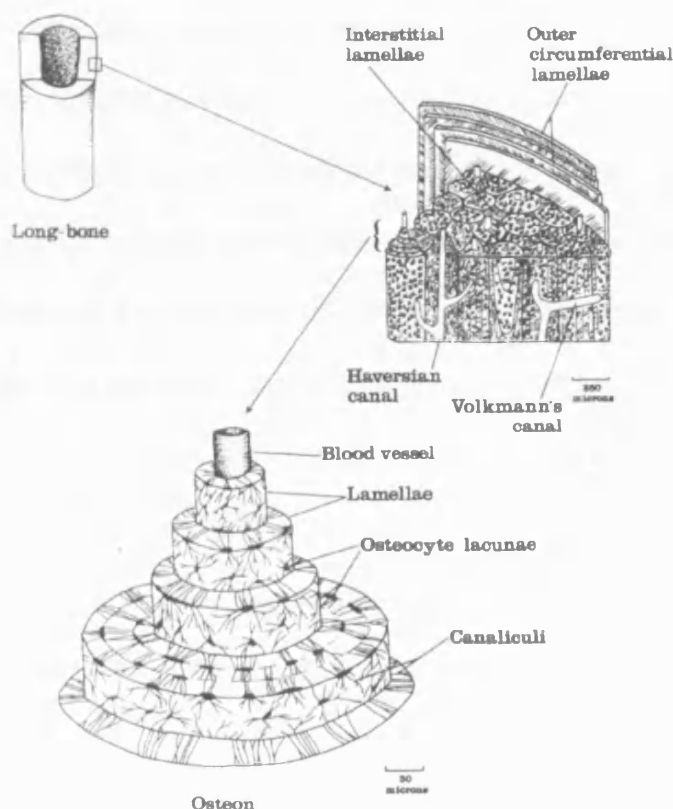


Fig 3.1: The microscopic structure of cortical bone (Mays, 1998: Fig 1.5)

The basic units of cancellous bone are trabeculae (thin, bony plates that surround variably small air cells), which are arranged along lines of stress (Reid and Roberts, 2005: 600). These cells are filled with collagen, a soft, fibrous connective tissue, which has the effect of transferring stress to the walls of the bone itself (Schwartz, 1995: 7). In contrast to compact bone, complete osteons are usually completely absent from cancellous bone due to the thinness of the trabeculae (Martiniaková, 2006: 20). Cancellous bone is more metabolically active than compact bone due to its larger surface area for remodelling (Martiniaková, 2006: 18) (section 3.5).

In addition to these two main types of bone there is another form, woven bone, which needs to be taken into consideration. This primitive form has a non-lamellar structure, and is laid down during foetal development and, in adult life, during bone repair and tumour formation (Reid and Roberts, 2005: 600). Microscopically, the osteocytes, a type of bone cell, (discussed in section 3.3) seem to be randomly scattered through the ground substance, and are present in greater numbers than in lamellar bone. However, the stability of the bone is reduced due to a reduction in mineral content by comparison. This makes it more resistant to traction and flexion (Schultz, 1997: 191). Later, it is often replaced by lamellar bone (Reid and Roberts, 2005: 600). The trend from woven to lamellar bone is seldom reversed even in disease, although in Paget's disease in humans, canine craniomandibular osteopathy and hypervitaminosis D, lamellar bone is removed and replaced by woven bone (Jubb *et al.*, 1993: 9).

3.3 Bone cellular structure

Bone cells are identified on the basis of their activity (Kardong, 2002: 179).

There are three main types (Reid and Roberts, 2005: 601):

1. Osteoclasts are large cells that destroy bone. They are derived from marrow precursors and are related to white blood cells. They produce acid and enzymes to remove bone, as well as collagen degradation products such as urinary HO proline – a marker of bone destruction,
2. Osteoblasts are the cells that form new bone. They are derived from osteoprogenitor cells and produce Type I collagen and other proteins, as well as secreting alkaline phosphatase – a marker of bone formation. This new bone is called 'osteoid'. They also control calcium and mineral deposition,
3. Osteocytes are cells inside the bone that derive from osteoblasts. During bone formation, some of the osteoblasts turn into osteocytes. These are then surrounded by new bone. Long branches known as filopodial processes connect them to other osteocytes via canaliculi and permit them to sense pressures or cracks in the bone and direct the osteoclasts.

As stated in section 3.2, the intercellular matrix is composed of both organic and inorganic materials, as well as water. In fresh bone, it is estimated that these are present in a ratio of 25% organic material to 50% inorganic material to 25% water (Schultz, 1997: 189). The inorganic materials consist of bone minerals such as phosphate (about 50%), calcium (about 35%), carbonate (6 – 7%), as

well as citrate, nitrate, sodium, magnesium, fluoride and strontium (Schultz, 1997: 190). Approximately 90 – 95% of the organic materials, on the other hand, consist of bone collagen, although other proteins such as osteonectin, osteocalcin and osteopontin, as well as proteoglycans and glycosaminoglycans can also be found in the intercellular matrix (Schultz, 1997: 191).

The multiple elements that make up a bone are joined by cement. This is a well-mineralised, collagen-free connective tissue with a high sulphur content and a higher calcium: phosphorus ratio than lamellar bone (Jubb *et al.*, 1993: 10). In histologic sections, cement appears as basophilic lines of two different types: smooth and scalloped. The smooth lines are ‘resting lines’, which indicate that previous cell activity was formative. The scalloped lines are ‘reversal lines’, which indicate that activity had been resorptive (Jubb *et al.*, 1993: 10).

There is a time lag between the production of matrix and its mineralisation. Thus, a layer of unmineralised osteoid normally covers surfaces where bone is being formed. The layer may be relatively wide on lamellar bone because a time lag of several days is usual, but narrow on woven bone, which mineralises rapidly after it is formed (Jubb *et al.*, 1993: 11-12). The rate of osteoid production and the lag between that and mineralisation vary between species, and within species according to the age of the individual and the site in the bone (Jubb *et al.*, 1993: 12).

The activities of the different bone cells are closely linked in the normal process of bone turnover. In adult humans 10% of the skeleton is replaced annually

(Reid and Roberts, 2005: 601). This is part of bone remodelling and repair, discussed further in section 3.5.

3.4 Bone development and growth

Alternative criteria by which bone can be classified are that of the pattern of embryonic development, from which we have two types (Kardong, 2002: 179):

1. Endochondral bone,
2. Intra-membranous bone

Development of both types begins with local aggregations of loosely-arranged mesenchymal cells, which derive mainly from the mesoderm (the middle layer) of the embryo. Thereafter, the two processes differ. In intra-membranous development bone is formed directly with no cartilage intermediary. In contrast, in endochondral development, cartilage is formed initially and subsequently replaced by bone (Kardong, 2002: 179).

Endochondral means within or from cartilage, and bones resulting from this process are sometimes referred to as “cartilage or replacement bones” (Kardong, 2002: 180). During this developmental process we can recognise in some bones three regions: the middle shaft is the diaphysis; each end is an epiphysis; and the region between is the metaphysis or epiphyseal plate. Endochondral bone development involves the formation of a cartilage model of future bone from the mesenchymal tissue and the subsequent replacement of this model by bone tissue. This cartilage replacement begins in the diaphysis and continues in the

metaphysis, the epiphyseal plate being the active area of cartilage growth, calcification, cartilage removal and new bone deposition (Kardong, 2002: 180). Bones in fishes, amphibians and reptiles grow in this manner throughout their lifetimes, although growth slows in later life. Birds and mammals, however, cease growing once adult size has been attained (Kardong, 2002: 182). This epiphyseal fusion typically occurs in a particular order within the skeleton, and within particular age ranges, it is therefore a common method of assessing the age of an animal in archaeozoology.

In intra-membranous development, bone forms directly from mesenchyme without a cartilage precursor. Initially, this mesenchyme is compacted into sheets or membranes; hence, the resulting bones are occasionally referred to as “membrane bones” (Kardong, 2002: 182). As the mesenchymal cells condense, they become richly supplied with blood vessels. Between these there appears a gel-like ground substance in which dense bars of bone matrix are deposited. Subsequent growth proceeds by application of successive layers of new bone to these bars (Kardong, 2002: 182). An example of this process is the formation of the flat bones of the skull (Jubb *et al.*, 1993: 16).

Once bone matrix appears, the two developmental routes proceed through the same stages. Firstly, formative immature (woven) bone arises. This contains numerous cells and irregularly strewn bundles of collagen. This is replaced in the second stage by mature (lamellar) bone that is sparsely populated with bone cells, but possesses orderly-arranged layers of matrix. It is impossible to tell

from gross visual appearance which method of development produced mature bone (Kardong, 2002: 179).

It is when these naturally-occurring processes of development are not controlled by the normal mechanisms that pathological conditions such as tumours or neoplasms occur. These are independent of adjacent tissues and grow in a parasitic fashion (Baker and Brothwell, 1980: 96). Neoplasms are typically divided into two categories: benign and malignant. Benign growths grow slowly and are usually discrete entities that displace rather than invade adjacent tissues. Malignant growths, however, tend to grow much faster and have an indistinct surface due to their invasion of other tissues. Unlike benign growths, malignant tumours often spread to other parts of the body where they produce secondary lesions, also known as metastases (Baker and Brothwell, 1980: 96).

3.5 Bone remodelling and repair

Bone is a living, dynamic tissue. It, therefore, reacts to intrinsic and extrinsic stimuli in predictable ways. It responds either by adding bone to, or removing bone from, the skeleton (Martiniaková, 2006: 25). Such responses are achieved through modelling and remodelling. The first is the simple addition or removal of bone from an existing surface. The second involves the resorption of existing bone, coupled with the formation of new bone to replace the old in the same location (Martiniaková, 2006: 25).

This process is undertaken by the basic multicellular units of osteoclasts and osteoblasts (Martiniaková, 2006: 25). The osteoclasts erode channels through

the existing bone. In the wake of these, large populations of osteoblasts line the newly eroded channel and deposit new bone in concentric rings, forming a new osteon that often overrides the lamellae of older osteons (Kardong, 2002: 183). Bone repair such as this is not only an important part of preventative maintenance – repairing the micro-fractures that accumulate in the mineralised matrix of bone over time and which, if left unattended, might result in bone fracture – it is also a continuous process through which bone adapts to new functional demands through an animal's lifetime (Kardong, 2002: 183).

Despite the preventative maintenance, however, it is still possible for an unexpected blow or twist to break a bone. This initiates a four-step repair process (Kardong, 2002: 184):

1. A blood clot forms between the broken ends of the bone. Smooth muscle contraction and normal clotting seal the severed ends of the blood vessels that run through the bone.
2. A callus develops between the ends of the break, mostly from the activity of cells within the periosteum. This callus is composed of hyaline and fibrocartilage, often with remnants of the blood clot. New bone spicules also begin to appear at this stage.
3. The cartilaginous callus is replaced by bone, largely through a process reminiscent of endochondral bone formation. Cartilage calcifies, chondrocytes die, vascular tissue invades, osteoblasts and osteoclasts arrive, and bone matrix appears. This leaves the broken ends knitted together by irregular spicules of bone.

4. Osteoblasts and osteoclasts participate in the remodelling of the roughly mended bone to finish the repair process. This process can continue for months and, if the original break was severe, the area might remain rough and uneven for many years.

The process of fracture repair is a unique form of wound healing during which bone is regenerated for the purpose of accepting mechanical loads (Einhorn, 1992: 89). Involving both endochondral ossification and membranous bone formation (Einhorn, 1992: 89), it repeats events that take place during normal growth and development (described in section 3.4). One of the most complex phenomena in vertebrate biology, it involves a series of cellular, physiological and mechanical events which begin with inflammation, chemotaxis (the response of cells to chemical stimuli by directed movement), proliferation and differentiation, and culminate in a stage where the healing tissue is converted to a mechanically competent structure (Einhorn, 1992: 98).

The same processes of bone formation and bone destruction also take place as a response to pathological conditions. For example, infection or injury may stimulate osteoblasts lining the subperiosteum resulting in the formation of plaques of woven bone upon the bone surface. In time, if the infection is healed, such plaques may themselves be remodelled (Larsen, 1997: 83). More severe infections involving pyogenic (pus-producing) micro-organisms such as *Staphylococcus aureus*, may enter the arterial system of a bone resulting in osteomyelitis, a condition frequently associated with destructive cloacae or sinuses at the site of infection from which pus is exuded (Larsen, 1997: 83-84).

3.6 The skeletal system

The skeletal system of animals is very important for several reasons (Withers, 1992: 449):

- It reflects their morphological adaptations for locomotion and feeding;
- It maintains a constant body shape, the body tissues being supported against external forces that would deform them and against internal muscular forces;
- It allows terrestrial and aerial animals to resist the force of gravity.

There is an almost infinite variety in the shapes of bones because different vertebrates use them in many different structural roles. However, there are four general shapes (Withers, 1992: 455):

1. Long, thin bones *e.g.* the limb bones;
2. Compact-shaped bones that are about as long as they are wide *e.g.* carpals and tarsals;
3. Flat, thin bones *e.g.* scapula, pelvis and skull;
4. Vertebrae.

Each bone is sheathed in a connective tissue called the periosteum. The outer layer of this functions in the attachment of tendons and also carries blood cells, lymphatics and nerves. Endosteum lines the bone marrow cavities as well as the trabeculae of spongy bone and the vascular canals of compact bone. The inner cellular layer of both periosteum and endosteum is capable of producing bone

cells that participate in growth as well as in fracture repair, described in more detail in sections 3.4 and 3.5, and responses to infection and inflammation (Schwartz, 1995: 10).

Bone is a suitable material for skeletal elements involved with support and movement because it has high tensile and compressive strengths. However, it is a heavily mineralised tissue and so it is important to minimise the amount of bone (and hence its weight) in structural elements without compromising the mechanical strength required for their particular role. The general mechanical principles that determine shape and structure can be illustrated using the femur, a long bone in a vertebrate leg.

A long, thin bone that is expanded at each end for articulation at the hip and knee joints, the shape of the femur reflects the nature of the forces it experiences, and the surface features (*e.g.* spines, ridges and tubercles) are for attachment to muscles. A bone cannot be made lighter simply by making it smaller as this compromises its structural role. However, the internal structure can be modified to maintain integrity and minimise weight (Withers, 1992: 455-456).

The beam model used by engineers to design and analyse man-made structures can also be used to analyse other structures provided that they are long relative to their width (Ruff, 1992: 37). It has, therefore, been found applicable to the analysis of long bone diaphyses, as well as certain other skeletal regions such as the mandible and the femoral neck.

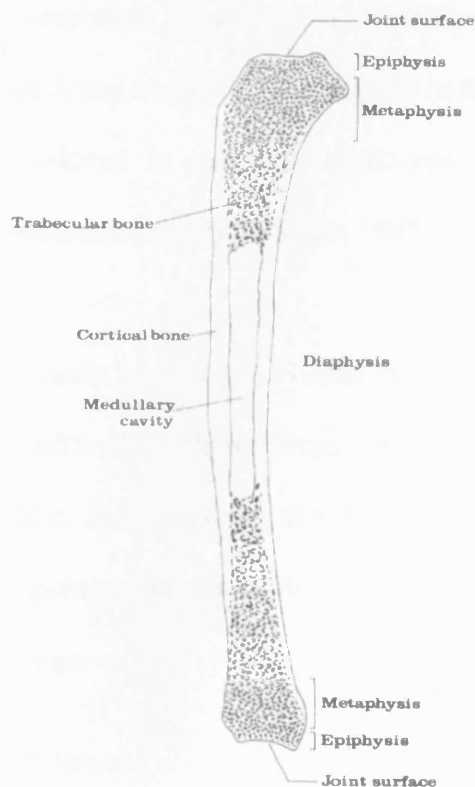


Fig 3.2: The structure of a long bone

(Mays, 1998: Fig 1.2)

In beam model analysis, cross sections are taken perpendicular to the long axis of the beam (bone) and certain other geometric properties are determined from the amount and distribution of material (bone) in the section. These properties are direct measures of the mechanical characteristics of the bone at the section – that is, they reflect how strong (or rigid) the bone is at that location for resisting mechanical forces placed upon it (Ruff, 1992: 37). Beam theory shows that a hollow bone has greater mechanical strength than a solid bone of the same mass. The femur is, therefore, like most bones, hollow. The cavity is filled with bone marrow and cancellous bone (Withers, 1992: 455-456).

Compact bone, as described in section 3.2, is very dense, almost solid bone. This has a maximum tensile and compressive strength, but is also very dense.

Consequently, compact bone is found where maximum compressive or tensile forces must be resisted, *e.g.* articular surfaces. Cancellous bone, on the other hand, has numerous large spaces in the bone. The struts of cancellous bone are orientated in particular directions, which correspond to the directions of mechanical forces (Withers, 1992: 456-457).

A basic knowledge of these principles is required to understand pathological conditions as these forces act upon pathological and non-pathological bones alike. It is possible, therefore, that we can see these forces at work when viewing examples of deformation or abnormal bone formation, amongst other things.

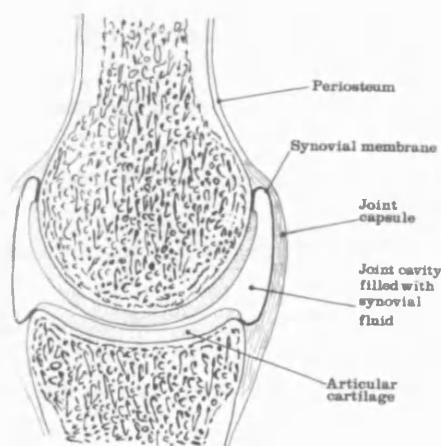
3.7 Joints

Where separate bone or cartilage elements meet, joints or articulations are formed. Their function is to provide a turning place between the stiff elements (Currey, 1970: 40). These joints may be defined functionally dependent on whether or not they are movable. If a joint permits considerable movement, it is said to be a synovial joint or diarthrosis. If a joint permits little or no movement, it is termed a synarthrosis (Kardong, 2002: 184).

Structurally, a synovial joint (Figure 3.3) is defined by a synovial capsule whose walls consist of dense fibrous connective tissue lined by a synovial membrane. This secretes a lubricating synovial fluid into the confined space. The ends of the contacting bones are capped with articular cartilage. Synarthroses lack these synovial structures and are thus structurally distinct. Within synarthroses, if the

connection between elements is of bone, it is called a synostosis, if it is composed of cartilage, it is a synchondrosis, and if it is composed of fibrous tissue, it is a syndesmosis (Kardong, 2002: 184).

Such dual criteria – one functional, one structural – are based largely on mammalian articulations. Once these terms are applied to other vertebrates, exceptions occur. In snakes, for example, the mandibular symphysis permits considerable relative movement of the jaw rami, whilst in birds some cranial bones form syndesmoses. However, the articulated bones may be thinned, thereby permitting significant flexion through the joint as part of the bird's system of cranial kinesis (movement). As a result joint function cannot always be predicted from joint structure alone, or vice versa (Kardong, 2002: 184).



*Fig 3.3: A generalised synovial joint
(Mays, 1998: Fig 5.11)*

In joints, great freedom of action, and the ability to transfer large loads, tends to be incompatible (Currey, 1970: 40). Joints such as the knee, which only moves in one plane and about one axis, can bear heavy loads without the necessity of a large number of muscles spanning the joint to keep it stable. In contrast, a joint

such as the shoulder has freer movement, but is incapable of taking really large loads (Currey, 1970: 40).

However, with degenerative joint disease, the structure of the joint begins to break down. As a response to mechanical stress, body weight, age, sex and other factors, degenerative changes can occur. These changes include the formation of new bone (osteophytes) on joint margins and/or the erosion of bone on joint surfaces (Larsen, 1997: 165). This represents the body's attempt to stabilise the joint following the failure of the cartilaginous tissue that covers the articular surface.

3.8 Vertebrate locomotion

3.8.1 Introduction:

All modes of locomotion require a close co-ordination between muscles, nerves and skeletal structure. To function effectively during locomotion, the skeleton must bear the weight of the animal, as well as receive the forces of the attached muscles and the animal in motion. These forces leave their imprint in the form of muscle attachment scars on the bones themselves. Thus, the entire skeleton, as well as individual elements, is shaped by locomotion (Reitz and Wing, 1999: 58).

One of the earliest forms of vertebrate locomotion is swimming, a motion achieved through the undulation of the body by action between trunk muscles and the vertebral column. This form of locomotion is obviously most clearly seen in fish (Reitz and Wing, 1999: 58). However, members of each of the

higher vertebrate classes have returned to the water and adapted secondarily to swimming. This secondary adaptation also involves the undulation of the trunk, either from side to side or up and down, accompanied by paddling and steering with the limbs. Such aquatic returnees include: seals (Pinnipedia), whales (Cetacea) and sirens (Sirenia) amongst mammals; penguins (Sphenisciformes) and petrels (Procellariiformes) amongst birds; and turtles (Testudines), crocodilians and snakes amongst reptiles (Reitz and Wing, 1999: 59). The humerus of these aquatic species is usually short, heavy, and has a large deltoid process for muscle attachment. The femur is generally short and broad with large processes for muscle attachment (Reitz and Wing, 1999: 59-60).

Locomotion on land ranges from walking to running and hopping (Reitz and Wing, 1999: 60). Animals with different gaits frequently exhibit different morphological features to accommodate the requirements of each mode of locomotion, and these are discussed further in sections 3.8.2 and 3.8.3.

Flight is a highly complex form of locomotion that requires the specialised adaptation of the entire body. The development of wings adapted for flight in bats (Chiroptera) and birds followed different routes. In bats the wing is composed of a flight membrane supported by greatly elongated forelimb elements, whilst in birds the wing skeleton is highly modified from the ancestral forelimb. Unlike the bat, where the humerus, radius and phalanges are very long and the ulna greatly reduced, the bird wing exhibits fusion of the elements of the 'hand'; the major ones being the carpometacarpus and the phalanges (Reitz and Wing, 1999: 62-63). The enlarged sternum for the attachment of the flight

muscles and the placement of the coracoid and clavicle (furcula) between the scapula and the sternum to provide a rigid framework are viewed as essential for avian flight. The pelvic girdle and hind limbs are also highly modified (Reitz and Wing, 1999: 63).

3.8.2 Gait:

The gait of an animal is defined by the pattern of foot contacts with the substrate during locomotion. The gait selected depends upon the rate of travel, obstructions in the terrain, manoeuvrability and the body size of the animal (Kardong, 2002: 339). Two variables for each foot, the relative phase between the cycle of each foot and duty factor, the fraction of time that the foot is on the ground, can be used to describe each gait (Withers, 1992: 462).

The amble is seen in long-legged animals such as camels (*Camelus sp.*) and cheetahs (*Acinonyx jubatus*) when travelling at low speeds. In this gait the animal swings its fore and hind feet on the same side more or less in unison. A fast amble is termed a pace; some harness horses being trained to use this during racing (Kardong, 2002: 346). A diagonal gait, or trot, is characterised by simultaneous placement of diagonally opposite feet into contact with the ground (Kardong, 2002: 339). This gait is advantageous because the connecting line of support between diagonally opposite limbs runs directly under the centre of body mass. This makes it more stable than the pace, and the trot is a favoured walking gait of salamanders, reptiles and broad-bodied mammals such as hippopotami (*Hippopotamus amphibius*) (Kardong, 2002: 346).

In the bound, called the pronk in artiodactyls, all four feet strike the ground in unison. Although this gait abruptly jars and decelerates the animal, it also provides four-footed stability whilst the feet are in contact with the ground (Kardong, 2002: 346). The half-bound and gallop are more complex and are used at high rates of speed. When a pair of feet approach the ground, the leading foot strikes in front of the trailing foot. In the half-bound, the hind feet make contact more or less in unison, but the fore feet make contact with a distinct leading and trailing pattern. In the gallop, both fore and hind feet display this leading and trailing pattern (Kardong, 2002: 346). At slow speeds, the gallop is termed a canter. Galloping and half-bounding are said to be asymmetrical gaits because of the uneven spacing of the footfalls during a cycle. Whilst less stable than symmetrical gaits such as the trot and pace, they nonetheless have the advantage of introducing a suspension phase to the cycle, an interval during which all four feet are off the ground. This increases the reach of the limbs, and thus increases the stride length (Kardong, 2002: 346).

3.8.3 Cursorial locomotion:

Cursorial locomotion, or rapid running, has evolved in many terrestrial vertebrates. It provides a means for predators to catch their prey, and for the prey to run away from a predator, as well as providing a way to move from areas of locally depleted resources to new pastures, and to locate dispersed resources in sparse lands. The speed or velocity attained by a vertebrate is a product of its stride length and stride rate. Other things being equal, vertebrates with longer strides can cover more ground than those with shorter legs, so they

attain greater speeds. The faster the rate of limb oscillation, the faster the animal travels (Kardong, 2002: 344).

One way to increase stride length is to lengthen the limbs. Highly cursorial vertebrates, therefore, frequently exhibit marked lengthening of their distal limb elements. Humans walk with the entire sole of their foot in contact with the ground, what is known as a plantigrade posture. Cats (Felidae) walk in a digitigrade posture in which only the digits bear the weight. Deer (Cervidae), though, use an unguligrade posture, travelling on the very tips of their toes. The change from plantigrade to digitigrade to unguligrade effectively lengthens the limb and increases the length of stride (Kardong, 2002: 344), as well as affecting weight-bearing. In addition, those digits which are no longer weight-bearing have in many instances become reduced or are even entirely absent. An example of this is seen in the horse (*Equus caballus*).

An alternative way of achieving the same end is to increase the distance through which the limbs move whilst they are off the ground. For example, the cheetah, when increasing its speed from 50 to 100 kph, does not appreciably change its rate of limb oscillation. Instead, it increases its length of stride, putting greater spring into each forward leap and increasing the flexion and extension of its vertebral column. This permits it to extend its reach during each stride, and thus increase speed (Kardong, 2002: 344-345).

The velocity of travel also depends upon the rate at which the limbs move. An increase in this can be achieved by:

- 1) having larger, more mechanically efficient muscles,
- 2) lightening the distal end of the limb in order to reduce the inertia created by mass,
- 3) reducing the number of digits.

This is why deer, horses and other fast animals possess bunched limb muscles in their shoulders and hips, and why many also show the reduction or loss of peripheral digits with the rest strengthened in order to counteract impact with the ground (Kardong, 2002: 345).

3.9 Gross tooth anatomy

Bone is not the only material that may be studied by animal palaeopathologists. Teeth can also exhibit pathological alteration and, as one of the most survivable elements of the skeleton, are worthy of particular consideration.

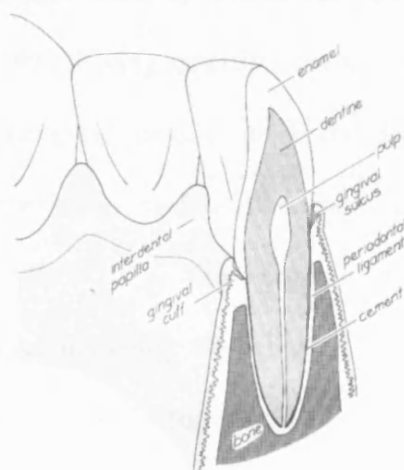


Fig 3.4: A generalised tooth (Hillson, 1986: Fig 1.1)

Teeth consist of two main elements: the crown and the root (Figure 3.4). The crown is normally the only part protruding into the mouth, although this is not always the case, whilst the roots are held firmly in the bony sockets of the mandible (Hillson, 1986: 9). The crown is coated by a layer of hard, crystalline tissue called enamel, the root with a layer of bone-like material called cement. Underlying these surface layers is a tough, resilient tissue known as dentine (Hillson, 1986: 9). At the very centre of the tooth is the pulp chamber. An extension of this runs, like a canal, down the centre of the root, to emerge at its tip. The pulp that fills this chamber in a living tooth is a soft, cellular tissue that includes the blood and nervous supply (Hillson, 1986: 9). The same basic elements are present in even the most complicated tooth. Crowns may become wider, taller or flatter. There may be extra mounds, known as cusps, or there may be folds in the enamel layer. Cement may cover the crown as well as the root, and extra roots may be added. Nonetheless, there is a basic uniformity of design (Hillson, 1986: 9).

Enamel, dentine and cement are all mineral/organic composites (Hillson, 1986: 107). Living calcified tissues contain between 66% and 99% (by weight) of inorganic material. In dental tissues, this inorganic component consists almost entirely of calcium phosphate minerals, mainly in the form of apatite (Hillson, 1986: 107). The organic component, on the other hand, is derived predominantly of collagen, a fibrous protein that is also found in dentine, cement and bone (section 3.3) (Hillson, 1986: 107).

3.10 Tooth development and growth

The earliest phase of tooth development is called the 'bud stage' (Hillson, 1986: 177). Mesenchymal cells begin to proliferate, forming the dental papilla, and these cells are responsible for dentine and pulp formation. Alongside these, cells derived from the epithelium begin the process of enamel deposition. As the tooth bud grows, it takes on a cap-like shape, and passes into its 'cap stage' (Hillson, 1986: 177). The edges of the indentation in the enamel organ continue to grow until the tooth enters its 'bell stage', during which hard tissue deposition begins. During this time, tissues have become more differentiated and, outside the growing tooth germ, bone is developing that will eventually become the crypt that contains the tooth within the mandible (Hillson, 1986: 177).

Dentine is the first hard tissue to be laid down. Formed by odontoblasts (Hillson, 1986: 151), the dentine is built up in a series of conical layers that stack one inside the other. With each new layer, the layers increase in size to fill the contours of the crown. Growth continues as a series of sloping, sleeve-like layers with a space in the middle which becomes the pulp cavity (Hillson, 1986: 152).

A short time later, the first dome-shaped layer of enamel matrix is created. Formed by a closely-linked sheet of cells called ameloblasts, the process of enamel formation is known as amelogenesis, which has two stages: matrix production and maturation (Hillson, 1986: 113). Matrix production involves the formation of an organic matrix and the seeding of crystallites within it. This matrix, which has many of the structural features of fully mineralised enamel

but a higher organic content, consists of a complicated mixture of proteins called amelogenin (Hillson, 1986: 114). Maturation is the process of removing this amelogenin and replacing it with apatite to produce the heavily mineralised mature enamel (Hillson, 1986: 114).

Cement is formed on the surface of enamel and dentine by cells known as cementoblasts. These manufacture first an organic matrix, precement (or cementoid), which later becomes mineralised (Hillson, 1986: 163). In actively growing cement, a layer of precement covers the surface, itself overlain by a sheet of cementoblasts. These cells may become trapped within the developing tissue and become cementocytes (Hillson, 1986: 163). The primary function of root cement is to attach the tooth to the periodontal ligament (Hillson, 1986: 164).

The first part of the tooth to develop is the crown. Cusps grow by apposition of layers of enamel upon the initial dome. Then, subsequently, sleeve-like layers are deposited towards the cervix of the tooth. After the crown is complete, the root is formed (Hillson, 1986: 179). As the root of the new tooth grows, bone between the crypt and the crown is resorbed and the crown moves upwards. This is the process of tooth eruption (Hillson, 1986: 180).

Unlike skeletal development, dental development overall is insensitive to environmental constraints (Larsen, 1997: 23). The various stressors that influence stature and bone age have been demonstrated to have little effect on dental development. Eruption rates and timings are somewhat more responsive

to environmental factors, such as caries experience, tooth loss and severe malnutrition (Larsen, 1997: 23). However, whilst the timing of development and growth may not be generally affected, virtually any environmental change that leads to metabolic disturbance may result in visible changes in the structure of the tooth enamel (Larsen, 1997: 44). The most common example of this is enamel hypoplasia (see section 4.4.4).

Following eruption, the tooth will begin to wear (Hillson, 1986: 183). The wear is caused by grinding of the crowns against one another, and contact with food, cheeks and tongue (Hillson, 1986: 183). This wear can take two forms: attrition and abrasion. Attrition is the “formation of well-defined wear facets where teeth meet in chewing, often with fine parallel scratches resulting from abrasives in the food,” (Hillson, 1986: 183). Abrasion, on the other hand, “is a more diffuse wear, with scratches randomly orientated,” (Hillson, 1986: 183).

Having reviewed the biological processes that can influence and determine pathological change, the following chapter will consider pre-existing recording protocols in palaeopathology before looking at more specific methodologies designed to answer specific research questions.

Chapter Four: Current Methods in Skeletal Palaeopathology

4.1 Introduction

The principal aim of this thesis is to develop a generic recording methodology. In order to achieve this, it is necessary to consider current methods within animal and human palaeopathology with the intention of determining good practice, which can be taken forward in the design of the recording system (chapter five), as well as to establish something of the range of pathologies to be recorded. This chapter will start with a consideration of pre-existing recording protocols, and then look at more specific methodologies designed to answer specific research questions.

4.2 Current recording protocols

In the past twenty or thirty years, recording protocols within archaeozoology have developed from paper pro-forma sheets, to tailor-made computer software, and on to off-the-shelf software of significant power and flexibility (O'Connor, 2003: 117). Different authors have advocated different methodologies (*e.g.* Davis, 1992; Harland *et al.*, 2003) which reflect two different types of approach to recording: qualitative and quantitative. These protocols are intended to record faunal data generally, not palaeopathology specifically. However, it is worth noting how these protocols tackle the subject of palaeopathology as this will reflect how archaeozoologists generally record such signs of disease and injury within assemblages. The York System (Harland *et al.*, 2003), for example, makes provision for pathology and non-metric variation based upon a system of diagnostic zones, which enable the location of the pathology upon the bone to

be established. A number of common pathological conditions, such as dental enamel hypoplasia, are 'pre-entered' to allow their systematic recording, and the importance of description is emphasised; though no guidance is given by the authors as to what should be included in any description.

Advances in bioarchaeological method and theory in human osteology have necessitated an expansion in data collection protocols within this area of study too, but there has frequently been a significant amount of variation between one author and another (Vann and Thomas, 2006: 3.0). Although this is a sign of a robust and growing discipline, it has made it increasingly difficult to compare findings between investigators. One factor that has made it particularly urgent to standardise such methodologies is the increase in repatriation activity in countries such as the United States. There is a potential loss of information involved in every case of reburial and, as such, a protocol is required to ensure comparisons can be made even when the collection itself is no longer available for study (Larsen, 1997: 340).

In order to address this concern, a recording standard (Buikstra and Ubelaker, 1994) was developed by a group of biological anthropologists to serve as a proposed guide to data collection from the initial skeletal inventory through the determination of age and sex, measurement, pathology, non-metric traits, taphonomy, cultural modifications, biochemistry and microstructure (Larsen, 1997: 340). This begins with an inventory of the bones present, completeness being coded from one (complete) to three (poor). Absence is indicated by leaving the space blank. This inventory is modified for commingled and

incomplete remains such as cremations. There are also separate forms for the dental inventory, pathology, cultural modification, morphology and measurements (Buikstra and Ubelaker, 1994).

Buikstra and Ubelaker (1994: 112) have grouped pathological bone conditions into nine categories for recording purposes:

1. Abnormalities of shape;
2. Abnormalities of size;
3. Bone loss;
4. Abnormal bone formation;
5. Fractures and dislocations;
6. Porotic hyperostosis and cribra orbitalia;
7. Vertebral pathology;
8. Arthritis;
9. Miscellaneous conditions.

Three digit codes are then used to record each pathology. These are located using other numeric codes to indicate the skeletal element affected and, where applicable, the side, section and aspect affected. For example, lipping of an articular surface due to arthritis would be recorded as 8.1.1 if it were barely discernable, 8.1.2 if it had a sharp ridge, 8.1.3 if it had extensive osteophyte formation and 8.1.4 if it had advanced to the stage of fusing elements together. To record the extent of the circumference affected would require additional three digit codes: 8.2.1 for less than one-third, 8.2.2 for one-third to two-thirds,

8.2.3 for greater than two-thirds. Another code, 4.3.1, would be required to indicate that it was the femur that was affected, and yet other numeric codes to establish the exact part of the femur showing pathological change. However, this system has been criticised as being too cumbersome and restrictive for practical use in contract archaeology due to the extensive, detailed coding required (Brickley and McKinley, 2004: 36). This is a valid concern given the restrictive time limits and budgets imposed by contract archaeology when compared to research archaeology.

Similar guidelines have also been published by organisations such as the Institute of Field Archaeologists (Brickley and McKinley, 2004) in the United Kingdom. Aimed particularly at those engaged in recording human bone for commercial purposes, these set out what is considered a standard record of an assemblage. This includes an inventory of the bones present, the prevalence of pathological lesions and non-metric traits, as well as an accurate record of these traits, the age and sex of the individual and metric data.

The use of visual recording forms is recommended in order to allow not only completeness, but also fragmentation of an individual skeleton to be demonstrated, and such forms are provided in the appendices. The authors consider these superior to those provided by Buikstra and Ubelaker (1994), as they allow greater detail to be recorded. They do, however, acknowledge that many of those recording sheets provided in Buikstra and Ubelaker (1994) are very useful, particularly those recording individual skeletal elements rather than complete skeletons. Other forms of visual recording such as photographs,

radiographs, drawings and sketches are also recommended (Brickley and McKinley, 2004: 6).

The section dealing with the recording of disarticulated and commingled material is particularly useful for someone attempting to identify methodologies that can be transferred to archaeozoology as most faunal assemblages fall into this category. It is recommended that the record of all such assemblages includes the minimum number of individuals present, age, sex and presence of pathological lesions. Potential ritual assemblages should also include such data as ancient modification by both natural and human activity. To assist with this, a grading system for recording erosion and abrasion to bone is provided, including photographs of type specimens. They also recommend close consultation with the archaeozoologist analysing the faunal remains from the site in order to make fragmentation data comparable between the two data sets (Brickley and McKinley, 2004: 15-17). Such comparison of methodologies can be seen in the use of zonation, a technique developed by archaeozoologists, to deal with fragmented human remains (Knüsel and Outram, 2004).

With specific regard to recording palaeopathology, the authors stress the importance of description over diagnosis, and the need for unambiguous terminology (Brickley and McKinley, 2004: 34). Their step by step procedure recommends recording to be taken of the following (Brickley and McKinley, 2004: 35):

- i. Which bone/tooth is affected (including side);

- ii. What part of the bone/tooth (*e.g.* proximal shaft), and aspect (*e.g.* medial) is involved, using anatomical terms);
- iii. What is the nature of the lesion itself? Is it a forming, destroying or mixed lesion?
- iv. If bone has been formed, is it woven (porous, disorganised and indicating active disease at the time of death) or lamellar (smooth and organised, indicating a healed and chronic lesion) or is it in the process of healing?
- v. If bone has been destroyed, is there any sign of healing *e.g.* rounding of the edges of the lesion;
- vi. What is the distribution pattern of the lesions if more than one bone/tooth is involved? Different disease processes have different patterning (*e.g.* leprosy affects the facial, hand and foot bones);
- vii. Can the abnormality be measured and compared with the normal opposite side?
- viii. Consider all potential diagnoses for the abnormalities recorded (differential diagnosis)

It is worth noting, however, that the guidelines of Brickley and McKinley (2004) are not self-sufficient. In many instances, for example with different ageing methodologies, researchers are directed to other published material rather than re-printing such data (Brickley and McKinley, 2004: 19). This is understandable, but does require the osteologist to have access to more than just these guidelines in order to be able to implement the methodologies recommended. This is in contrast to Buikstra and Ubelaker (1994) which provides illustrations of many of the scoring systems they recommend, for

example, the variation in margin form of resorptive lesions (Fig. 88: 133) after Ortner and Putschar (1981: Fig. 28), and examples of osteoporotic bone loss (Fig. 90: 134) after Ragsdale (1993: Fig. 2). These days it is generally accepted that detailed recording of pathological change is essential, although it is noted that that this can take up space in skeletal reports (Roberts and Manchester, 2005: 9). This problem can, however, be resolved by the use of CDs, microfiche or web archives. Increased use of such media also permits the transmission of data to greater numbers of individuals (Roberts and Manchester, 2005: 9).

The problem of the fragmentary nature of skeletal material is one that has been addressed in different ways by many different authors. Buikstra and Ubelaker (1994) proposed that long bone shafts be divided into proximal, middle and distal thirds, whilst the epiphyses were recorded separately. Of these, each segment was scored complete if 75% of the segment was present. However, one flaw of this recording methodology is the absence of landmarks to determine where the metaphysis ends and the epiphysis begins. For this reason, Judd (2002) used the 'system of squares' method first proposed by Müller *et al.* (1990), where the "proximal and distal interarticular segments composed of the epiphyses and metaphyses are delimited by a square whose sides are the same length as the widest part of the epiphysis in question," (Judd, 2002: 1258) (figure 4.1). Once these ends have been determined, the shaft can then be divided equally into three sections. After the segment has been identified, it can be assessed to determine whether an adequate amount of it is present to observe lesions. 75% presence was considered the threshold for completeness (Judd, 2002: 1258).

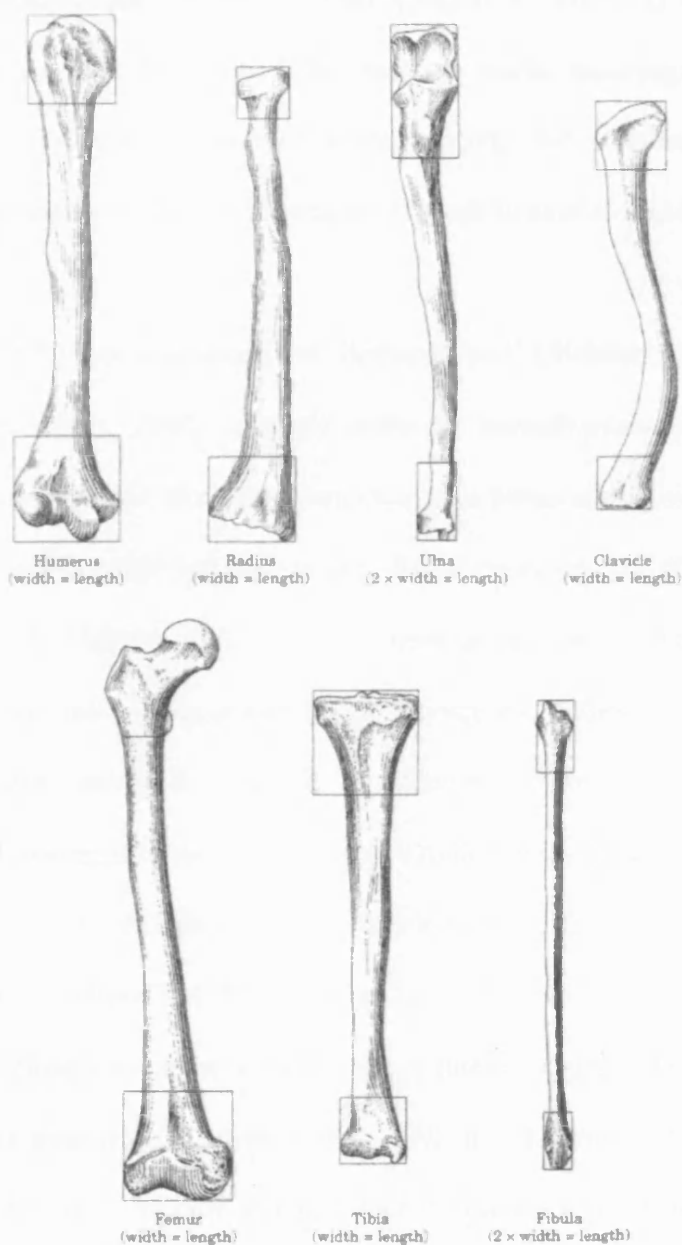


Fig 4.1: Width and length ratios for epiphyseal calculation using the 'squares method' (Judd, 2002: Fig 2).

Such zoning systems are obviously also pertinent to animal palaeopathology as the majority of faunal material will be in a disarticulated and commingled condition, and it is often from archaeozoology that such methodologies are drawn by human osteologists. Knüsel and Outram (2004), for example, adapted a system devised by Dobney and Reilly (1988) for animal remains. These assign a series of zones to each element. Each fragment is recorded by all zones

present, even if the zone is only a part of the whole, as well as from which bone, left or right, it derives. When butchery marks, gnawing, pathology or other such alterations to the bone are located on fragments, a series of codes can be used to accurately define each category of modification and its location.

Whilst no equivalent of Buikstra and Ubelaker (1994) or Brickley and McKinley (2004) currently exists for animal palaeopathologists, a number of more specific recording protocols have been created with the aim of answering specific research questions (*e.g.* Bartosiewicz *et al.*, 1997; Dobney and Ervynck, 1998; Higham *et al.*, 1981). An obvious problem with this is that it either relies upon the archaeozoologist identifying the pathology before recording takes place, and/or it is aimed at addressing a very specific research question. However, it is not always possible to determine the condition. There is a lack of diagnostic criteria for many pathologies and identification manuals (*e.g.* Baker and Brothwell, 1980; Jubb *et al.*, 1993) are far from perfect. Thus, it is necessary to devise a methodology that emphasises description over diagnosis. As stated by O'Connor (2000: 109), this description "needs to be sufficiently detailed to support any differential diagnosis which is offered, and to allow alternative diagnoses to be considered and tested." Such description and diagnosis should not be conflated (O'Connor, 2003: 195). It has also been proposed that analysis should be systematic, noting not only presence, but also absence, and that some indication of the prevalence within a sample should be given (O'Connor, 2000: 108). In addition, illustration should be encouraged, not just for its own sake, but as a means of explanation (O'Connor, 2003: 195).

To summarise, it can be seen that any generic recording methodology should take note of these points, as well as be informed by the methodologies, both general and specific, of human palaeopathology. The formative state of animal palaeopathology puts the discipline in a good position to learn from human palaeopathology (O'Connor, 2003: 195). By studying what is already in existence it is possible to determine what is useful and what is not. The rest of this chapter will, therefore, be devoted to the discussion of these specific methodologies and, where appropriate, comparisons will also be drawn with the techniques developed within human palaeopathology.

4.3 Joint disease

4.3.1 Introduction

One of the most commonly studied aspects of animal and human palaeopathology is joint disease (Bartosiewicz *et al.*, 1997; De Cupere *et al.*, 2000; Higham *et al.*, 1981; Johannsen, 2005; Rogers and Waldron, 1995; Rogers *et al.*, 1987). In humans, much of this research has centred upon activity-related change (Lovell and Dublenko, 1999; Stirland, 2000; Stirland and Waldron, 1997). In animals, arthropathies, *i.e.* pathologies of the joints, are of considerable economic significance. Lamé animals neither feed nor breed optimally and demand attention because of their discomfort (O'Connor, 2000: 99). This has obvious implications both for modern clinical studies and archaeological analyses as this would have been just as apparent in the past as it would today (O'Connor, 2000: 99). In addition, as arthropathies affect skeletal elements that have a greater density than others, they are likely to survive well in the archaeological record. It is, therefore, unsurprising that there has been

interest in what such pathologies can reveal about animal husbandry, activity and other aspects of human-animal relationships.

4.3.2 The identification of traction animals

One area in particular where there has been abundant research pertaining to recording methodologies and joint disease is the identification of traction animals. The interest in this subject can be seen in the number of papers in a recent volume of palaeopathological research (Davies *et al*, 2005); of the sixteen chapters, four deal directly with this issue.

The use of animals for traction is considered important because it can be related directly to the use of animals in agricultural settings. It therefore fits neatly into hypotheses concerning the use of secondary products in general. These are “products for which animals may be utilized repeatedly over the course of their lifetimes” (Greenfield, 1988: 573) such as milk and milk products, wool and traction. Indeed Bogucki (1993: 497) argued that the emergence of the use of animals for traction during the 4th millennium BC provided a reason for male cattle being kept alive for longer than the four years needed to fatten them up for slaughter, their presence solving two of the most labour-intensive problems of an agrarian economy: the production of field crops and the transport of bulk goods from remote locations to the residential base. Prior to mechanisation, the use of animals for transport, trade and communication was important to all communities, and working animals continue to play a valuable role in many countries even now (Pearson *et al.*, 1999: 1).

The archaeological evidence for the use of draught cattle has included the interpretation of mortality patterns, and indirect indicators such as yokes, wheeled vehicles, and marks and pictorial evidence. The earliest artefactual evidence comes from the Uruk period (mid 4th millennium BC) of Mesopotamia and the Old Kingdom (late 4th-early 3rd millennium BC) of Egypt. There are depictions on cylinder stones, temple and tomb friezes of cattle ploughing and pulling carts, and cuneiform texts that mention ploughs. Similarly, there is abundant artefactual evidence in South Eastern and Central Europe beginning in the Chalcolithic/Eneolithic (end of the 4th millennium BC) which implies the advent of the use of animals for milk and wool production and for traction (Greenfield, 2002: 14-15). However, mortality patterns cannot themselves confirm or refute the presence of draught cattle in an economy and non-osteological evidence has the disadvantage of not necessarily sharing the chronology of cattle traction. As Johannsen notes, “the introduction of cattle traction into a given area may, for example, not necessarily coincide with the introduction of the ard or the wheeled vehicle” (2005: 39).

Working from the basic premise that “cattle have not evolved in nature to pull wagons, tilling instruments or other heavy loads” (Johannsen, 2005: 40), speculation about the potential use of archaeological specimens as draught animals generally stems from observations of osteophytes and other deformations of the feet and lower limbs, with conditions such as spavin and osteoarthritis being commonly recorded. Reference to the Compton Lameness Survey, which included 136,931 cows in Britain, showed that approximately 88% of all recorded lesions occurred in the feet. It is for this reason that the

metapodials and phalanges are often chosen for study (Bartosiewicz *et al.*, 1997: 11-13). Pathologies that have been recorded include (Bartosiewicz *et al.*, 1997: 33):

“...exostoses, lipping and osteoarthritis on the phalanges and metapodials; broadening of the distal epiphysis and plantar/palmar depression on the metapodials; transverse striations on the shaft of the metatarsals; ‘striated facets’ on the metacarpals; and fusion of the second metacarpal.”

Exostoses have been defined as formations of “new, abnormal, osseous tissue on the outside of the bone” (Baker and Brothwell, 1980: 225). Lipping, meanwhile, is the formation of an overgrowth of bone, which projects beyond the margin of the affected articular surface (see glossary), whilst osteoarthritis, a term frequently misused in archaeological literature, is “a degenerative disease primarily affecting the articular cartilage” (Baker and Brothwell, 1980: 114). In order for a definitive diagnosis of this condition to be made on archaeological material then at least three of the following changes should be present (Baker and Brothwell, 1980: 115):

- (i) grooving of the articular surface of the bone,
- (ii) eburnation,
- (iii) extension of the articular surface by new bone formation,
- (iv) exostoses around the periphery of the bone

In modern animals, the earliest changes are seen in those areas of the joint that are subjected to the greatest pressure and movement. The articular cartilage becomes fibrillated and thins, exposing the bone beneath. Before the cartilage is entirely removed, the bone beneath is strengthened by means of a natural thickening of the subchondral plate. As a result of constant friction with the opposite joint surface, this exposed bone develops a hard, smooth appearance like that of ivory; this is known as eburnation. Osteophytes form around joint margins, indicating gross cartilage damage to the surface they border. Eventually these can fuse to form large blocks of bone (Vaughan, 1960: 534).

Higham *et al.* (1981) examined the insertions of the tendons on the third phalanx on the grounds that the development of exostoses at those points was related to age, sex, weight and stress caused by regular activities. Using multivariate statistics, a modern comparative sample of both cattle (*Bos taurus*) and water buffalo (*Bubalus bubalis*) was analysed and compared with prehistoric material from Thailand. Based on the observation in Bishop's (1937) review of the 'Origin and Diffusion of the Traction Plough' that the method of harnessing employing a yoke attached to the neck and withers causes a considerable weight to be borne by the forelimbs in draught animals, not only to support the greater weight of the forequarters, but also to disperse the forces generated in traction, only the third phalanx of the right forelimb was studied by Higham *et al.* (1981). The authors concluded that exostoses around the extensor process were mostly influenced by weight, whereas those around the flexor process were mostly affected by traction. This evidence made it possible to suggest that only water buffalo were used for traction in prehistoric Thailand.

However, there are two problems associated with applying this study archaeologically. The first of these is that the distal (or third) phalanx is less robust than the first and second, and therefore not as commonly found in archaeological material. Secondly, the third phalanges from the fore- and hind limb are so similar that distinguishing between them is nearly impossible (Dottrens, 1946).

Bartosiewicz *et al.* (1997) therefore took a different approach. In 1991, the metapodials and phalanges of eighteen modern draught oxen with known age, weight and life history were collected from two slaughterhouses in Romania (De Cupere *et al.*, 2000: 256). The animals comprised cross-breeds of two major types, the local variety of 'steppe cattle' which belongs to the same group of 'Podolian' breeds as the Hungarian Grey, and a traditional brown dairy cattle influenced by the Alpine breeds imported into the area. When alive, they had been kept in neighbouring villages in the vicinity of Buzău and Sibiu, a region characterised by low hills of 300 to 700m altitude (Bartosiewicz *et al.*, 1997: 15). Their age ranged from six to nineteen years and all had been used for pulling carts and ploughs, or hauling timber, albeit not for seven months prior to slaughter. Seven young bulls that had been bred for their meat and slaughtered at the age of two years were collected from the same source for comparative purposes (De Cupere *et al.*, 2000: 256-257).

A coding system was drawn up to record the pathologies observed on the bones, with one representing a lack of deformity and four indicating the anomaly was manifested in an extreme form. Other pathologies (*e.g.* proximal lipping and

palmar/plantar depressions) were recorded on a scale between one and three only, whilst others (*e.g.* transverse striations, that is minute grooves or scratches that form in parallel series right angles to the long axis of the bone) were recorded as present or absent (one or two). This allowed a pathological index (PI) to be established for each individual bone which varied from 0 to 1 (Bartosiewicz *et al.*, 1997: 20):

$$\text{PI} = (\text{sum of scores} - \text{number of variables}) / (\text{maximum score} - \text{number of variables})$$

$$\text{PI (Mc)} = (\text{sum of scores} - 9) / 17$$

$$\text{PI (Mt)} = (\text{sum of scores} - 8) / 16$$

$$\text{PI (Ph1)} = (\text{sum of scores} - 5) / 11$$

$$\text{PI (Ph 2)} = (\text{sum of scores} - 5) / 11$$

$$\text{PI (Ph 3)} = (\text{sum of scores} - 3) / 7$$

From these data, an individual's pathological index could then be calculated (Bartosiewicz *et al.*, 1997: 20):

$$\text{IPI} = (\text{sum of PI of the skeletal elements present}) / (\text{number of considered skeletal elements})$$

In order to reduce inter-observer error the authors created a reference collection illustrating each stage of abnormality in each element and clear photographs of these are illustrated in the volume. They also tested the system by having three

observers record each specimen independently and then averaging the results (Bartosiewicz *et al.*, 1997: 20).

It had long been supposed that the medio-lateral asymmetry of cattle metapodials increased with age and especially live weight, in terms of both linear measurements and bone density, and that such changes could be linked to sex, weight and, indirectly, the exploitation of the animal for draught use (Bartosiewicz *et al.*, 1993). It was evident from the PI values of the Romanian oxen (Figure 4.2) that a higher degree of pathological deformation occurred in the front feet, especially in the case of the phalanges, although there were individual exceptions to this trend. This may be explained by the fact that much of the live weight in cattle is carried by the thoracic extremities, possibly leading to more severe deformation in the anterior skeletal elements. This effect would have been exacerbated in draught oxen by the additional load exerted by the withers-harness (Bartosiewicz *et al.*, 1997: 61). Given that many pathologies are observed only in older animals, advancing age itself means a greater live weight, prolonged use and a higher probability of bone modification. Indeed, the significance of the age and live weight of the Romanian specimens was correlated against their PI-value and it was found that, whilst there was no distinct correlation between age and pathological score, there was a correlation with live weight at the 95% confidence level (Bartosiewicz *et al.*, 1997: 62-64).

It was not, however, possible to attempt a correlation between sex and pathological changes as the bones of cows were absent from the Romanian sample. For this reason, metapodial measurements gathered in the Hungarian Agricultural Museum, Budapest, of an assemblage of Hungarian Grey cows,

bulls and oxen were analysed. This showed only one instance of spavin amongst the 66 cows studied, although this was from a relatively young individual. This is obviously significantly lower than the frequency in the older and heavier Romanian draught oxen (Bartosiewicz *et al.*, 1997: 66-68).

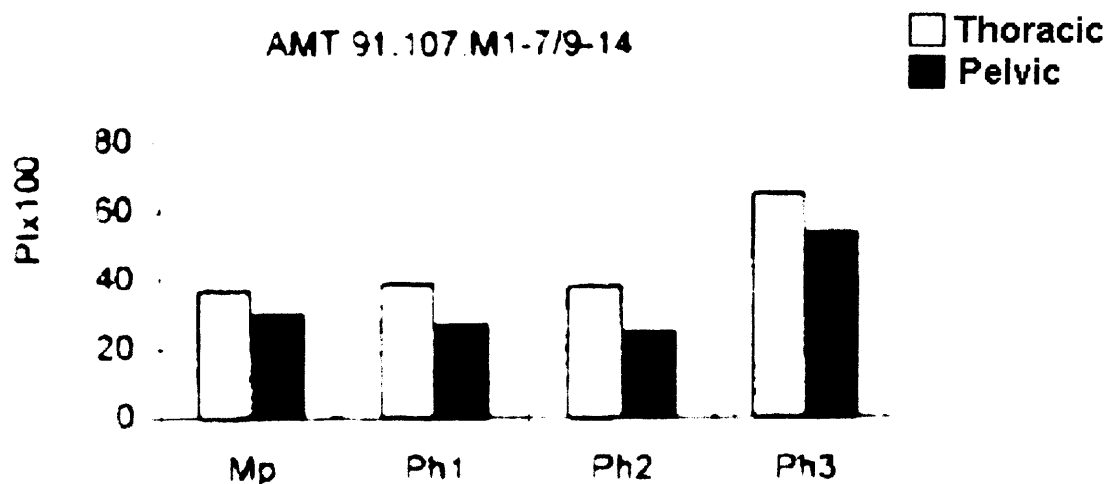


Fig 4.2.: Pathological indices in thoracic and pelvic extremities of Romanian oxen (Bartosiewicz *et al.*, 1997: Fig. 42)

The methodology developed in the earlier work (Bartosiewicz *et al.*, 1997) was subsequently applied to an archaeozoological assemblage by De Cupere *et al.* (2000). Four Roman assemblages were used during this analysis from sites where the foot bones had shown considerable deformity. These were the site of Sagalassos in Turkey, built on the rocky hill slope of the western Taurus range at an altitude of 1490-1600m above sea level, and three sites in Belgium: Liberchies, Namur and Torgny. These are situated in the southern part of the country where the topography is generally hilly.

Only slight differences could be observed in the PI of the first phalanges of the front and hind legs in the archaeozoological assemblages and so these elements were combined in the results. In comparison with the mean PI of the Romanian

bulls and oxen, which were calculated during the 1991 study as 0.014 and 0.325 respectively, the material from Sagalassos gave a mean PI of only 0.223. Those of the Belgian sites were 0.241 for Liberchies, 0.192 for Namur and 0.275 for Torgny (De Cupere *et al.*, 2000: 261). These are obviously significantly lower than the results for the Romanian oxen that had been used as draught animals.

As previously mentioned, factors such as age, sex and weight can contribute to the development and occurrence of pathologies, as can breed, inherited traits and the environment in which the animal has been kept. It is worth noting that, as the study of modern cattle was based on animals that had all been used for heavy work during their lifetime, the scored results are founded upon a collection that demonstrates several extreme pathologies. Less stressful exploitation would obviously result in less pronounced deformations. Consequently, the highest score (four) on the scale devised by Bartosiewicz *et al.* (1997) was almost never recorded in the study of archaeozoological material (De Cupere *et al.*, 2000: 263).

The collections from Roman Turkey and Belgium also differed from the modern assemblage in that they contained both male and female individuals. This increased the likelihood that the sample contained animals that were never put to work, which would obviously affect the mean PI of the assemblage. If the Romanian oxen assemblage can be considered as a 100% draught population with a mean pathological ratio of 100%, then the modern Romanian bulls show a pathological ratio of 4%, Sagalassos 68%, the *vicus* at Namur 59%, the *vicus* at Liberchies 74%, and the *villa* at Torgny 84% (De Cupere *et al.*, 2000: 264).

These results are interesting because they suggest a possible economic difference between the sites, although the small sample size from Torgny should also be taken into consideration.

Cattle bones from Viking Age to Medieval deposits from Eketorp Castle, Sweden, were also recorded using the system devised by Bartosiewicz *et al* (1997). This found that only 148 (12.2%) of the total 1211 bones studied showed evidence of deformation. Three types of pathologies were observed: depressions/lesions, lipping and exostoses, and these conditions were more frequent in Period III (900-1300 AD) in comparison to Period II (400-700 AD), an increase in prevalence hypothesised to be associated with the introduction of a new type of plough (Telldahl, 2005: 66).

Unlike the previous study (De Cupere *et al.*, 2000), Telldahl's (2005) analysis of the Eketorp Castle assemblage found some variation in the type of pathology exhibited by cows and bulls. The majority of skeletal changes on the first phalanges of cows were located on the medial side of the foreleg. This was in contrast to those of bull/bullocks, which were more often to be found on the lateral side of the hind leg. It was suggested that this difference was due to the fact that the *Musculi middle interosseus* of bull/bullocks had a greater number of attachments in the foreleg than was the case for female cattle, thus providing more support for the skeleton. Consequently, cows were at a greater risk of developing pathologies in that region when stress was placed upon it (Telldahl, 2005: 66).

A further study, concentrating on the proximal (or first) phalanx of cattle, was conducted by Johannsen (2005) using the method devised by Bartosiewicz *et al.* (1997). This element was chosen firstly because of the high frequency of morphological change observed in the earlier study, and secondly because of the usual abundance of this element in faunal assemblages from archaeological sites. Of the five types of morphological change defined by Bartosiewicz *et al.* (1997), Johannsen concentrated on the occurrence of lipping at the proximal articular surface and exostoses near the distal end, discounting the other changes due to their rare occurrence and inconsistent scoring.

Due to the irregular way some skeletal changes such as exostoses develop, they are hard to quantify biometrically in a rigorous manner. The employment of an artificial scale, such as that developed by Bartosiewicz *et al.* (1997), allows some quantification to take place, but is not itself without problems. These include the application of discontinuous scores to continuous variation, inter-observer variability, especially when the condition falls halfway between the defined stages of development, and the difficulty in distinguishing between normal and slightly abnormal variation (Johannsen, 2005: 41).

One weakness of the original study (Bartosiewicz *et al.*, 1997) was the difference in age structure of the group of draught oxen and the comparative group of young bulls. This made it difficult to evaluate the influence of individual age on the changes in skeletal morphology. In an attempt to counteract this, the proximal phalanges of eight adult aurochs (*Bos primigenius*) were studied, the age of which had been determined by epiphyseal fusion and

tooth wear (Johannsen, 2005: 42). Whilst the sample of aurochs phalanges was too small to draw firm conclusions, certain general trends could be seen to emerge. Firstly, the overall occurrence of morphological change was low, with the mean value for proximal lipping recorded as 1.2 and that of distal exostoses 1.5. Secondly, there was no consistent correlation between age and morphological change and thirdly, there was no consistent correlation between sex and morphological change. However, with both the latter factors, it is possible that the small size of the sample obscured any potential pattern (Johannsen, 2005: 42).

Another conclusion concerning an individual specimen also led to the value of distal exostoses for the identification of draught animals being questioned. The Prejlerup bull, which was examined as part of the group of aurochs, showed pronounced distal exostoses, most likely due to advanced age or genetic predisposition. This showed that it is hard to attribute the presence of this phenomenon in archaeological specimens to a specific factor, given its presence in a wild population (Johannsen, 2005: 42), a fact emphasised by the presence of pathological exostoses on the third metacarpal of extinct Pleistocene equids from the Yukon Territory of Canada (Choquette *et al*, 1975).

Other pathological phenomena have also been linked to the use of cattle for traction. At a Roman period site at Tiel-Passewaaij, in the central Netherlands, degeneration of the acetabulum, or hip joint, of cattle was hypothesised to relate to traction. This was due to the fact that there was no incidence of such degenerative changes in the pelves of horses from the site, an animal of roughly

the same size that also lived to a comparative age. Thus, whilst ageing was still a potential factor, the eburnation present in the acetabulum could possibly be due to stresses such as repeated over-rotation of the femoral head which can occur when an animal pulls a cart on a hard or uneven surface or ploughs in heavy soil. Overall, 11.4% of proximal femora and 6.7% of acetabula at Tiel-Passewaaij displayed evidence of eburnation, but the sample size was small and it is possible that this distorted the analysis (Groot, 2005: 55).

It was interesting to note that several of these pelves could be positively identified as female. As previously mentioned, correlation between morphological changes in the feet of cattle and the sex of the animal has been difficult to determine. However, it is often generally assumed that draught animals are male oxen or castrates in archaeological literature. The evidence presented by Groot (2005: 55-56) challenges that assumption.

Bovines are not the only animals to have been employed for traction purposes. Ethno-historic records show that dogs have also been employed in a related manner. Among the Assiniboin, for example, dogs wore packs that consisted of two pouches cinched around their middle, which could carry loads between 30 – 50 pounds in weight (Walker *et al.*, 2005: 83). Various Plains groups are also described as using dogs to pull travois, two long poles tied to the midsection of the dogs, whilst dog sleds were a regular feature of historic Inuit life (Walker *et al.*, 2005: 83). The results of studies such as those by Armour-Chelu and Clutton-Brock (1985) and Isaakidou (2006) can, therefore, be compared to the results of a survey of the huskies employed by the British Antarctic Survey as

sledge dogs. This found that the stresses and strains involved in pulling a loaded sledge in such adverse conditions as those found in polar regions were the main factors involved in the formation of degenerative joint disease of the hips and shoulders (Bellars and Godsall, 1969: 31). Following radiographic analysis, post-mortem examination and histological studies, the lesions were found to be not only on similar joints, but also generally in a uniform position on the articular surface of the humerus and femur. Whilst there was variation in size and depth, there was invariably bilateral symmetry of these erosions, which were found on the areas of greatest pressure when a dog was pulling (Bellars and Godsall, 1969: 17-18). Support for the hypothesis that these changes were activity-related can be found in other studies, which found degeneration of the shoulder joint in modern dogs to be uncommon (Campbell, 1968: 194).

In addition, burials from sites such as that at Dust Cave in the South-eastern United States display antemortem damage to the dorsal spinous processes, as well as caudal curvature of the scapular spine (Walker *et al.*, 2005: 88). It has been suggested that such pathologies were caused by weight bearing down upon that region of the dogs' backs. Similar damage has been observed on animals used as pack animals in the South-western and Midwestern United States, as well as in the eastern Arctic (Walker *et al.*, 2005: 88) and that explanation has been proposed for other archaeological assemblages (Warren, 2000).

Such inter-specific similarities raise the possibility that, if a methodology could be developed for the recording of such pathologies in one species such as cattle, it might be applicable to those of other species such as horses, dogs, donkeys

etc., although problems with different anatomic configuration do obviously need to be taken into account. Comparisons of this nature have to some extent already begun. For example, Izeta and Cortés (2006) compare and contrast pathologies in adult llamas from Argentina with those observed in cattle (*e.g.* De Cupere *et al.*, 2000). Whilst there is a lack of evidence for the draught exploitation of camelids in the Andean area, there is evidence for the use of some as cargo animals. The authors, therefore, conclude that forced and recurrent activity during caravans could be the cause of degenerative changes seen in the feet of llamas. They do also note, however, that other aetiologies are possible and that more research is required in this area.

4.3.3 The identification of horse riding

Palaeopathological evidence is often cited as evidence for the use of horses for riding and traction, and consequently as evidence for the domestication of this species and its later use in transport and communication. As Levine *et al.* (2000: 123) discuss, conventional methods for differentiating between wild and domestic animals produce ambiguous results when applied to horses and, therefore, palaeopathology can make a worthwhile contribution to this question.

Concentrating on the post-cranial skeleton, Levine *et al.* (2000; 2005) set out to determine the abnormalities that would affect horses being used for riding and traction, working on the assumption that the stresses of such usage would be different to those affecting wild individuals. They also hypothesised that it should be possible to differentiate between animals being used for traction and

those used for riding for the same reason (Levine *et al.*, 2000: 125; Levine *et al.*, 2005).

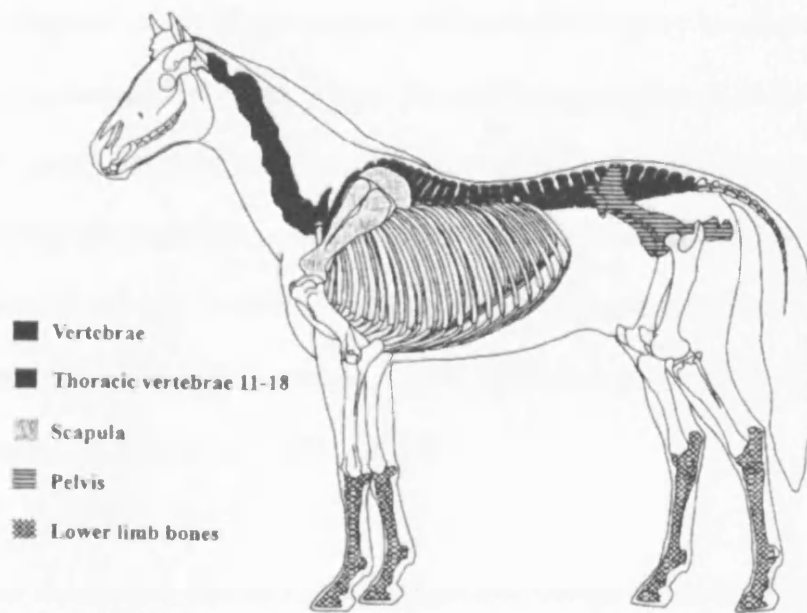


Fig 4.3: Horse skeleton showing anatomical sites of interest (Levine et al., 2000: Fig 14.2)

As can be seen from figure 4.3, the study particularly concentrated on four anatomical areas: the lower limb bones, hip, shoulder and spinal column. This was because these areas were believed to be particularly subject to work-related pathological change. Injuries of the hip and shoulder regions are often attributed to traction, whilst those of the vertebrae may relate to riding-related stresses (Levine *et al.*, 2000: 125). This hypothesis is supported by work on modern huskies which demonstrated that, whilst not immune to mechanical stress on the vertebral column, the use of a chest harness was less traumatic to the spine of a sledge dog than to its limb joints; incidences of spondylosis deformans being lower than those of degenerative joint disease in the hips and shoulders (Bellars and Godsall, 1969: 33-35).

Modern comparative collections are frequently used in archaeozoology and palaeopathology and a good reference collection is essential. This includes studying bone material from animals of known life history in order to develop a good understanding of the reason for certain pathologies. It is for this reason that Levine *et al.* (2000) used a wide variety of comparative material that included thoroughbreds, Arabians, ponies and other horses that had been ridden or used as draught animals, as well as modern Exmoor and New Forest ponies whose free-living lifestyle made them a suitable comparison to the veterinary collection (Levine *et al.*, 2000: 125-126).

These collections, and an archaeological assemblage of Scythian horses dating to the Early Iron Age of the Altai Mountain region, led the group to identify four types of pathology that were present in the archaeological assemblage, which was strongly believed to be composed of riding animals due to the fact that they were buried with or near humans and in association with riding equipment, but were either slight or absent in the collection of Exmoor ponies. These pathology types were (Levine *et al.*, 2000: 127):

- (i) Deposition of spurs of new bone (osteophytes) on the ventral and lateral surfaces of the vertebral bodies (centra) adjacent to the intervertebral space;
- (ii) Overriding or impinging dorsal spinous processes;
- (iii) Horizontal fissures through the caudal epiphyses;
- (iv) Periarticular exostoses: deposition of new bone on and above adjacent articular processes between vertebrae.

Horse skeletal remains from the medieval sites of Marvelė and Masteikiai in Lithuania, revealed that 12.5% (35 of the 280 skeletons) showed some form of pathological condition. In particular they showed that the teeth, vertebrae and the lower limb bones of both the fore and hind limb were most susceptible to change (Daugnora and Thomas, 2005: 71). These are the same areas identified as being significant in the identification of traction and riding by Levine *et al* (2000: Fig 14.2). It was suggested that because the majority of the recorded pathologies could be categorised as arthropathic, namely the ossification of the interosseum ligaments of the metapodials, deformations of the tarsus (or spavin) and spinal ankylosis, the horses may have been used for riding or traction. These conditions can be triggered by other, natural factors such as age and weight; however the interment of bridle bits with the burials supported this hypothesis (Daugnora and Thomas, 2005: 72).

A scoring system for the ossification of these interosseous ligaments (Bendrey, 2007: 209) divided the severity of expression into five descriptive stages:

- 0. No apparent evidence for ossification of the ligaments between the metapodials.
- 1a. Metapodials attached, but no visible signs of new bone formation. In museum specimens this stage could include specimens in which connective tissue still remains in the joint following the preparatory process of the skeleton, or specimens that might have been glued *e.g.* for display.
- 1b. Metapodials unattached, but evidence for new bone

formation between the skeletal elements, in particular along the edges of the area where the two bones join.

- 1c. Metapodials attached with visible signs of new bone formation, but this new bone has not yet bridged the interosseous border between the two skeletal elements.
- 2. Metapodials attached and new bone deposition clearly bridges the interosseous border.

It was proposed that a single score be awarded for each of the joints between the metapodials (*i.e.* left metacarpal ii-iii, left metacarpal iii-iv, *etc.*). These scores could then be tabulated together in the analysis of complete skeletons, or presented as cross-tabulated scores and compared between different populations (Bendrey, 2007: 209). Preliminary studies suggested that the development of the lesion can be linked to age, with scores of one (a-c) more common in younger age groups and scores of two more common in the older age bracket (Bendrey, 2007: 210). Lesions also appeared to be more severe in the metacarpals than metatarsals, suggesting that the lesion occurred first in the forelimbs and later in the hindlimbs (Bendrey, 2007: 211). Further research on larger samples is required to confirm whether these patterns hold true across time and space. However, as a simple methodology with little need for specialist equipment, this scoring system would be easy to replicate by other researchers and such additional analysis would therefore seem appropriate and worthwhile.

A comparison of spinal ankylosis in various equine species revealed that fusion seldom occurred in wild species, but could be found in domestic horses, Shetland ponies and Arabians (Stecher and Goss, 1961). This fusion of the intervertebral joints usually occurred as multiple lesions, not only with the involvement of several intervertebral joints, but also in association with the ankylosis of lateral transverse joints and bridging. Fusion was usually bilateral, although the bridge could alternate from one side to the other. This undoubtedly painful process would presumably interfere with the function of the animal and render it more vulnerable to predators. It may be for this reason that such ankylosis has only been found in captive animals (Stecher and Goss, 1961: 254). Another possibility is that domestication in general has brought about a number of pathological phenomena that would not be tolerated in the wild by natural selection, the increased frequency of the lesions rather than their cause being regarded as evidence of this process (Bartosiewicz and Bartosiewicz, 2002: 828-829).

However, it should be observed that not all cases of spinal arthritis relate to riding. Examples of spondylosis deformans, a disease “characterised by the formation of bony spurs and bridges across the intervertebral spaces” (Harris, 1977: 183; Morgan, 1967) has been identified in animals that have never been utilised in this manner by humans, such as the red fox and the dog. Even in horses, not all cases of spinal arthritis are attributed to riding-related stress. An instance of ‘bamboo spine’ in a Migration Period horse from Hungary was instead hypothesised to have an inherited component as the authors felt the animal in question was too badly affected for the lesions to have been solely due

to a repetitive stress injury. Thus it was proposed that genetically predisposed individuals might have extensive intervertebral fusion triggered or exacerbated, but not exclusively caused, by riding (Bartosiewicz and Bartosiewicz, 2002: 829).

Studies have also shown that changes, such as cartilage degeneration, wear lines, subchondral bone sclerosis and osteophytosis, consistent with degenerative joint disease, occur in the metacarpophalangeal joints of wild horses. This confirms that there is naturally occurring, age-related pathological change, although it is plausible that trauma relating to racing or riding might accelerate this process (Cantley *et al.*, 1999: 79-80). This emphasises the necessity for a combination of factors to be present before a diagnosis of riding-related pathology is made.

Another consideration is the fact that detailed recording of vertebrae is unusual in archaeozoology and, in general, is only carried out when attempting to answer specific research questions. This means that not only is there no wide pool of outstanding data that could be used for comparative purposes, but to create such data would require a change in practice for many researchers. It is also worth noting that all of the assemblages used in the case study conducted by Levine *et al.* (2000) were small (less than twenty Exmoor ponies and only six Scythian skeletons), and that this would necessitate further testing of the hypothesis on larger numbers of skeletons, preferably from a range of geographic locations and time periods in order to ensure that other variables such as age, sex and breed were not interfering with the results. They do,

however, show that further work in this area could produce a significant contribution to the understanding, not only of the effects of riding upon the skeleton of the horse, but also of the culture of the peoples using the species in their daily lives. If it is possible to convincingly identify those features in animals that had been ridden, the methodology should then be able to be transferred to those animals for which such a certainty is currently absent.

4.4 Oral pathology

4.4.1 Introduction

Tooth enamel is one of the substances most resistant to decomposition in the body and teeth are commonly found on archaeological sites, sometimes even after the bones themselves have decayed. It is perhaps not surprising, therefore, that a number of methodologies have been devised to record oral pathologies and other abnormalities of teeth. One such general methodology for recording the pathology and other anomalies of ungulate mandibles was developed by Levitan (1985); maxillary teeth are not recorded as they are less frequently found as tooth rows in archaeological assemblages. This methodology records tooth presence/absence, wear stages, fragmentation, attrition, periodontal disease, abscesses, supernumerary or absent teeth, hypoplasia, calculus, pigmentation, pulp cavity exposure, butchery, nutrient foramina, disturbances of the ventral margin and other anomalies. In some instances, such as with supernumerary or absent teeth, this is a simple case of recording presence or absence. For others, such as periodontal disease, “an infection not only of the alveolar bone, but also of the soft tissues of the mouth” (Brothwell, 1981: 154), it is graded into stages based upon the degree of severity. Studies, such as those

on the skeletal remains of *Smilodon californicus* from Rancho La Brea (Shermis, 1984: 193), suggest that the latter is one of the most common oral disorders, with initiating factors likely to include gingivitis, attrition or inflammation subsequent to trauma.

Levitan's system is devised for use primarily on mandibles. This was due to their good survivability in the archaeological record, and also because the intimate contact of the teeth with the external environment makes oral pathology one of the most common aspects of pathology. Moreover, mandibles are more sensitive to change than many other bones (Levitan, 1985: 41). Investigations of these pathologies can provide indications about the diet and health of domestic animals, their management by humans, housing and the type, quality and management of grazing and fodder (Davies, 2005: 80).

To ensure that no preservational bias is present, it is obviously necessary when recording oral pathologies to record not just the affected teeth, but also the presence or absence of all teeth. This also makes it possible to calculate the prevalence of a condition within the population. It is commendable that Levitan (1985) takes this factor into consideration. It was also interesting to note that conditions such as supernumerary or absent teeth were recorded using this methodology. These would obviously be relevant to anyone analysing patterns within the population, however there is some debate as to whether these conditions are strictly 'palaeopathological' (chapter 2). For example, the absence of premolar teeth in ruminants has been sporadically reported in the archaeological literature. The reason for this absence can be varied; a failure to

erupt, fusion with one of the other teeth, premature loss or congenital absence (Andrews and Noddle, 1975: 137). Whilst there is no question about possible interest in the patterns such recording gives, it is worth noting that such congenital absence in humans of teeth such as the third molars or wisdom teeth is not generally considered to be of major pathological significance. Instead, they are examples of non-metric variation.

Whilst Levitan's (1985) methodology is generally sound, the necessity of using arrows to indicate direction of attrition, for example (Levitan, 1985: 42-43), suggests that this system could be greatly improved with regards to the coding used. This would increase the chances of being able to record pathologies using a computer database or spreadsheet, and enable statistical analyses to be conducted, which in the form currently presented would be difficult. This methodology has been used by a few workers (*e.g.* Baker, 2002; Levitan, 1984) but does not appear to be widespread.

4.4.2 Caries and other cavities

Dental caries is one of the more common dental diseases, particularly in humans (Roberts and Manchester, 2005: 65). It is caused by the fermentation of food sugars, especially sucrose in the diet, by bacteria that occur on the teeth in plaque, such as *Lactobacillus acidophilus* and *Streptococcus mutans* (Roberts and Manchester, 2005: 65). Carious cavities usually develop in three regions of the tooth (Brothwell, 1981: 153):

- 1) on the occlusal (biting) surface, generally in the region of natural fissures;

- 2) in the region of the neck (cervical area) of the tooth, either on the lingual (tongue) or labial (lip) side;
- 3) in the region of the neck of the tooth, but between the teeth (mesial and distal).

It has been common practice to record caries simply as present or absent for each tooth, however the location of the carious lesion is significant since it may reflect different aetiologies (Hillson, 2001: 250). Several studies showing the natural history of caries in humans demonstrate that different cultures and different modes of subsistence can result in strongly contrasting patterns of dental caries. In archaeological material it is, therefore, important to distinguish between the various forms, the different stages of development (particularly of coronal lesions), age and sex, and between different types of teeth. The generally symmetrical nature of caries means that making a distinction between left and right is not as important as differentiating between the upper and lower dentition (Hillson, 2001: 254). These considerations have led to the development of scoring systems such as that by Hillson (2005) (table 4.1).

Score	Crown caries (including occlusal, contact area and smooth surface)	Root surface caries
Missing value code	Potential site lesion missing for any reason (attrition, tooth fracture, tooth loss) or fully obscured (calculus, concretion)	No part of root surface or cement-enamel junction (CEJ) preserved, or at least not visible if present
0	Site present but enamel is translucent and with a smooth surface	Root surface/CEJ present and visible, with no evidence of staining or cavitation
1	White or stained opaque area in enamel with smooth glossy or matte surface	Area of darker staining along CEJ or on root surface

2	White or stained opaque area with associated roughening or slight surface destruction	Not used
3	Small cavity where there is no clear evidence that it penetrates the dentine	Not used
4	Discolouration in exposed dentine of an attrition facet (only used for worn teeth)	Not used
5	Larger cavity which clearly penetrates dentine	Shallow cavity (stained or unstained) following the line of the CEJ or confined to the surface of the root
6	Large cavity within the floor of which is the open pulp chamber, or open root canals	Cavity involving the CEJ or root surface alone, within the floor of which is the open pulp chamber, or open root canals
7	Gross coronal caries involving this particular lesion site and one or two more neighbouring coronal lesion site(s)	Gross cavity, including the CEJ or root surface, which involves any neighbouring crown sites
8	Gross coronal caries, within the floor of which is the open pulp chamber, or open root canals	Gross cavity, as in score 7, within the floor of which is the open pulp chamber, or open root canals

Table 4.1: Scoring for carious lesions (Hillson, 2005: Table 5.1)

However, such systems are almost too detailed and as a result can quickly become cumbersome. Hillson (2005: 298) notes that separate scores should be recorded for the occlusal, mesial contact area, distal contact area, buccal crown side, mesial cemento-enamel junction (CEJ), distal CEJ, buccal CEJ and lingual CEJ of each tooth. This undoubtedly provide a fine level of detail with regard to the distribution of the carious lesions, but is also time-consuming and could potentially introduce a false sense of accuracy to results for two reasons. Firstly, post-mortem tooth loss or damage can affect the results. Secondly, dental attrition or wear is often far more significant in archaeological populations; thus

occlusal surfaces may be worn before conditions such as caries can develop, or any traces of caries that occurred earlier in life may be removed. In extreme cases of wear, any abscesses present may relate to subsequent infection of the exposed pulp cavity, rather than carious lesions (Ortner and Putschar, 1981: 439). It is possible for teeth with more than one root to develop these cavities at the base. Other authors (Brothwell, 1981: 157) have, therefore, recommended that only one cavity be recorded for that tooth if it is not possible to determine their independent origin.

4.4.3 Calculus

Dental calculus, or tartar, is one of the commonest types of ectopic concretions affecting teeth. It is the calcified remains of dental plaque and is very durable in archaeological material. Two types are seen: supragingival calculus (above the gum) is more common and is usually thicker and grey or brown in colour, while subgingival (below the gum), often seen on exposed tooth roots, is harder and green or black in colour (Roberts and Manchester, 2005: 72). In cervids, a metallic silver appearance has also previously been noted. The use of a scanning electron microscope can provide great detail, not only about the oral pathology itself, but also about the ancient oral ecology trapped within it (Dobney and Brothwell, 1988). In humans, calculus is often recorded in stages dependent upon severity (Figure 4.4). While such stages are inevitably artificial, the stages in reality grading from one into the other, this approach permits the comparison of the severity in one individual mandible, as well as between individuals and populations, something that might provide useful dietary information.

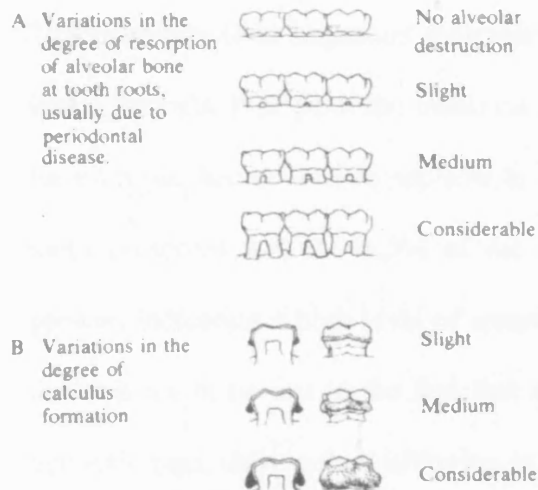


Fig 4.4: Stages of A) Alveolar Resorption and B) Calculus Formation (Brothwell, 1981: fig 6.14)

4.4.4 Enamel hypoplasia

Enamel hypoplasia (LEH) has been defined as “defects in the teeth... observed as lines, pits or grooves on the enamel surface,” that form as a result of pauses in the growth process (Roberts and Manchester, 1995: 58). If the cause of this arrest is not severe, or acts for only a short period of time, then the hypoplasia will be “merely a ring of shallow pits with some areas of enamel opacity and whiteness. If the severity is greater and the condition lasts longer, the pits became deeper and confluent, producing ring-like grooves around the teeth” (Miles and Grigson, 1990: 438). Due to the manner in which enamel is formed (chapter 3) it is possible to see a clear chronological sequence in the LEH lines. Those that formed near the tip of the tooth are younger than those near the cervix. Moreover, as enamel does not remodel itself, the lines will remain into adulthood as an archive of developmental stress (Dobney and Ervynck, 2000: 598).

This condition is an important indicator of nutritional deficiency and illness in young animals. Pigs from the medieval site of Starigard in Northern Germany, for example, had enamel hypoplasia in 30% of all mandibles with at least one tooth preserved and in 43.5% of the mandibles with dp4, M1, M2 or M3 present, indicating a high level of stress (Teegan, 2005a: 91). Teegan suggests that this might be due to the fact that as most wild pigs, as well as primitive domestic pigs, deliver their offspring in early spring, the juvenile animals, and thus also the mother sows, were being affected by famine, disease or other stress during the winter months (Teegan, 2005a: 91).

Research into the use of LEH as a chronological marker found that a similar pattern of lines could be observed on teeth from a variety of different sites. This may suggest that pigs were more susceptible to stress at certain times of the life cycle. For example, crown formation of the first permanent molar begins *in utero* and is completed at the age of two to three months. The major physiological changes that might cause the formation of LEH are therefore birth and weaning, two critical periods of physiological and nutritional stress (Dobney and Ervynck, 2000: 602-603). Similar linkages were also made to major life events and seasonality for the lines present on other teeth, leading to the conclusion that analysis of this condition could allow an evaluation of the impact of environmental factors and husbandry practices on the animals from archaeological sites (Dobney and Ervynck, 2000: 606; Ervynck and Dobney, 1999).

In humans, population analyses are based upon the assumption that differences in Linear Enamel Hypoplasia (LEH) frequency, severity and age at formation reflect differences in the stress levels of a population. However, there is still debate about the conclusions that can be drawn, some workers arguing that the greater the severity and frequency of the LEH, the greater the childhood stress of the population and thus the less favourable their living conditions. On the other hand, other researchers suggest that stress markers indicate the survival and recovery of that individual, possibly due to improvement in living conditions in comparison to those who died in childhood and thus had no LEH (Palubeckaitė *et al*, 2002: 190). This latter is known as the ‘osteological paradox’ (Chapter Five).

In a study conducted in an attempt to reconcile some of these differences, three medieval/early modern human populations were studied in Denmark and Lithuania. An earlier study by the same researchers had revealed differences in LEH between the upper and lower dentition. Only individuals with complete upper and lower teeth of either the left or right side were included in the analysis. All permanent dentition were recorded on the left-hand side. In the case of a missing tooth, the antimere from the right side was used, as the earlier study had also revealed no differences in side prevalence (Palubeckaitė *et al.*, 2002: 191).

Severity of hypoplasia was recorded as: first degree – mild; second degree – moderate; and third degree – severe. Estimation of this severity was based upon the width, depth and definition of the hypoplasia (Palubeckaitė *et al.*, 2002:

191), this being comparable with Duray's (1996: 278) grades A-C where grade C were often questionable cases, grade B had grooves which did not exceed 0.50 mm in width, and grade A exceeded 0.50 mm in width or resulted in gross morphological changes, and all individuals were classified in accordance with the most severe episode. There are other methods available for determining severity, but most rely upon detailed histological analysis, which is not considered cost effective for large samples (Palubeckaitė *et al.*, 2002: 191) and would not be feasible for archaeozoological analysis.

The number of stress episodes per individual was defined by the age at which the defect formed. If LEH on several teeth of the same individual matched the age at formation, they were defined as one stress episode (Palubeckaitė *et al.*, 2002: 191). It was found that LEH was an objective indicator of life conditions that could be used for comparative purposes, regardless of the debates about interpretation. However, it was considered advisable to assess all ecological and cultural circumstances when defining morbidity and mortality patterns, and that non-specific stress markers ought to be examined to reveal any correspondence with LEH levels (Palubeckaitė *et al.*, 2002: 198).

Dobney and Ervynck set out a protocol for recording Linear Enamel Hypoplasia (LEH) on pig teeth (1998). This was developed and tested on material from five sites: late Neolithic Durrington Walls (UK), and the medieval Belgian sites of Wellin, Ename, Sugny and Londerzeel (Dobney and Ervynck, 1998: 264).

The authors decided to record only mandibular teeth because these were more often preserved in rows than the teeth of the maxilla. They also decided to restrict themselves to the permanent molars for two reasons. Firstly, these teeth represented the developmental period of the animal in a continuous, uninterrupted way. Secondly, only the permanent molars and the fourth deciduous premolar were preserved in sufficient quantities as to make the sample statistically valid. Furthermore, the fourth deciduous premolar showed a significantly lower frequency of LEH, which may be due to the rapid crown development that occurs in deciduous teeth (Dobney and Ervynck, 1998: 264).

Whilst the greater frequencies of LEH in permanent teeth at the site of Starigard was consistent with this pattern, it is interesting to note that slight LEH was found in 21 out of 60 mandibles with a deciduous fourth premolar (dp4). As Teegan states, “the tiny lines were in most cases located near the dento-enamel junction. However, in two cases they were found in the middle of the distal cusp. Only in one case were two slight lines identified on a dp4” (2005a: 90-91).

After identification of the tooth type, the eruption or wear stages of the tooth were recorded using the system devised by Grant (1982). This was to determine whether the identification of LEH would be obscured, either by partial eruption or by its removal due to wear. Finally, any abnormalities, pathologies or unusual preservation condition were noted that might hamper observations (Dobney and Ervynck, 1998: 264-265).

As only one aspect of the tooth crown needs to be examined for evidence of LEH, it was decided that the lingual surface would be the most suitable as the crown reaches its greatest height at this point. This means that LEH lines are more likely to show obvious separation at this point also, and thus be more easily recorded. The authors recommended that the lines be recorded individually for each cusp as these develop at different rates and it was noted in the samples that this sometimes produced differences between them (Dobney and Ervynck, 1998: 265). The LEH groove can be either shallow or deep, with rounded edges. It was most often noted on the bottom third of the first and second permanent molar. However, multiple occurrences of LEH on an individual crown are not uncommon and these were noted separately (Dobney and Ervynck, 1998: 265-266).

Once the presence of LEH had been established, the lines were graded as 'slight', 'moderate' or 'severe', and illustrations of these are set out in the article for the reference of other researchers. The position of the LEH was recorded by measuring "the distance between the groove and the cemento-enamel junction on each cusp, along a perpendicular axis" (Dobney and Ervynck, 1998: 267).

The authors observed several difficulties whilst carrying out their study. These included the use of the naked eye which could cause some lines to be overlooked, and made it occasionally difficult to establish the lowest point of the cemento-enamel junction due to the early eruption of the tooth and/or abnormal wear. Other difficulties included poor preservation, unusual morphology or the presence of pathological conditions. However, the use of a

magnifying lens under strong oblique lighting managed to eradicate most of these problems (Dobney and Ervynck, 1998: 269).

This methodology was adjusted during later testing so that left and right lower jaws were used, observations continuing to be restricted to the lingual surface of the molars M₁, M₂ and M₃. LEH lines were recorded per individual cusp (with ‘a’ indicating the anterior cusp, ‘b’ the posterior or middle cusp in the case of M₃, and ‘c’ the posterior cusp of M₃). The wear stage was determined as previously discussed using Grant (1982). Measurements of the distance between the LEH line and the cemento-enamel junction, and the crown heights of unworn or slightly worn molars were taken (Dobney *et al.*, 2002: 37).

The frequencies of LEH were then calculated for the cusp of each molar and combined using the following index:

$$\text{Index}_{(\text{site A})} = \text{average} [F_{(\text{tooth} \times \text{cusp} \times \text{y})(\text{site/phase A})} / F_{(\text{tooth} \times \text{cusp} \times \text{y})(\text{all sites/phases})}]$$

Where F = number of LEH lines observed / no. of specimens observed, calculated per population (sites or phases), for each individual tooth cusp, when number of specimens > 0 (Dobney *et al.*, 2002: 37). This allowed a comparison of relative average frequency to be made.

In the later study a clear division was also made between ‘lines’ (defects in enamel formation with restricted width and sharp edges) and ‘depressions’ (broad defects with rounded edges). This refinement was introduced to enable

the quantification of the subjective impression of differences between the heights of the two forms of LEH (Dobney *et al.*, 2002: 37).

The analysis of LEH on pig teeth from the Saxon site of Flixborough, UK, and 15th century Raversijde, Belgium, corroborated the postulation that the consistent height distribution could be explained by a regular, underlying chronology linked to major physiological effects such as birth, weaning and winter. This pattern was made even clearer by discriminating between lines and depressions, with depressions on the M₂ and M₃ indicating stress caused by under-nutrition in winter. On the M₁ the effect of stress related to birth and weaning manifested itself as both lines and depressions (Dobney *et al.*, 2002: 46).

The assumption that the relative frequency of LEH follows the same pattern along the molar row was tenable for six of the assemblages studied by the authors. However, this was not the case for the material from Raversijde, where domestic pigs appear to have been part of a different type of husbandry scheme compared to the other sites. It was, therefore, recommended that the index be calculated not only for all molars combined, but also per tooth in an attempt to make this variation evident (Dobney *et al.*, 2002: 46).

Enamel hypoplasia has been noted in other animals such as dogs (Onar *et al.*, 2002: 332) and bison (Niven *et al.*, 2004) where it is also associated with general health and diet. Methodologies developed upon pigs might, therefore, be transferable to other species. It is worth noting, however, that the studies upon

bovids in particular have been criticised for not taking into consideration potential misrepresentation (Kierdorf *et al.*, 2006). The crowns of the cheek teeth of cattle and some other ungulate species with a hypsodont dentition are covered with cementum. The presence of this prevents direct inspection of the enamel, and thus identification of enamel hypoplasia solely by macroscopic examination of the tooth surface is inherently more difficult than in species such as human or pigs that do not usually possess such a cementum layer on their tooth crowns (Kierdorf *et al.*, 2006: 1691). Microscopic analysis of tooth thin sections has, therefore, been recommended by the authors as a means of differentiating between horizontal lines or grooves in coronal cementum and true enamel hypoplasia (Kierdorf *et al.*, 2006: 1695).

4.4.5 Malocclusion and dental malalignment:

Malocclusion, the incorrect positioning of one or more teeth within the jaws, either relative to adjacent teeth in the same jaw or in relation to the 'fit' between upper and lower dentitions (Brothwell, 1991: 27), and dental malalignment are considered to be worthy of research as they can provide evidence of evolution and domestication, for example, in many species. In Brothwell's (1991) study of dogs and wolves it was decided that the median plane of the skull, as established by the median suture of the palate, would be the baseline to which all references were made. Each tooth was related to this by an angular measure (figure 4.5), the margins of the crown being considered the most accurate and repeatable measurement points as they prevented cusp shape and tooth wear from interfering with the result. It was then possible to plot the results of the

measurements against one another to demonstrate variation (Brothwell, 1991: 31-33).

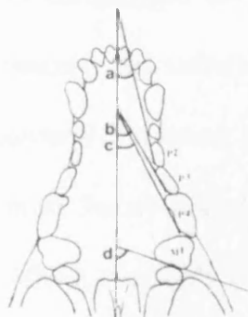


Fig 4.5.: Details of the construction of angles used (Brothwell, 1991: Fig. 3)

The comparison of modern dog breeds with archaeological specimens as well as wolves using this methodology demonstrated that variation in the alignment and crowding of the posterior teeth was more subtle in archaeological specimens than in modern dogs (Brothwell, 1991: 31), and that there was a general overlap between the results derived from the archaeological specimens and wolves – the wolves, in particular, exhibiting greater variation than anticipated (Brothwell, 1991: 35). However, whilst setting out a simple methodology that could be easily adopted by other workers, Brothwell (1991) intended this only as a pilot study and it is not unproblematic. The sample size used was quite small, and the pooling of the data from a variety of modern dog breeds could have influenced the results, given the variation shown between many modern breeds. Measurements were also taken from photographs of the palatal view of skulls. However, there is no mention of whether there would be any difference made by recording from the actual skull compared to recording from archival photographs. Such questions would need to be answered before this methodology could be used on a regular basis by other researchers as this might affect accuracy.

4.5 Infectious disease

In comparison to human palaeopathology, the study of infectious disease in animals has suffered from a variety of factors, including the lack of diagnostic criteria for many conditions, the fragmentary and disarticulated condition of most faunal assemblages, and thus the difficulty in tracking systemic disorders. Whilst the study of infectious diseases is perhaps not as prevalent in animal palaeopathology as it is in human palaeopathology, it can nonetheless provide fascinating insights into human-animal interactions in the past. Zoonotic diseases, those that can be transmitted from animal to human, are of particular interest.

4.5.1 Tuberculosis

One example of a zoonose that has been subject to some scrutiny is tuberculosis. In contrast to the wealth of literature on tuberculosis in human palaeopathology, the literature on the appearance of tuberculous lesions in animal bones is sparse, and the only English language survey of animal palaeopathology (Baker and Brothwell, 1980) devotes only cursory attention to the disease.

Human tuberculosis is “an acute or chronic infection of soft or skeletal tissues by *Mycobacterium tuberculosis* or *M. bovis*” (Aufderheide and Rodríguez-Martín, 1998: 118). The first of these is conducted via droplet infection from human to human, the second through ingesting meat and milk from animals, particularly cattle, or via droplet infection (Roberts, 2000a: 151). Considered to be a disease of poverty, tuberculosis is becoming an increasing problem

worldwide in modern society, especially in its drug-resistant form, in people of low socio-economic status with HIV and AIDS (Roberts, 2000a: 151). Its epidemiology is a complex mix of variables: the young, the old, and the malnourished are susceptible; poor environmental living conditions, high population density, certain occupations, the co-occurrence of HIV, and the lack, or breakdown of, public health infrastructures in some countries are some of the main factors to consider in its occurrence (Roberts and Buikstra, 2003: 11).

With the development of rapid transportation and the global economy, the potential for isolated outbreaks of this, and many emerging diseases, to develop into pandemics has also increased significantly (Schrag and Wiener, 1995: 319). Approximately one third of the world population is infected with *Mycobacterium tuberculosis* complex bacteria, with about 8 million new cases annually, leading to 2-3 million deaths each year. Modern research efforts have, therefore, been focussed not just on the development of new vaccines, but also on identifying the evolutionary pathways of the disease in an attempt to understand its global dissemination and pathogenicity (Brosch *et al.*, 2002; Zink *et al.*, 2004: 404-405). It is, however, a disease of considerable antiquity, and a likely case has been described from the Iron Age of Dorset, England (Mays and Taylor, 2003). The existing evidence seems to suggest that tuberculosis was originally transmitted to human populations in Britain from continental Europe sometime during the prehistoric period (Mays and Taylor, 2003: 194) as there are examples of older cases from the continent, such as those from Neolithic Italy (Canci *et al.*, 1996; Formicola *et al.*, 1987).

Skeletal lesions are relatively late manifestations of tuberculosis and occur in only a minority of cases. These characteristic bony changes are caused by haematogenous spread of infection from soft tissue foci, and are sufficiently characteristic to permit the recognition of the disease in ancient skeletal material. Characteristically lytic, with little perifocal new bone regeneration, favoured sites for these lesions are the vertebral bodies, particularly in the lumbar and thoracic spine (where it is also called Pott's disease), and the major joints of the appendicular skeleton (Mays, 2005: 128). In addition, rib involvement has been documented in both clinical and anthropological literature. This may arise by extension from spinal lesions, from haematogenous spread from some remote soft-tissue focus, or from direct contact with the disease in the lungs, pleura or chest-wall lymphatic system (Mays *et al.*, 2002: 27), although the veracity of this has been challenged by others (Cremin, 1999: 237).

Whilst both *M. tuberculosis* and *M. bovis* may affect the skeleton, it is impossible to distinguish the two forms of tuberculous infection using osteological criteria, as the bony lesions caused by the two pathogens are anatomically similar. This distinction has recently become possible using ancient DNA (Mays, 2005: 129), however the use of this methodology is not without its limitations. Haas *et al* (2000) found that, when examining a variety of skeletons for tuberculosis, only two of the three cases with the typical morphological features of the disease could be confirmed by ancient DNA analysis. Ancient DNA is a fragile molecule whose survival is dependent upon factors such as soil conditions, temperature and humidity. Negative results,

therefore, do not always indicate an absence of the disease. On the other hand, a positive result could help to confirm a diagnosis in less characteristic cases of a condition, or even in skeletal remains that show no osteological changes (Haas *et al.*, 2000: 303).

Another biomolecule group with potential for disease diagnosis is the bacterial lipids (Redman *et al.*, 2002: 114). More stable than both DNA and proteins, due primarily to their insolubility in water, lipids are waxes, oils and fatty acids. The mycolic acids of *M. tuberculosis* complex are specific, and distinct from those produced by environmental bacteria (Redman *et al.*, 2002: 114). These attributes make them easy to detect and identify in archaeological remains. It is worth noting, however, that at present the mycolic acids of all members of the *M. tuberculosis* complex are considered to be identical (Redman *et al.*, 2002: 116). Thus this method, whilst potentially more reliable than DNA analysis, is still unable to differentiate between *M. tuberculosis* and *M. bovis*.

Tuberculosis in animals has been documented by writers back to at least the 5th century BC, but the evidence from animal bones themselves has been negligible (Roberts and Buikstra, 2003: 270). Rothschild *et al* (2001) confirmed the presence of *Mycobacterium tuberculosis* complex DNA from a macroscopically recognised infection from an extinct longhorn bison of Pleistocene date. This is particularly interesting as it suggests the disease was present in the Americas by that date, probably reaching the region by 20,000 years BP, long before the domestication of cattle. It is hypothesised that bovids were the likely vector for dispersion of the ‘white plague’, carrying it with them as they immigrated over

the Bering Strait connection. This is supported by the presence of similar pathology in fossil bighorn sheep and musk ox (Rothschild *et al.*, 2001).

A recent article illustrated the case of a fully articulated dog skeleton from a 16th-century Neutral Iroquoian site in Ontario, Canada, which demonstrated the osteological condition known as hypertrophic osteopathy (Bathurst and Barta, 2004). This is “a progressive, symmetric and bilateral periosteal reaction secondary to chronic, space-occupying lesions of the inter-thoracic region such as pneumonia, cancer or tuberculosis” (Bathurst and Barta, 2004: 918). Other examples of dogs with this condition are also known from prehistoric sites in Alabama (Cole and Koerper, 2002: 177). Most commonly recorded in dogs and humans, although other animals such as deer, cats, birds, apes (Hime *et al.*, 1972) and horses (Bendrey, 2004) may also be afflicted, the condition results in thick periosteal new bone exostoses, primarily on the appendicular skeleton (Bathurst and Barta, 2004: 918).

Mycobacterium tuberculosis complex DNA was extracted from two complete carpals of the skeleton, confirming the presence of this bacterium (Bathurst and Barta, 2004: 921). This is the first confirmed example of an archaeological dog with pulmonary tuberculosis in the Americas, and indicates that the dog should be considered as a possible reservoir or vector for the disease. It has been previously noted that in approximately 67% of cases of tuberculosis in dogs there had been direct contact with known human cases (Thomsett, 1964: 68). Furthermore, since dog bone remodels at a faster rate than human bone, changes in reaction to stressors may be more immediately reflected in the canine

skeleton. It is possible, therefore, that palaeopathological lesions might develop more quickly in dogs and act as indicators of overall stress in the human population, despite the lack of evident pathology on human remains due to the longer time needed for them to materialise (Bathurst and Barta, 2004: 922-923).

Though all domestic animals are susceptible to tuberculosis, statistics show that it is mainly cattle, pigs and carnivores that are affected, whereas the frequency in sheep, goat, water buffalo and horse populations is clearly lower. Wild mammals are also susceptible to the disease, with tuberculosis being recorded in bovids, cervids, camelids, elephants, primates and carnivores. Avian tuberculosis is noted quite frequently in poultry, and has also been observed in other bird species (Lignereux and Peters, 1999: 339).

Infection is generally respiratory (up to 95% of cases in cattle), sometimes digestive (contaminated milk), and only exceptionally through the skin (inoculation tuberculosis), and results in the formation of a primary complex. This is followed by the secondary, or dissemination, stage, which corresponds to the spread of the bacillus, either *per continuitatem*, or by means of the circulatory or lymphatic system. Bone tuberculosis is most frequently located in cancellous bone, as well as in red bone marrow, which results in tuberculous osteomyelitis. It can also be observed occasionally below the periosteum (tuberculous periostitis), and exceptionally within the vascular connective tissue of the central canals of the osteons (Lignereux and Peters, 1999: 340-341).

In domestic mammals, tuberculosis generally affects vascular cancellous bone. In order of decreasing importance, these lesions can be found in the vertebral bodies, extremities of long bones, ribs, sternum, skull and other flat bones (coxal bone). Bone tuberculosis begins only occasionally in the diaphyses of long bones. This condition begins with demineralisation and osteoporosis, and is followed by an ulcerating or cavitory osteolysis, which can be diagnosed anatomically. Because of ongoing destruction processes, the bone becomes progressively weaker, resulting in collapses or fractures that cause typical bone deformities (Lignereux and Peters, 1999: 341).

Cattle and pigs show a higher affinity for articular tuberculosis in which a single swollen articulation is generally observed. In these cases the primary lesion is located either in the synovial membrane or in the bone. Once it has reached the articular cartilage, the latter may be destroyed and the underlying subchondral bone damaged by erosion and eburnation. In the course of the disease, the epiphyses of the articulating bones may be completely destroyed and the remaining ends fuse (Lignereux and Peters, 1999: 342).

Insufficient studies have been carried out to effectively determine diagnostic criteria for this condition in animals, a task rendered even more difficult by the generally disarticulated and fragmentary condition of faunal assemblages. It is noteworthy that virtually all of those examples of positive identification in animals come from complete or near complete articulated skeletons. Moreover, many of the key elements affected by the disease are poorly recorded in archaeozoological assemblages. Ribs and vertebrae, in particular, are often

recorded solely on a presence/absence basis or as a total number count. More detail is needed in the recording of elements such as these if respiratory conditions, including tuberculosis, are to be studied in more depth.

In addition, the fragmentary condition of many archaeozoological remains can create problems when using DNA analysis, as if the disease cannot be recognised osteologically it is not possible to know which specimens to target for biomolecular analysis (Mays, 2005: 130), particularly as other conditions such as pyogenous osteomyelitis, brucellosis, actinomycosis, echinococcosis and tumours may also demonstrate similar symptoms (Lignereux and Peters, 1999: 345-346). Nevertheless, it is likely that DNA techniques will play an important role in the analysis of tuberculosis in both human and animal remains. DNA has enabled infection from *M. tuberculosis* to be distinguished from that due to *M. bovis* in human remains. Additionally, because different strains of *M. bovis* may infect different animal species, it may be possible in the future to determine, using ancient DNA, whether cattle or some other animal vector was responsible for instances of *M. bovis* infection in human skeletons (Mays, 2005: 132).

As it has been noted that humans can act as a reservoir for *M. bovis*, reintroducing the disease into tuberculosis-free livestock (Brothwell, 1988b: 18), the identification of this disease in either animals or humans has implications for both populations. It is perhaps not surprising, therefore, that in a recent work on the bioarchaeology of tuberculosis two human palaeopathologists called for greater attention to be paid to this disease by

archaeozoologists. A focus upon areas of the world where early animal domestication took place would permit the testing of the hypothesis that tuberculosis occurred in humans at the time of the domestication of animals (Roberts and Buikstra, 2003: 270-271).

4.5.2 Avian osteopetrosis

Another infection that can reach epidemic proportions is avian osteopetrosis. Caused by a virus that stimulates the proliferation of osteoblasts in chickens, this leaves characteristic evidence on the skeleton (Brothwell, 1993: 41) that is visible macroscopically to the archaeozoologist, such as thickening of the metatarsals, symmetrical thickening of the long bones, and changes in other parts of the skeleton which are similar but not as pronounced (Biltz and Pellegrino, 1965: 1365). This proliferative growth of immature bone fails to become fully mineralised even after the growth of new bone subsides and a new phase of osteogenesis becomes evident (Biltz and Pellegrino, 1965: 1376).

Chemical and histological analysis of avian osteopetrotic bone from modern chickens has shown the disease to be characterised by (Biltz and Pellegrino, 1965: 1374-1375):

1. An increase in total bone mass caused by overproduction of bone and resulting in hypermineralisation;
2. Decreased hydrated-bone density reflecting an increase in water content and an increase in vascularity or porosity;

3. A decrease in the apparent densities of dry bone, mineral, and organic fractions;
4. A decrease in the degree of mineralisation or dry-bone density

Avian osteopetrosis has many similarities with human osteopetrosis and infantile cortical hyperostosis, all manifesting distinctive histological features and presenting similar appearances in x-rays. Chemical evidence of disturbance of maturation in avian osteopetrotic bone also accords well with histological evidence of a similar defect in humans with the condition (Biltz and Pellegrino, 1965: 1375). Indeed, osteopetrosis has been described not just in man and chickens, but also cattle and rodents (Smith and Ivanyi, 1980: 523). The study of avian osteopetrosis therefore presents an opportunity to not only study such a condition in chickens, but may also be helpful in understanding the disorder in other species (Biltz and Pellegrino, 1965: 1375).

Whilst currently infrequently reported in archaeological material, this may be due to either small sample size or a failure to recognise the early stages of the condition. The variable incidence of complete chicken bones in the archaeological record also makes it difficult to determine the prevalence in *Gallus* populations. However, as the virus causes bone changes in only a small proportion of infected birds, even one incidence of pathology may indicate a notable infection within the flock (Brothwell, 2002: 318). It can, therefore, provide evidence for the conditions in which the stock were kept.

4.6 Trauma

Traumatic injuries can occur due to accident, violence or other cultural activities. Interest in the identification of such lesions in humans stems from what they can tell us about individuals and ancient population's practices for dealing with warfare, interpersonal violence, knowledge of their terrain and other aspects of daily life (Aufderheide and Rodríguez-Martín, 1998: 19). In animals, the lesions have the potential to address questions such as inter- and intra-specific conflict, and human therapeutic intervention (Udrescu and Van Neer, 2005). However, it is worth bearing in mind that trauma may affect only the soft tissues and will not, therefore, always be observed in the skeleton. In addition, long-standing traumatic lesions may have been subject to bone remodelling and thus evidence for it may have been lost (Roberts, 2000b: 337).

Trauma in humans is frequently divided into several categories. For example, Steinbock (1976) refers to:

- 1) fractures
- 2) crushing injuries
- 3) bone wounds caused by sharp instruments
- 4) dislocations
- 5) transverse (growth) lines

Ortner and Putschar (1981), on the other hand, identify eight categories:

- 1) fracture
- 2) dislocation
- 3) deformation
- 4) scalping
- 5) mutilation
- 6) trephination
- 7) traumatic problems arising from pregnancy
- 8) sincipital T mutilation

This latter refers to T or cross-shaped lesions of the skull, in which the vertical portion of the T is associated with the sagittal suture whilst the cross bar is often associated with the lambdoid suture. One suggested reason for such a lesion is the use of cautery in the treatment of mental illness. Weapon-related injuries were placed in the ‘fractures’ category, being injuries to bone that resulted in a discontinuity. As observed by Merbs (1989: 161), despite the differences, there is more agreement than disagreement between what is and is not included, with fractures, weapon-related injuries, and surgical intervention often heading the list.

One of the most common types of traumatic injury seen on the skeleton is fractured bone. This is “a discontinuity of or crack in skeletal tissue, with or without injury to overlying soft tissue” (Aufderheide and Rodríguez-Martín, 1998: 20), and the treatment of these has a long history, with examples dating back into prehistory (Clark, 1937).

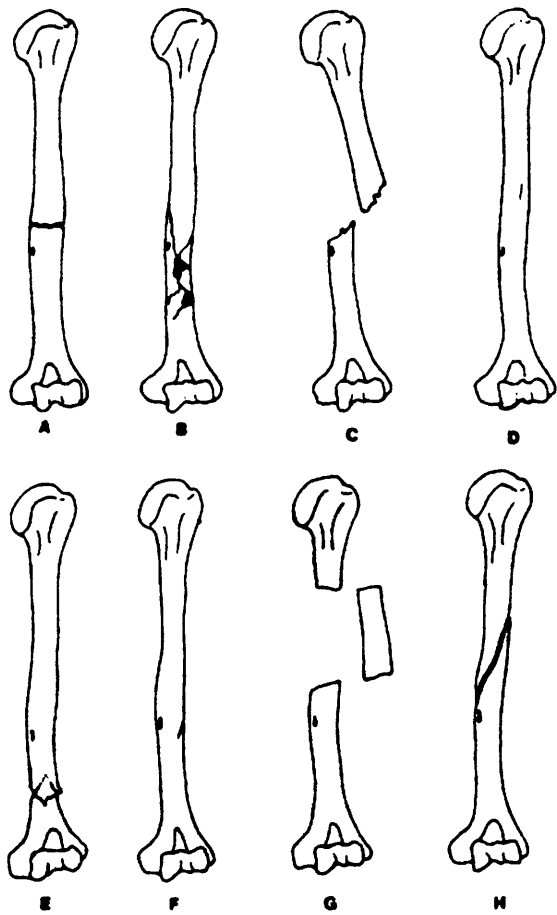


Fig 4.6: Types of long bone fractures (Mann and Murphy, 1990: Fig 97).

As illustrated in figure 4.6, there are several types of fracture including (Mann and Murphy, 1990: 158-159):

- a) transverse – fracture in which the bone is broken perpendicular to its long axis;
- b) comminuted – fracture in which the bone is broken into many pieces or fragments;
- c) oblique and displaced – fracture in which the bone is completely broken at an angle diagonal to its long axis;
- d) hairline – minor fracture in which bone fragments remain in perfect alignment;

- e) impacted – fracturing and subsequent wedging of one bone end into the interior of another;
- f) incomplete – fracture more severe than hairline, but less severe than a complete with no separation of bone fragments;
- g) segmental – fracture in which a significant portion (intact segment) of the bone is displaced;
- h) spiral – oblique fracture commonly associated with ‘fresh’ bone

Other types of fracture that can be described are stellate, a fracture in which lines radiate from the central point of impact; stress, a fine hairline fracture; undisplaced, a fracture in which the bones remain in their approximate anatomical position; and greenstick, in which the thick periosteum of sub- adult bones results in bending of one side of the cortex and the fracture of the other (Mann and Murphy, 1990: 159). However, these descriptive systems are not recording methodologies, although they could be incorporated into such.

A prerequisite for any detailed analysis is an initial detail description including such features as (Roberts, 2000b: 346-347, Table 1):

- 1) Age and sex of individual;
- 2) Bone affected;
- 3) Side affected;
- 4) Fracture position (proximal, mid, distal for a long bone, for example; use anatomical terms);
- 5) Fracture type;

- 6) State of healing (healed, unhealed, healing, woven/lamellar/mixed bone);
- 7) Evidence of infection (pitting, new bone formation, osteomyelitis);
- 8) Evidence of underlying pathology;
- 9) Evidence of joint degeneration in adjacent joints;
- 10) Evidence of linear/rotational deformity in degrees (measure on radiograph);
- 11) Amount of overlap/apposition in millimetres (measure on radiograph);
- 12) Alignment of bone (consider features 10 and 11).

In addition to such macroscopic recording, it is recommended that a radiograph be taken with a minimum of two views, antero-posterior and medio-lateral. This will not only aid in collecting the previously described data, but also may contribute additional information that is not visible with the naked eye. Additional features to note on radiographic evidence include (Roberts, 2000b: 349, Table 2):

- 1) X-ray view taken: antero-posterior, medio-lateral, *etc*;
- 2) Fracture type; may be different from that observed macroscopically;
- 3) Visibility of fracture line (clearly visible, partially obliterated, totally obliterated);
- 4) Is there cortical or cancellous continuity (links to features 3 and 5);
- 5) State of healing; is the bone formed opaque (more recent) or translucent (older and remodelled)? – links to features 3 and 4;

- 6) Evidence of shortening of affected limb (if long bone); measure on radiograph and compare with opposite side;
- 7) Evidence of infection (new bone formation, osteomyelitis);
- 8) Evidence of underlying pathology (*e.g.* osteoporosis, neoplastic disease);
- 9) Evidence of joint degeneration in adjacent joints (*e.g.* subchondral cysts);
- 10) Evidence of linear/rotational deformity (measure linear on radiograph);
- 11) Amount of overlap/apposition of bone fragments (measure on radiograph);
- 12) Alignment of bone.

As with any pathological lesion, it is important to note the total number of bones, both pathological and non-pathological, present so that relative prevalence rates can be calculated. Moreover, the number of individuals affected, and bones affected as a percentage of bones present should be recorded. Additionally, particularly if specific fractures are being considered, the number of each skeletal element present should be recorded to allow prevalence rates for that specific fracture to be calculated. Finally, in order to allow for socio-environmental context within the interpretation, it is necessary to compare prevalence by age, sex and status (Roberts, 2000b: 350). This allows patterns to be determined and results compared temporally and spatially, for example between a medieval leper hospital (Judd and Roberts, 1998) and a medieval farming village (Judd and Roberts, 1999), or between a Late Woodland population from Ohio (Lovejoy and Heiple, 1981) and a Late Roman – Early Byzantine site in Egyptian Nubia (Strouhal and Jungwirth, 1980).

Analysis of weapon-related injuries amongst archaeological assemblages can provide valuable evidence for interpersonal relations in the past. Patterns of violence and warfare vary according to social context, and the quality and precision of the manufacture of the weapons themselves obviously depend upon the material used and the technology available (Boylston, 2000: 357). A good example of this is the analysis carried out upon the Towton battlefield mass grave. This included refitting, illustration, description, interpretation and the sequencing of the wounds. Schematic drawings were made for each cranium during refitting to document wound and fracture margins and detailed measurements were included. Similar documentation was also prepared for post-cranial injuries. These wounds were then identified as antemortem, perimortem, or postmortem dependent upon whether there was any evidence for such factors as healing (Novak, 2000: 90).

Initially, injuries can be subdivided into three main categories; sharp force, blunt force and projectile trauma (Boylston, 2000: 359). The first of these is perhaps the most easily identified on the skeleton, with the diagnostic criteria being (Boylston, 2000: 361):

- Linearity;
- A well-defined clean edge;
- A flat, smooth, polished cut surface;
- The presence of parallel scratch marks on the bone surface when viewed by light or scanning electron microscopy.

In addition, it may be possible to determine the direction of the cut from studying the angle at which it passed through the bone. In contrast, blunt trauma may dent, crack or splinter bone. It can normally be identified by the presence of concentric or radiating fractures, depending upon the force with which the blow is delivered (Boylston, 2000: 361). Blunt force wounds are perhaps the most variable in nature and can appear as crushing with little evidence for the weapon used, or as wounds with discrete shapes producing a detailed delineation of the weapon margin (Novak, 2000: 91). The characteristic appearance of a projectile wound, on the other hand, is due to the velocity with which the weapon enters the body. This can leave distinct entrance and exit wounds, indicated by flaking around the margins. High velocity weapons can often produce extensive fracturing, but reconstruction of these bone fragments can often delineate the weapon profile (Novak, 2000: 91).

Recognition of trauma patterns is often dependent upon the reconstruction of fragmentary material. Detailed recording is essential and should include diagrams, descriptions and measurements. Mandatory information includes age, sex, the situation of the wound by skeletal element, and any indication of the direction of the blow. In the case of injury from a bladed weapon, both acute and obtuse sides of the injury should be described, including patterns of flake removal, bevelling, polish or chatter marks. Where possible scanning electron microscopy should be performed (Boylston, 2000: 375), which enables high-resolution images, with three-dimensional information, of the bone surface to be produced. Large, fragile archaeological samples could not originally be placed in the scanning electron microscope, it being customary to prepare a latex

negative of the surface, an epoxy resin positive replica then being cast from this which could be gold-coated and viewed (Wakely, 1993: 206). However, the development of environmental scanning electron microscopes removed this problem, permitting actual samples of bone to be scanned, although the size of the sample is still limited.

In comparison to human palaeopathology, evidence of trauma is only occasionally reported from archaeozoological assemblages (Gál, 2004; Thomas, 2001), and there seems to be little systematic recording of such conditions, despite the light it could cast on human-animal interactions. For example, cranial fractures in canids, particularly of the facial area, have been found at several sites (Harcourt, 1971; Makowiecki and Daugnora, 2004; Onar *et al.*, 2002). This is an area of the skull where the thin bones fracture easily beneath a severe blow, as well as being the area most likely to be struck by humans following aggressive behaviour by the animal or for other reasons of control or rebuke (Makowiecki and Daugnora, 2004). The issue of human maltreatment of animals has also been examined by analysing the prevalence of rib and vertebral fractures in medieval dogs from Northern Germany (Teegan, 2005b). This condition has been seen on other sites, particularly in the Archaic period of the United States, where it has been proposed that vertebral process fractures could be the result of heavy packs or travois-like poles placed on the back (Scarre, 2005: 326; Warren, 2000). However, fractures in archaeozoological assemblages do not always have to be related to human activity. Fractures of the baculum, or *os penis*, in walrus (*Odobæenus [Trichechus] rosmarus* L. 1735) have been linked to intra-specific aggressions during the mating season

(Bartosiewicz, 2000; Capasso, 1999). They, therefore, provide information about the sexual behaviour of this species.

Fractures are also one of the most characteristic pathologies seen in bird bones, although there is variety in the degree and mode of healing. For example, some bones might show slight deformation, others a callus bridge. Intra- and inter-specific conflicts can also result in mechanical trauma from the beaks of other birds (Gál, 2004: 13). Not all trauma will relate to natural accidents occurring in the wild however and, as with dogs, trauma in birds can tell us much about human behaviour. Brothwell (1993: 37), in his overview of avian osteopathology, for example, quotes the case of Mexican macaws from Arizona whose stress arthropathies and healed trauma were hypothesised to relate to their transport during trade and exchange.

4.7 Conclusion

As has been noted by several authors (Brickley and McKinley, 2004; Buikstra and Ubelaker, 1994; O'Connor, 2000; O'Connor, 2003), description is key to the recording of palaeopathology. This recording should be carried out in a systematic manner, noting absence as well as presence, so that the prevalence of conditions can be calculated. The resulting description should be “sufficiently detailed to support any differential diagnosis which is offered, and to allow alternative diagnoses to be considered and tested,” (O'Connor, 2000: 109). Those specific methodologies (*e.g.* Bartosiewicz *et al.*, 1997; Dobney and Ervynck, 1998) that are compatible with these aims and that it appears beneficial to encourage the use of should be incorporated into the design of a

generic recording methodology; it is unnecessary to create a recording protocol when one already exists that is suitable for the purpose.

In the following chapter, the methodology that was developed based upon these observations will be described and the approach by which it can be used, following analysis, to aid diagnosis and interpretation will be explained.

Chapter Five: Developing a Methodology

5.1 Introduction

In line with the recommendations of O'Connor (2000; 2003), a decision was taken to develop a recording system that encouraged description, but also enabled pre-existing quantitative recording schemes to be embedded. The recording methodology was based upon the types of bone reaction noted above (section 2.4.2). However, these descriptive categories are not mutually exclusive or discrete (Ortner, 1994: 74). For this reason it was considered necessary to keep them separate, permitting the user to complete more than one, if appropriate, for each lesion. Flexibility is, therefore, one of the key factors of the methodology. It is intended to encourage a systematic approach, which to date has been lacking and has thus hindered the development of the discipline. It does not, however, represent a minimum standard for animal palaeopathology; few of the fields are mandatory, allowing the user to enter only the data they wish. The question of minimum standards is one that has been much debated within archaeozoology (Vann and Thomas, 2006: 1), and as a concept has been embraced with varying degrees of enthusiasm by specialists within the field. It is important nonetheless to establish a common language and share methodological approaches to common problems (Vann and Thomas, 2006: 1).

It should be noted, however, that not all pathologies are necessarily significant, whether that be to us, the animal concerned, or the past human population (or in some instances possibly all three). Their effect upon the health of the animal when it was alive should be taken into consideration. Some conditions,

especially in a mild form (*e.g.* calculus), would have little impact upon the general health of the living animal. This obviously impinges directly upon the way that animal would have responded to the disease, and also the way humans would have responded to an animal with that condition. If the pathology was not making the animal ill or weak, then there is a reasonable possibility that it would have been ignored by animal and human alike. That does not mean though that we should also ignore them. At this time, the aetiology of many pathological lesions remains unclear. Some may prove to be vital to our understanding of life in the past, others may not. However, unless all are recorded consistently, it will be difficult – if not impossible – to determine which are useful and which are not. In addition, conditions that may have had little impact on a living creature may still be of interest in answering particular questions. Genetic conditions, even non-metric traits, may help us to investigate population expansion and movement in the past, for example.

It is a well recognised fact that a coherent strategy is needed to record an assemblage of animal bones, especially if it is to be subject to any form of later analysis (*e.g.* Harland *et al.*, 2003). With this in mind, a number of user requirements were established at the start of the process to design a system for recording animal palaeopathology. These included:

1. Ease of use: a help file (Appendix 2) has been included to guide users through the recording process,
2. Error handling: the system limits the opportunities for error by using logical text rather than numeric codes, where possible,

3. Flexibility: the system can be adapted to meet user requirements,
4. Output in usable form: once entered, the data can be retrieved in the form of a Microsoft Access database report or exported to other software packages,
5. Usability: The implementation of the system with a well-known database package will enable a large number of people to access the system,
6. Ease of updating: the software chosen is a widely available package and Microsoft products can be upgraded to more recent versions.

These requirements, along with other elements of the methodology, were drawn from observations of existing practice outlined in chapter four of this volume. This chapter will present the recording protocol that underlies the database and discuss the issues surrounding its creation.

5.2 Terminology and nomenclature

One of the first steps taken in the creation of the generic methodology was the definition of the terminology to be used (see Glossary). This was necessary because of the inconsistencies present in existing vocabulary; these have come about in a variety of ways. Firstly, there is the question of whether clinical veterinary terminology should be adopted by animal palaeopathologists. Since a number of veterinarians have greatly contributed to the field of animal palaeopathology (Baker and Brothwell, 1980), it is perhaps not surprising that clinical terminology has been adopted by non-clinicians. In many instances this has been beneficial, providing an internationally recognised, scientific basis for research; however, we should always bear in mind that modern veterinarians will not observe, nor be interested in, all of the conditions exhibited in

archaeological assemblages. Many modern animals are slaughtered before pathological conditions become sufficiently chronic to become visible upon the skeleton. It is fair to say, therefore, that veterinary terminology is not always sufficient (Vann and Thomas, 2006: 4.3).

Another problem has been the use of colloquial expressions within the discipline (Vann and Thomas, 2006: 4.3). These are terms used by both farmers and veterinarians that, whilst generally understood, are often localised in distribution. For example, 'bog-lame', an osteodystrophic condition of lactating sheep and cattle, is known by a variety of Gaelic synonyms: 'croiteach', 'croitich', 'creutach' and 'cruban' (Baker and Brothwell, 1980: 164). None of these appear to be used in non-Gaelic speaking regions and, as can be seen by the variation in spelling, local dialectical variations prevail even within the same region. Such terminology may, therefore, be a source of confusion by others working in another area of the same country, let alone those working in other countries whose first language may be different. It was deemed necessary, therefore, to ensure that as many of these colloquial terms were avoided within the recording system.

A decision was taken to reduce the many terms found in the animal palaeopathological literature to a smaller number of more generic descriptors that would be easily comprehensible, even to non-specialists, whilst at the same time providing sufficient options to cover the great majority of pathological characteristics. This was considered necessary on two counts. Firstly, because animal palaeopathology makes use of a substantial vocabulary derived from

clinical sources that are not immediately comprehensible to those without a clinical background. Secondly, because different terms have in the past been applied to the same condition. For example, individual bony growths on vertebrae have been referred to as bony spurs, spondyles, or vertebral osteophytes (Morgan, 1967: 7). The condition characterised by the formation of these has also been discussed under a number of different names, including spondylitis deformans traumatica, spondylitis ossificans deformans, spondyloarthritis, ankylosing spondylitis, spondylosis deformans, spondylitis deformans, spinal osteoarthritis, syndesmitis ossificans and spondylitis (Morgan, 1967: 7). This has had the effect of increasing, rather than reducing, confusion in many instances.

Smooth outgrowths of bone that might be osteomas, osteophytes, enthesophytes or exostoses, depending on their location and appearance, are, therefore, at first simply termed 'nodules' in this recording system. Destructive lesions that may be cysts, myeloma, cloaca *etc* are recorded as 'cavities' in the first instance.

As much as the variation in terminology is dependent to some degree on diagnosis, the restriction created by this protocol helps to focus attention purely on what is seen and can be described in the first instance, rather than the cause of the condition. More specific terminology can then be applied once more information has been gained about the lesion.

5.3 The database structure

Microsoft Access 2000 was chosen as a platform for the database because it is widely available and can be integrated with other programs such as Excel, Word, SPSS, Quattro Pro *etc.* It was thus compatible with the aim of making the finished methodology available to a broad research body. Another advantage was that, since Microsoft products are generally easily updateable, the software and data should remain supportable. It is for these reasons that Microsoft Access 2000 has also been chosen by the designers of other archaeozoology recording systems such as the York System (Harland *et al.*, 2003).

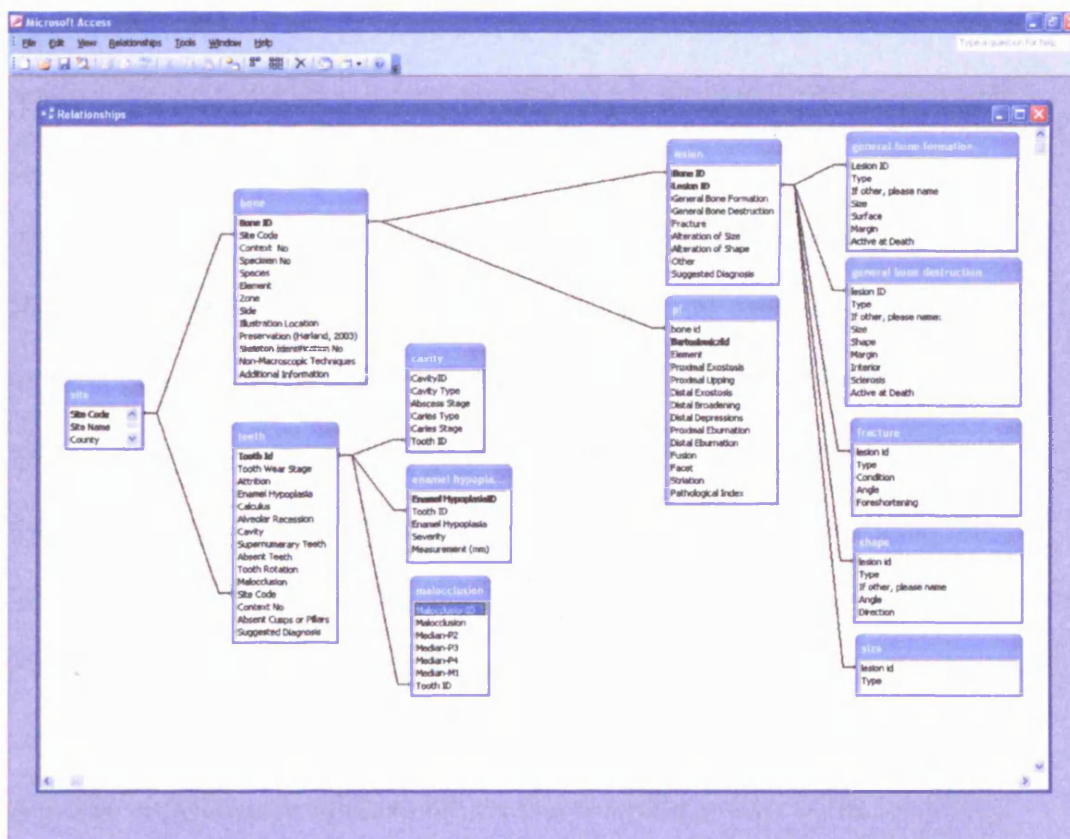


Figure 5.1: Table Relationships

Access, as a relational database, permits the user to define relationships among the data it contains. Such databases are superior to flat-file databases because they permit discrete information to be stored in separate locations and for that information to be brought together as necessary, without needless duplication of data (Ray and Ray, 1999: 3). The relationships between the different tables that form the backbone of this particular database are illustrated in Figure 5.1. At the highest level, linked via the site code, the database divides into two strands: post-cranial and oral. The relationship is one-to-many, thus each site can have multiple bones and teeth recorded, but the site data only needs to be inputted once.

The 'bone' table is the foundation of the post-cranial pathology recording system. Via the Bone ID, a unique automatically generated identifier, this table is connected to the 'lesion' and 'pi' (pathological index) tables. The latter permits recording of the pathological index developed by Bartosiewicz *et al.* (1997), included (as were other pre-developed recording systems) with the aim of encouraging their use amongst archaeozoologists and to avoid duplication of effort during the recording process. The 'lesion' table is subsequently linked to additional sub-tables via the lesion id: general bone formation, general bone destruction, fractures, shape and size. These correspond to the sub-forms found within the protocol for recording specific conditions.

A similar structure also exists within the oral recording protocol. The foundation table of this system is 'teeth'. This table is subsequently linked to additional sub-tables via the Tooth ID: malocclusion, enamel hypoplasia and cavity. These

correspond to the sub-forms found within the protocol for recording specific conditions. Each tooth can have multiple enamel hypoplastic lines, malocclusions and cavities recorded, for example. The specific details of the database will now be discussed.

5.3.1 Recording post-cranial pathology

To ensure that it was possible to link together elements from the same individual, a means of associating records was included. This was achieved by permitting each skeleton to be assigned a skeleton identification number, which should be noted on each bone recorded for that skeleton. Whilst articulated skeletons and partial skeletons are less common in archaeozoology than in human osteology, neither are they entirely unknown (*e.g.* Bendrey, 2004; Fabiš, 2005). It seemed essential under those circumstances, therefore, to be able to track those elements that were related, particularly as this may reveal the distribution of the lesions across the skeleton. The distribution of lesions can be used to differentiate between conditions whose symptoms may be very similar, and can, therefore, be an important diagnostic tool.

Moreover, it is strongly encouraged that all elements, both in articulated and disarticulated material, be recorded. As noted in section 4.3.3, the detailed recording of some elements such as vertebrae and ribs is unusual in archaeozoology unless specific research questions require it. However, it is precisely these elements that can provide answers about particular pathological conditions. Not only have they been linked to the use of horses as riding animals (section 4.3.3), but they are also commonly affected by respiratory infections

such as tuberculosis (section 4.5). It is, therefore, considered important to record these elements as regularly and consistently as other skeletal elements.

As noted in chapter four, one critical aspect of any recording system for pathology is the provision of a mechanism to record the precise location of lesions using anatomical terminology. Such information is required not only to aid in differential diagnosis and to record the extent of the lesion, but it is essential if the prevalence of particular characteristics is to be established. Recent years have seen the adoption of a number of zoning systems within zooarchaeology (*e.g.* Dobney and Reilly, 1988; Serjeantson, 1996). Such systems are ideally suited to the recording of palaeopathological lesions since each anatomical element is divided into a series of anatomically unique zones. Moreover, the use of such systems by faunal analysts is already widespread (*e.g.* Albarella and Serjeantson, 2002; Outram *et al.*, 2005). Provision was therefore made to include these within the protocol, a user being able to input multiple zones if applicable. The system applied should, however, be explicitly stated in any subsequent report to facilitate inter-site comparison.

In addition, where possible, skeletal elements should be assigned to the side of the body from which they came (*i.e.* left or right) or, in the case of elements such as the phalanges, to whether they were the anterior or posterior element (*e.g.* Dottrens, 1946). As noted in section 4.3.2, for example, the use of cattle for draught is believed to exacerbate the naturally greater deformation of the anterior skeletal elements because of live weight leading to a higher degree of pathological deformation occurred in the front feet. To confirm this pattern, it is

necessary to differentiate between pathological change in anterior and posterior elements.

Another factor considered important to be recorded was taphonomic condition, to provide some indication as to whether post-depositional processes might have in some way affected the appearance or extent of any pathological lesion, as well as to determine whether a lesion might actually be pseudopathological, *i.e.* not a true pathology, but a false one created by taphonomic processes. As with the diagnostic zones, these should follow published criteria (*e.g.* Harland *et al.*, 2003) or be otherwise clearly stated.

In addition to the four classes of bone reaction previously discussed (section 2.4.2): bone formation, bone destruction, change in shape and change in size, two further categories were included for post-cranial elements: fractures and other pathologies. The latter was for those miscellaneous conditions which were not appropriately described by the previous headings, *e.g.* eburnation, but which it was essential to make provision for within the protocol (Vann and Thomas, 2006: 4.4).

To aid the description of bone forming lesions, a number of descriptive terms have been provided: nodule, callus, periostosis, fusion, increased density and other. These terms are defined in the Glossary and provide a basic description of the sort of lesion being recorded. They reflect the different ways new bone can be formed and range from discreet 'nodules' to layers upon the periosteum, and from the unification of two or more bones into a single entity to a bone

appearing heavier and/or thicker than normal due to an increase in bone density. Once the type of bone formation has been defined a number of other factors can then be recorded, not only to provide as full a description as possible, but also to give some indication of the nature of the condition concerned, which can be used when attempting differential diagnosis. The first of these is the size and extent of the lesion. This allows comparisons to be made between lesions based upon metric data, increasing the scientific rigour of any analysis. It can also provide an indicator of the severity of the condition, as more advanced or aggressive bone formation will often be more florid.

The general shape of the pathology can be described from a predetermined selection of linear, round/oval or irregular, although this list can be expanded. This is intended to provide a basic general guide to the lesion's appearance. The nature of the margin between normal and abnormal bone should also be recorded. The reason for this is that those pathologies that have well defined margins of dense compact bone are typically the result of a relatively slow process. Conversely, those with porous, less well-organised, bone tend to be faster forming and often more aggressive, or have not had time for repair to take place (Ortner, 1994: 75).

Seven types of bone destruction lesions have been defined: cavity, porosity, osteopenia, articular depression, articular groove, necrosis and other. As before, these are defined in the Glossary and reflect the different ways in which bone can be removed. This ranges from a hollow area, or cavity, within the bone to a bone surface that possesses numerous small pits or pores, and from a decrease in

bone matrix formation to bone death resulting from the loss of blood supply to a bone or region of bone. The size and extent of the lesion, the general shape of the pathology and the nature of the margin between normal and abnormal bone should be completed as discussed above.

In addition, two further characteristics should be recorded where possible: a description of the interior of the lesion and the presence or absence of sclerosis (if an x-ray has been taken of the bone to allow this to be determined). The interior of a lesion can vary in appearance depending upon the precise nature of the destructive lesion. For example, cysts are generally smooth-walled because of their lining membrane, whilst a rough interior can be indicative of infection. Sclerosis is the “pathological hardening or thickening of tissue” (see glossary). This can be seen on x-rays as white areas of unusually dense bone and can be an indicator of certain pathological conditions such as lines of arrested growth.

Alteration in size should be recorded simply as whether the abnormality was an enlargement or reduction of the norm for that population. This can obviously only be determined in relation to other specimens from that population as size can vary naturally between populations due to, genetics and environment; and thus this needs to be taken into consideration when determining whether or not an alteration in size is ‘abnormal’. With regards to the alteration in shape, a record should be taken of whether this was due to bowing, expansion of the diaphysis, expansion of the metaphysis, articular extension, displacement, thickening of the epiphyseal plates or some other means. Definitions for these terms are provided in the Glossary, and reflect the different regions of a bone

that can be subject to change, as well as the resultant variations in form. These include: curvature of the bone shaft; expansion of either the diaphysis or metaphysis; increase in the dimensions of the bone around the junction of the epiphysis and metaphysis, in which growth of a juvenile bone takes place; extension of the articular surface; and the removal of a bone or segment of bone from its normal position.

Fractures have been placed in a separate category both because of their common nature and also for the sake of simplicity given the number of variables specific to them. These variables related to the nature of the force and the osseous area of distribution of the force. Factors such as magnitude, direction, loading, rate and duration can affect the nature of the force, for example. Susceptibility to fracture is determined by (Rothschild and Martin, 1993: 51):

1. Bone density: the quantity of bone that, when measured, helps to indicate bone strength;
2. Fatigue strength: the stress level that the bone can endure;
3. Resilience: the ability of the bone to recover from shock;
4. Elasticity : the ability of the bone to return to normal after distortion.

The most basic form of information regarding a fracture to be recorded is the type: transverse, comminuted, oblique, hairline, impacted, incomplete, spiral and greenstick. This selection is based upon previous descriptions of well-defined fracture types (Mann and Murphy, 1990: Fig 97) (chapter 4) and should improve comparability between researchers by encouraging the use of similar

terminology. In addition, the angle and direction of any resulting deformation or foreshortening should be noted, as well as the presence or absence of any evidence of healing. Such information can provide an indication of whether the injury has been left to heal unattended, or whether some form of therapeutic intervention has taken place (Udrescu and Van Neer, 2005).

Conditions such as eburnation and the congenital non-formation of bone, which do not fall into any of the above categories, can be placed in a separate category termed 'other'.

A number of other pre-existing methodologies, such as that devised by Bartosiewicz *et al.* (1997), have also been incorporated within this generic recording protocol and these are described in further detail in the User Guide. Such systems are already in use by archaeozoologists, and it was felt appropriate to include them to avoid duplication of effort during the recording process. It was also hoped that such incorporation would further encourage their wider use, particularly by non-palaeopathological specialists, to facilitate future research by increasing the number of comparative data sets. Future analysis may prove that particular aspects are more or less useful, but there is a need to record all of them at present in order to understand the processes that underlie them. It is, therefore, recommended that all cattle metapodia and phalanges be recorded in this manner, not just the pathological examples, in order to create such comparative data and ensure that it is possible to calculate accurate prevalence rates from them.

A number of other fields have also been included in the recording system; for example, it is possible to record any results gained from non-macroscopic examination (*e.g.* biomolecular analysis, histology *etc.*). Whilst such studies are still relatively infrequent and under-utilised, it is important that all information relating to a particular bone be kept together to aid diagnosis or later reassessment.

5.3.2 Recording oral pathology

In terms of oral pathology, a system was designed to allow the pathology of each tooth to be recorded separately; thus allowing for potential variation across an individual mandible, as well as variation between individual specimens (Vann and Thomas, 2006: 4.5). The tooth wear stage was noted in order to provide some basis for identifying where wear might reflect missing or malformed teeth within the dentition. The use of systems such as that devised by Grant (1982) is encouraged since these are already commonly used by many archaeozoologists. This would increase inter-user comparability and comprehension.

Dental attrition is caused by the opposing forces of growth and wear and is related to physiological, environmental and individual factors. Anomalies of attrition can occur in two ways: anomalies in crown height, and intra-dental attrition. The latter occurs when an adjacent tooth rubs against its neighbour and wears away the enamel sheath of the tooth (Levitan, 1985: 43). Irregular tooth wear, or tooth wear that is excessive for the population to which it belongs, can

be either general or more localised, however the precise form it takes can vary depending upon the cause (Miles and Grigson, 1990: 486-489).

It is recommended that calculus and alveolar recession be recorded by stage (*e.g.* slight, moderate and severe) based upon the scheme devised by Brothwell (1981). While these are slightly subjective, this approach permits the comparison of the severity in one individual mandible, as well as between individuals and populations, something that might provide dietary information.

Abscesses of the alveolus or pulp cavity may result from a number of infections, some of which may be caused by injury, others from eruption anomalies or periodontal disease. However, the gross effects are likely to produce similar conditions in the bone (Levitan, 1985: 45). Meanwhile, several studies in humans showing the natural history of caries demonstrate that different cultures and different modes of subsistence can result in strongly contrasting patterns of dental caries, whilst in animals it has been linked to past feeding practices. For example, the prevalence of caries in Hawaiian poidogs from prehistoric cave sites has been related to their being fed a starch-rich diet (Miles and Grigson, 1990: 477, 479). In archaeozoological material it is important, therefore, to differentiate between the various forms of caries, the different stages of development (particularly of coronal lesions), age, and between different types of teeth. The severity of cavities due to either abscesses or caries was therefore included, as was the type of caries by location, for example, whether it was upon the occlusal surface or the lingual surface. For abscesses, the stages of severity were based upon those defined by Levitan (1985: 45): stage one – low

grade infection, stage two – medium grade infection, and stage three – high grade infection, with each stage demonstrating variation in morphology.

Supernumerary and congenitally absent teeth should be recorded on a presence/absence basis, and should include a note of the affected tooth. Occasionally teeth may also lack cusps or pillars (Levitan, 1985: 46), and these should be noted, along with any signs of tooth rotation, including the direction and degree of rotation. This latter occurs primarily due to overcrowding, although it may also be the result of congenital or developmental disorders (*e.g.* where the tooth erupts with the wrong alignment or in the wrong location). In modern sheep, this seems to be confined mainly to maxillary teeth; however, in archaeological specimens mandibular teeth have also been found to be affected (Levitan, 1985: 46). Rotation may be lingual or labial (according to the angle of alignment in relation to the mesial edge), and displacement can be lingual, labial, mesial or distal (Levitan, 1985: 46).

Malocclusion can be defined as “the incorrect positioning of one or more teeth within the jaws, either relative to adjacent teeth in the same jaw or, more particularly, in terms of the nature of the ‘fit’ between upper and lower dentitions,” (Brothwell, 1991: 27). As noted in chapter four, Brothwell (1991) defined a series of measurements to record such abnormalities: the angles between the median and the second, third and fourth premolars and the first molar. Whilst, as previously noted (section 4.4.5), this recording system is not without its flaws, it was decided to include these in the general recording methodology because of the lack of an alternative protocol, the need for further

investigation in this area and the potential importance of mal-positioning in the identification of domestication (Vann and Thomas, 2006: 4.5).

Some pathological phenomena relate to stress events occurring during development. Examples of these are Harris Lines and Linear Enamel Hypoplasia, which represent deficiencies in the growth of a calcified tissue (Dobney and Ervynck, 2000: 597). Following methodologies already in existence (Dobney and Ervynck, 1998), the type of enamel hypoplasia (i.e. whether it was pit or linear) should be recorded, as well as the general severity, which is described as either mild, moderate or severe based upon the criteria established by Dobney and Ervynck (1998), and the distance between the cemento-enamel junction and the lowest part of the hypoplastic line (Vann and Thomas, 2006: 4.5). As noted by other authors (Davies, 2005: 83), hypoplasia can be estimated to have occurred at a particular time during the periods of dental enamel development when combined with accepted information of times of year when offspring are born. Thus, by recording the distance between the cemento-enamel junction and the line itself, enamel hypoplasia may provide indications of nutritional stress, such as winter shortage of food, weaning and periods of disease when patterns are studied at a population-level (chapter 4).

5.4 Diagnosis

This system has been designed in such a manner as to encourage the description and consideration of all forms of evidence prior to a determination of the aetiology. The recommended terms discussed above are intended to improve consistency between users and reduce inter-observer variability by encouraging the consistent usage of a limited number of terms. Only once a full description

has been made should a diagnosis, therefore, be considered. This does not, however, detract from the importance of that diagnosis. It is diagnoses that are typically used in subsequent analyses and interpretations, and it is diagnoses that contribute towards overviews of regional and temporal trends in disease. Nevertheless, the importance of differential diagnosis cannot be over-emphasised. It is essential that all possible diagnoses be explored to avoid drawing conclusions that are more specific than the evidence warrants. Moreover, the archaeozoologist should explicitly state those diagnoses which have been excluded and why.

How this process of differential diagnosis can be based upon description is illustrated in the following description of a horse (*Equus caballus*) metacarpal from an 18th century context from Dudley Castle (Figure 5.2 and 5.3) (Vann and Thomas, 2006):

Profuse nodular formation is present around both proximal and distal ends of the metacarpal. These are not all enthesophytes as they are not all located at the site of tendinous or ligamentous attachments, although some may represent stage 1b of the ossification of the interosseous ligaments according to Bendrey (2007), nor are all of them osteophytes as many are not confined to joint margins, although there is some evidence of this at the proximal end. The surface is smooth and margin is poorly defined. The area of new bone growth extends c. 50mm from joint margin along shaft at proximal end and c. 75mm from joint margin along shaft at distal end. A cavity is present on the dorsal surface c. 45mm from distal articulation. The opening of this cloaca is c. 10mm

in diameter and roughly circular or ovoid in appearance. The margin is smooth and rounded. The distal portion of the shaft is abnormally enlarged and swollen in appearance.

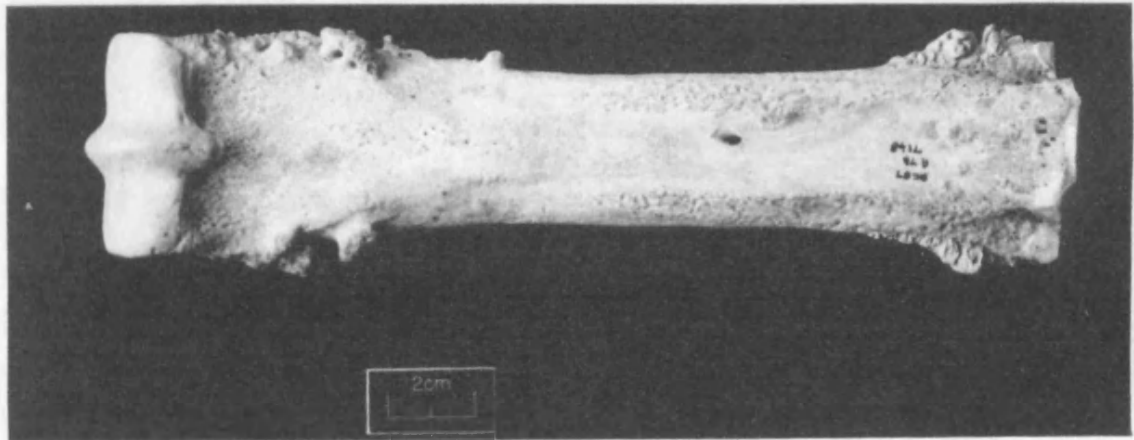


Figure 5.2: Horse (Equus caballus) metacarpal from an 18th century context from Dudley Castle exhibiting osteomyelitis

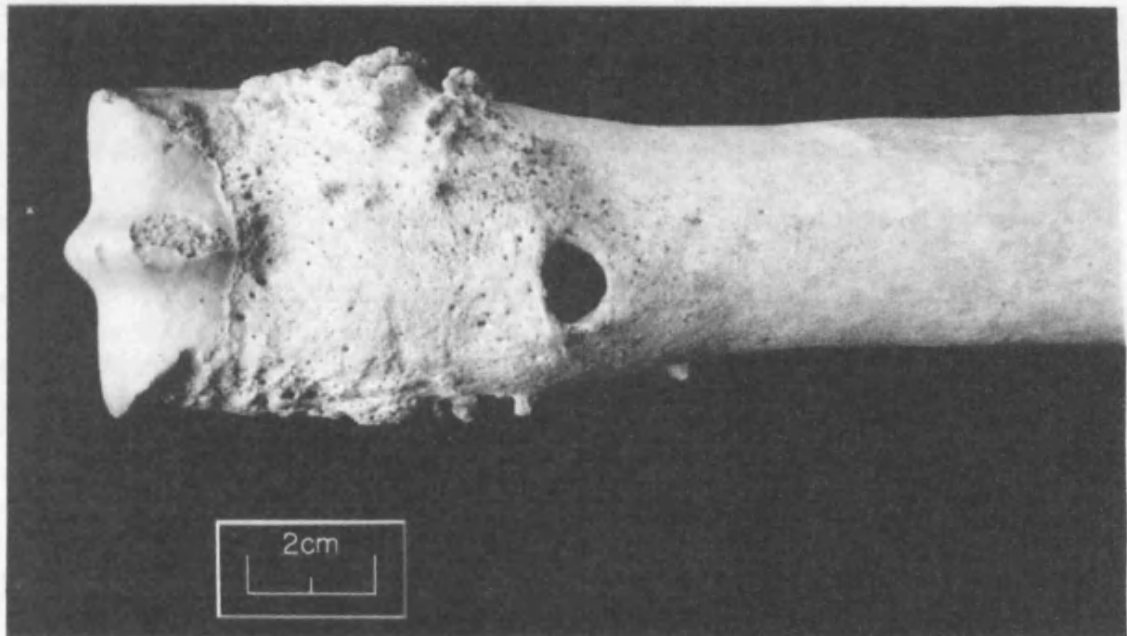


Figure 5.3: Close up of cloaca at distal end of horse metacarpal seen in Fig. 5.2

The extensive nature of the bone formation and the smooth, well-rounded edges of both nodules and cloaca indicate a chronic condition of long-term duration. This bone formation is unlikely to represent a neoplasm as the nodular growth is neither the discrete, often isolated, entity that is normal for a benign growth (*e.g.* an osteoma), nor the large, irregular formation of a more malignant growth. It is also unlikely that the nodular bone growth relates solely to activity as it is not located only at sites such as articulations or attachments for muscle or ligament, although the potential ossification of interosseus ligaments may indicate that the animal was used for riding and draught as other authors have noted the presence of this condition in riding animals. However, it can also be triggered by other, natural factors such as age and weight (Daugnora and Thomas, 2005: 72).

The cloaca and the enlargement of the shaft cavity of the distal end indicates the presence of pus, most likely due to infection or inflammation; pus is only generated by infection. The associated new bone growth on the distal shaft of the bone might therefore indicate the associated infection of the periosteum and/or its detachment, and subsequent ossification, by the infectious exudate. The suggested diagnosis is, therefore, osteomyelitis: the inflammation of the marrow cavity of a bone due to pyogenic (pus-forming) infection. The cause of the inflammation and infection is unknown. It could be the result of localised soft tissue trauma as the most common route for infection to reach the skeleton is via the over-lying or adjacent tissue (Baker and Brothwell, 1980: 64); there is no apparent evidence for a traumatic injury (*e.g.* a fracture) to the bone itself. Alternatively, the second common route by which infection may gain access is through the blood stream in which infectious agents are carried throughout the

body from another site (Baker and Brothwell, 1980: 64). However, as the element is an isolated one, rather than part of an articulated skeleton, it is not possible to investigate the distribution of lesions throughout the skeleton. Nor it is possible to compare it with its counterpart on the other limb to examine whether pathological change is bilaterally symmetrical or not. It is, therefore, not possible to establish which route was taken in this instance.

It can, however, be seen that, based on an uniformitarian assumption that the effects of disease in the past look similar to the effects of disease in the present, we can begin to propose diagnoses. This processual approach, akin to aspects of the '*Middle-range Theory*' associated with Binford (Johnson, 1999: 49), requires us to consult with relevant clinical literature (*e.g.* Jubb *et al.*, 1993; Miles and Grigson, 1990) and compare our results with case studies of known history (*e.g.* Bartosiewicz *et al.*, 1997; Levine *et al.*, 2000). From these comparisons, diagnoses can be proposed for the conditions described. It is worth noting, however, that studies amongst human palaeopathologists (Miller *et al.*, 1996) have demonstrated that accuracy is higher for general category diagnoses, for example, than for specific diseases. This has obvious methodological implications with regard to ensuring comparability between researchers, and injects a degree of caution into any diagnosis. As noted by Miller *et al.* (1996), impediments to specific diagnosis include the paucity of well-documented, clinically diagnosed samples, as well as the difficulty in finding skeletal abnormalities or patterns of abnormalities that are unique to individual disease entities (Miller *et al.*, 1996: 224). The tendency for modern animals to be slaughtered before chronic conditions becomes manifest compounds this

problem. In addition, there is no guarantee that diseases known today create changes that are identical to those in antiquity. There is a possibility that evolutionary selection processes may have eliminated some disease conditions of antiquity with no modern counterpart (Miller *et al.*, 1996: 224). This underscores the need for detailed descriptions, as well as the wisdom of including all differential diagnoses in any conclusions that are drawn.

5.5 Reporting

As with the York System (Harland *et al.*, 2003), data collected using this recording methodology can be queried and manipulated within Access, exported into other programs, saved as text files or summarised using a series of built-in reports. The latter produces several standard reviews of the data collected based upon queries that ask questions such as ‘what post-cranial lesions are present on each bone?’ and ‘what oral pathologies are present on each tooth?’ The data can then be analysed to determine the prevalence of pathological conditions within the assemblage, as well as to investigate any other patterns or anomalies that might be revealed.

5.6 Quantification and analysis

Recording should not, however, be an end in itself. If animal palaeopathology is to contribute to archaeology as a whole then it is necessary to frame research questions, raise hypotheses and consider all of these whilst collecting data (Roberts and Cox, 2003: 383). Therefore, once results have been collected, it is obviously necessary to interpret them in an appropriate manner, one that permits the data to contribute to questions of archaeological, or possibly wider,

significance. Deciding which questions should be addressed is the first step in the analytical process.

The second step is to decide what scale of analysis is appropriate in order to answer those questions. This can range from context level (analysis of individual specimens and the distribution of pathologies by body part, age and sex) through the investigation of a site area up to an entire site or region (analysis of general pathological types, or specific pathologies, or species). More than one of these may be necessary to answer the questions in full. As with archaeozoological data generally, both horizontal and vertical approaches to analysis can be attempted (Grayson, 2001: 16692-16693). In other words, inquiries can proceed, across space, within and between sites (horizontal), or through time (vertical). Interpretation of the results derived from this can not only be of value at site-level, permitting the investigation of inter- and intra-specific variation between different archaeological phases, but can also contribute to a wider study when results from more than one site are combined.

Once the questions to be addressed have been determined, quantification can begin. As noted in chapter four, prevalence is of utmost importance and the calculation of this should be one of the first tasks undertaken during the analytical process. It is essential that pathological specimens be recorded in conjunction with equivalent non-pathological specimens so that the prevalence of the condition within the population is known. The prevalence rates can be of specifically diagnosed pathologies or of general pathological categories. Differences in the prevalence between species, age, site or other variables can

contribute greatly to our understanding of those conditions and what role they played in human-animal relationships at that time, although not all will be relevant to all pathologies.

Common starting points for any analysis of palaeopathology at an archaeological site are, therefore, calculations such as:

- Relative frequency of palaeopathological lesions by species;
- Relative frequency of palaeopathological lesions by skeletal element;
- Relative frequency of different types of palaeopathological lesions;
- Relative frequency of different types of palaeopathological lesions by species;
- Relative frequency of different types of palaeopathological lesion by skeletal element.

This list is not exhaustive. Similar quantification can also be applied to other variables (*e.g.* age, sex, *etc.*) as appropriate and dependent upon the questions to be addressed. It is possible to perform similar calculations for the results derived from particular aspects of the assemblage to focus on the context, rather than site, level. For example:

- Relative frequency of different types of palaeopathological lesions for a single species (*e.g.* cattle);
- Relative distribution of palaeopathological lesions throughout the skeleton for a single species (*e.g.* cattle);

- Relative frequency of different types of palaeopathology belonging to a single major disease category (*e.g.* bone formation) for a single species (*e.g.* cattle);
- Relative distribution of a single disease category (*e.g.* joint disease) throughout the skeleton for a single species (*e.g.* cattle).

With this information it is then possible to address issues of epidemiology: the causes, distribution, and control of disease in populations. By examining both epidemic (excess) and endemic (always present) diseases and relating them to variables such as those mentioned above, it is possible to research questions of the occurrence of disease in a population or its subgroups and diachronic trends.

5.7 Interpretation

With the quantification and analysis of the dataset complete, the process of interpreting the results can begin. More than one theoretical approach may be taken to address the research question. For example, a processual interpretation might focus on the palaeo-economics of the site or region, whilst a post-processual approach might tell us more about the specific feature or help to draw out aspects of the social context. Research into horse burials (Daugnora and Thomas, 2005; Levine *et al.*, 2000), can be used to illustrate this point. The processual-based interpretation might reveal that such animals had been used for riding and subsequently investigate questions regarding the economic significance of riding horses to the human population in that area. A post-processual-based approach might focus more on the social and cultural aspects of horse riding, as well as examine specifically why those individual animals

were placed in that specific context. Was it a matter of ritual significance? Or was it instead an economic decision with old animals that were passed their usual working life being sacrificed? Perhaps it was even a combination of the two. Neither approach is wrong. Both are equally valid and help us to discover more about the archaeological assemblage. Which approach is taken will depend primarily upon the questions selected at the beginning of the research process.

As discussed in chapter four, however, one problem all palaeopathologists face when interpreting their data is the 'osteological paradox'. This relates to problems such as selective mortality, that is that the only animals we see of a certain age in an archaeological assemblage are the ones who happened to die (either naturally or through being slaughtered) at that age. There might be many in the population that were at risk at that age, but the observable characteristics of those who survived will be those of the age they did finally die at (Wood *et al.*, 1992: 344-345). Thus, animals with acute diseases are more likely to die at an earlier age than animals with chronic diseases. However, because of the vigorous and rapid nature of the acute disease, animals may exhibit fewer skeletal manifestations because there was not time for them to develop before death. There is also a greater probability of older animals showing signs of disease because they lived longer. This biases samples towards those lesions that represent chronic disease, particularly in older animals. In addition, the hidden heterogeneity of risks states that the archaeological assemblage was made up of an unknown mixture of individuals whose underlying susceptibility to death and disease was unknown (Wood *et al.*, 1992: 344-345). This does not

mean though that it is impossible to infer the health of a population from palaeopathological data. What it does suggest, however, is that, as Wood and Milner (1994: 636) state in their reply to Cohen (1994), that the processes linking frailty, stress, disease, tissue responses and the formation of mortality samples require some thought.

In the following chapter this methodology will be applied to the archaeozoological assemblages from two Roman sites in Britain: Alchester and Cups Hotel, Colchester.

Chapter Six: Applying the Methodology

6.1 Introduction

6.1.1 Aims

Applying the developed recording system to archaeozoological material was undertaken to demonstrate the potential of the system in enabling patterns in pathological data to be explained. The material selected for this purpose derived from two Roman sites in Britain: Alchester and Cups Hotel, Colchester. These assemblages were not chosen because unusual proportions of palaeopathology were already known to be present. Instead, they were selected because of their availability to the researcher and because they did not appear to be in any way 'extraordinary'. They represented the sort of assemblage that any archaeozoologist might be asked to report upon. The fact that both sites are Roman in date permits inter-site comparison and raises the possibility of novel insights being revealed regarding the economy, status or cultural attributes of the sites.

As one of the earliest Roman bases in inland Britain, with only a single generation of occupation, and given the excellent organic preservation, Thomas (in press) has argued that Alchester has a unique potential to illuminate the nature of the diet and provisioning arrangements of the Roman army during the first years of the conquest. The assemblage from Colchester, meanwhile, has the potential to shed light on diet and meat supply in Roman towns. Since these issues are extensive, however, this case study will focus specifically upon the

types of information that can be gained through a systematic examination of the pathological conditions present within the assemblages.

Questions that will be addressed include:

- What is the relative frequency of palaeopathological lesions by phase at Alchester and Colchester?
- What is the relative frequency of palaeopathological lesions amongst the different species represented in the assemblages?
- What is the skeletal distribution of these palaeopathological lesions amongst the different species?
- What types of palaeopathological lesions were most prevalent?
- What do the relative frequencies of the palaeopathological lesions reveal about skeletal and nutritional health?
- What do the relative frequencies of the palaeopathological lesions reveal about the presence of infectious disease?
- What do the relative frequencies of the palaeopathological lesions reveal about the economic significance of major domestic species such as cattle?
- Do the relative frequencies of palaeopathological lesions and the pathological index values support the use of cattle for traction?
- What do the relative frequencies of the palaeopathological lesions reveal about the social status of species such as dogs at Alchester and Colchester?

6.1.2 The Alchester assemblage

Alchester, a Roman small town located ten miles north of Oxford and two miles south of Bicester, has been the subject of investigation since the 1990s, first under the auspices of Oxford University Archaeological Society, then through the Universities of Leicester, Oxford and Edinburgh (Sauer, 2005a: 168). Excavation focussed initially on what was later interpreted as a Roman military parade ground and marching camp near the later Roman town, and then on an annexe of a large military compound, which was shown to be surrounded by a characteristic army-style V-shaped ditch (Sauer and Crutchley, 1998: 35). It was common practice for the Roman army, when operating in enemy territory, to build marching camps against surprise attacks, even when spending only one night. However, the comparative frequency of early artefacts from the site suggests that the camp may have existed for a longer time span, perhaps serving as winter quarters (Sauer and Crutchley, 1998: 36). The presence of the parade ground would also support the idea of a fairly permanent military base. Whether this ground was intended for the training of infantry or cavalry is as yet unclear (Sauer, 2001a: 32), although it possible that analysis of equid remains from the site may provide some indication of the significance of horses at the fort at Alchester (see section 6.1.2).

Alchester, which later occupied an important road junction, was in a key strategic position. Situated in the border region of the Catuvellauni and Dobunni tribes, it was in an ideal position to exercise control over wide areas and to obtain sufficient food supplies for the winter (Sauer and Crutchley, 1998: 36). It

seems likely, therefore, that this site represents a so-called 'vexillation fortress', a term coined by Frere and St. Joseph (1974) for forts of 8-12 hectares in size, with an estimated garrison of 2,500-3,000 men (Sauer, 2001a: 21).

In 1990, a road scheme led to a series of archaeological excavations (Booth *et al.*, 2001: 5). Alongside evidence of pre-Roman settlement, these uncovered extensive activity throughout the Roman period (Booth *et al.*, 2001: iv). In 2003, excavations began at the town wall near the west gate. This had been robbed out in post-Roman times except for two stones that were found *in situ* and the wall's rubble foundations (Sauer, 2005a: 168). Amongst the foundations were discovered the smashed fragments of an inscription that had been used for building material. This tombstone was for one Lucius Valerius Geminus, a veteran of the Legio II Augusta, a legion associated with Vespasian, who later became Emperor (Sauer, 2005a: 168-172; Sauer, 2005b), which may suggest that this site was a legionary fortress.

Investigation of what was believed to be the front gate, or *Porta Praetoria*, of the fortress revealed two wooden gateposts preserved by waterlogging. Dendrochronology gave both a felling date of between October AD 44 and March AD 45 (Sauer, 2001b: 191). However, there is now increasing evidence that this gate belongs to an annexe and thus is probably later than the fortress, which could well date to as early as AD 43, the date of the Roman invasion of Britain (Sauer, 2002: 355). This site, therefore, provides some of the earliest occupational evidence for the Romans in Britain. The date of abandonment of the site based upon numismatic evidence is placed before the death of Emperor

Nero in AD 68 (Sauer, 2001b: 191). Thus, occupation of the annexe may have last for only twenty-five years.

Following the abandonment of the fortress, the town of Alchester began to develop with occupation stretching to the fourth century AD. In the 1st to early 2nd centuries the Roman settlement was characterised by ditches aligned with the early Akeman Street. Later a series of ditched plots developed, which contained later Roman structures of varying plan and construction type, the character of the settlement at that time being largely agricultural (Booth *et al.*, 2001: iv). Settlement continued to the end of the Roman period and probably beyond (Booth *et al.*, 2001: iv).

Previous analyses of the faunal remains from Alchester (Grant, 2001; Powell and Clark, 2001; Thomas, in press) have demonstrated that the assemblage is dominated by the principal domestic species – cattle (*Bos taurus*), sheep (*Ovis aries*), pig (*Sus scrofa*), dog (*Canis familiaris*) and horse (*Equus caballus*) – although a small number of bones from wild animals, including red deer (*Cervus elaphus*), along with bird remains were also recovered (Grant, 2001: 63). Horses appear to be present in relatively high proportions, perhaps due to the essential role they played in the Roman army (Grant, 2001: 63), whilst the sheep appear to be typical in size and shape of those found on earlier Iron Age sites in the region (Grant, 2001: 63). Changes in the pattern of cut marks on their bones do, however, suggest that butchery practices had altered since that time (Grant, 2001: 63).

For this study, a sample of 1318 fragments were analysed from the site. Animal bones were recovered from early military phases and later civilian occupation (based on provisional phasing) (table 6.1); however, for the purposes of this analysis these have been combined in order to create a sample of a viable size. As the aim of the study was to demonstrate the potential of the system to enable patterns in pathological data to be explained, rather than to conduct a detailed diachronic analysis, this merging of more than one phase was not considered to be a significant problem.

Phase	Date	Total Number of Fragments
1	AD 40 – AD 60/65	972
2	Later 1 st century AD	11
3	Late 1 st to mid 2 nd centuries AD	61
4	Late 2 nd to mid 3 rd centuries AD	175
5	Mid 3 rd to early 4 th centuries AD	12
6	Late 4 th century AD	6
7	Unknown Roman	81
TOTAL		1318

Table 6.1: Sample of bones by phase employed in this study from Alchester

6.1.3 The Cups Hotel, Colchester assemblage

One of the most significant results of large-scale excavations in Romano-British towns since the 1970s has been the discovery that several of these towns were reused redundant military fortresses (Crummy, 1982: 125). Amongst the towns now known to have had origins closely bound up with the military bases they succeeded is Colchester, whose military defences were levelled so that the new town could cover an area larger than that of the original fortress (Crummy,

1982: 125). As a result, Colchester was largely unprotected during the Boudiccan revolt of AD 60-61, and may consequently have suffered to a greater extent during the uprising (Crummy, 1982: 125).

Colchester was an important settlement in the Roman, medieval and post-medieval periods, both because of its status as a port and because of its location in rich farming country (Luff, 1993: 7). During the past few decades, intensive excavation by the Colchester Archaeological Trust has yielded significant results from both inside and outside the town walls (Luff, 1993: 7). The site of the Cups Hotel was of potential archaeological interest because it lay in the centre of the Roman and medieval town (Crummy, 1992: 328). Permission was gained for a rescue excavation in 1973 after the demolition of the hotel before further construction work began (Crummy, 1992: 328). Extensive cellars were discovered to have already removed much of the archaeological remains, a north-south strip about 6m wide surviving intact that was the subject of the main phase of excavations (Crummy, 1992: 328).

In 1974, after contractors had removed modern cellars on the site, what appeared to be a narrow gravelled road with a cambered surface was revealed in section. The gravel lay on the natural sand and was sealed by typical post-Boudiccan dump-material (Crummy, 1977: 84; Crummy, 1992: 330). It was suggested that this apparently early road indicated the likely presence of the tribunes' house close-by, in keeping with equivalent distances in other fortresses at Caerleon and Neuss (Crummy, 1977: 84). A section of early Roman wall was also discovered at the site whose timber-framed construction was infilled with

fragments of segmental bricks that showed evidence of burning during AD 60 (Essex SMR No.: 12298).

The three buildings on the site represented occupation from the early Roman period (c. 49-60/1 AD) through to the later period (c. 225-400+ AD) (Crummy, 1992: 328). A bone comb was found in association with a dispersed hoard of coins and pottery, which securely dated the find to the late Roman rather than Anglo-Saxon period (Crummy, 1992: 333). In addition, a cast bronze belt-mount of the type in vogue in the second half of the 4th century AD was discovered in a Norman robber trench.

Phase	Date	Total Number of Fragments
Ia	AD 43 - 61	5
Ib	61 AD – 2 nd century AD	35
IIa	2 nd – 3 rd centuries AD	413
IIb	4 th century AD	494
TOTAL		947

Table 6.2: Roman occupational phases at Cups Hotel, Colchester and breakdown of bone sample

The previously unstudied faunal assemblage from this site was dominated by the principal domestic species – cattle (*Bos taurus*), sheep (*Ovis aries*), pig (*Sus scrofa*), dog (*Canis familiaris*) and horse (*Equus caballus*) – although bones from wild animals, including red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*), cat (*Felis domesticus*), fish and birds were also recovered. For this study 947 fragments were analysed from the site. As with the Alchester

assemblage, all Roman phases (table 6.2) were combined in order to create a sample large enough to be viable for analysis.

6.2 Methodology

All material from contexts securely dated to the Roman period (1st – 4th centuries AD) from the two sites was subjected to macroscopic examination. Phases were combined to create a sample of sufficient size to provide significant results. Full contextual information, including the data gathered during recent analysis by Thomas (in press), was available for the Alchester assemblage. A similar analysis of the Colchester assemblage was carried out to ensure that non-pathological data was available in order for prevalence to be calculated. Data gathered for each post-cranial fragment included, where possible, species, skeletal element, side, zones present (Dobney and Reilly, 1988), and taphonomic condition (Harland *et al.*, 2003). The tooth wear stages of mandibular teeth were recording using Grant (1982).

During the study of both sites, all potential palaeopathological data was inputted into the database created as part of this research (Chapter 5). The step-by-step process of recording that was employed followed that laid out in the User Guide (Appendix 2). All complete cattle metapodia and phalanges, regardless of their stage of deformation, were recorded using Bartosiewicz *et al.* (1997) (see also Appendix 2). All unaltered cattle metapodia and phalanges in the Pathological Index (see chapter four) were also included to ensure the profile generated was a genuine reflection of the frequency of bone deformation at these sites.

The resulting site-level data will first be examined and the prevalence of palaeopathological lesions amongst different species and their skeletal distribution at the two sites will be discussed. The focus will then be placed more specifically upon different types of palaeopathological lesion, with variations in prevalence between different species and upon different skeletal elements detailed. Finally, these results will be interpreted and the questions set out in section 6.1.1 will be addressed.

6.3 Overview of pathologies

Pathological change was more common at Alchester (11.3%) than Colchester (6.1%). As discussed previously (section 5.7), one of the first steps in the analysis of an assemblage should be the calculation of the prevalence of palaeopathological lesions by phase, species and skeletal element. The relative proportions of palaeopathological lesions by phase at Alchester are, therefore, represented in figure 6.1 and table 6.3. This demonstrates that the greatest proportion of palaeopathological lesions came from phase 1 (AD 40 – AD 60/65), the Roman fort, which supplied the greatest proportion of the assemblage. The second greatest proportion of lesions came from phase 4 (late 2nd – mid 3rd centuries AD), from the later civilian settlement, which supplied the second greatest proportion of the assemblage. Significantly smaller proportions of lesions were found in deposits dated to the other phases of occupation. It is clear from these data that there is a direct correlation between sample size and pathological frequency; this fact needs to be taken into consideration when inter- and intra site analyses are conducted.

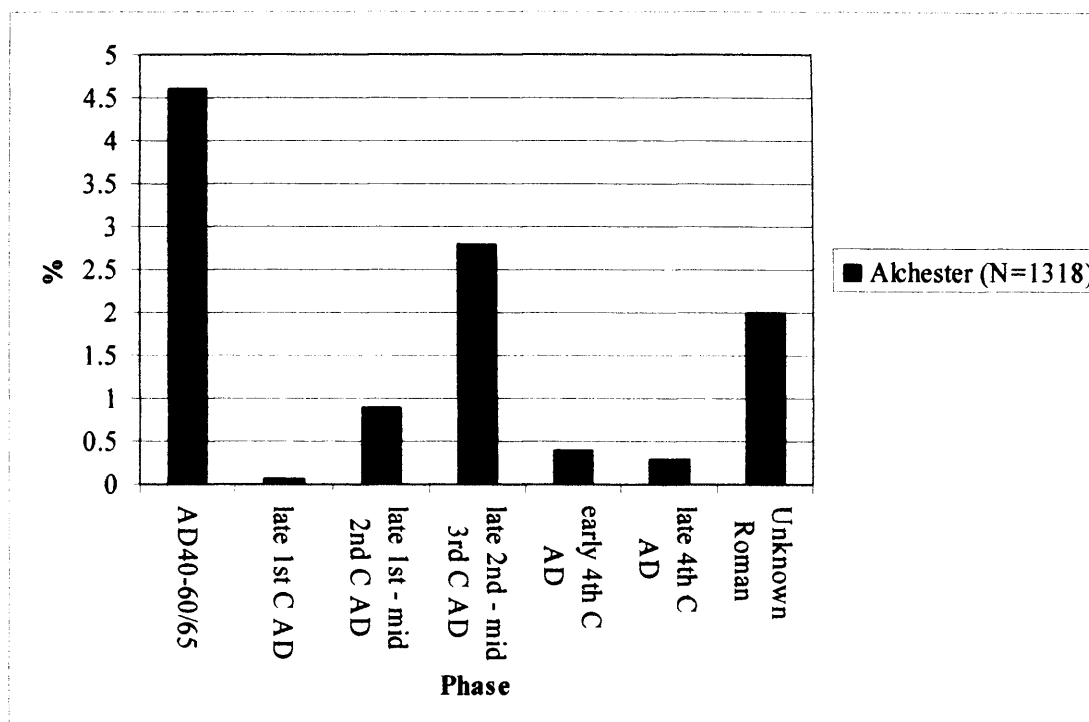


Fig 6.1: Relative proportions of palaeopathological lesions by phase at Alchester

Phase	Total No.	No. of Pathologies	% Pathologies of Total Assemblage
AD40 – 60/65	972	61	4.6%
Late 1 st C AD	11	1	13%
Late 1 st – mid 2 nd C AD	61	13	0.9%
Late 2 nd – mid 3 rd C AD	175	38	2.8
Early 4 th C AD	12	5	0.4%
Late 4 th C AD	6	4	0.3%
Unknown Roman	81	27	2%
TOTAL	1318	149	11.3%

Table 6.3: Relative proportions of palaeopathological lesions by phase at Alchester

At Colchester (figure 6.2, table 6.4), however, the palaeopathological lesions were found entirely within the deposits belonging to the civilian town, and not

the earlier military settlement. The greatest proportion of lesions came from phase IIb, dated to the 4th century AD. The second greatest proportion came from phase IIa, dated to between the 2nd and 3rd centuries AD. These phases provided the greatest proportion of the total assemblage. A small proportion (0.5%) of palaeopathological lesions come from phase Ib, dated to between the Boudiccan revolt of AD 61 and the 2nd century AD. As with the Alchester material, it is likely that these variations in frequency are an artefact of sample size.

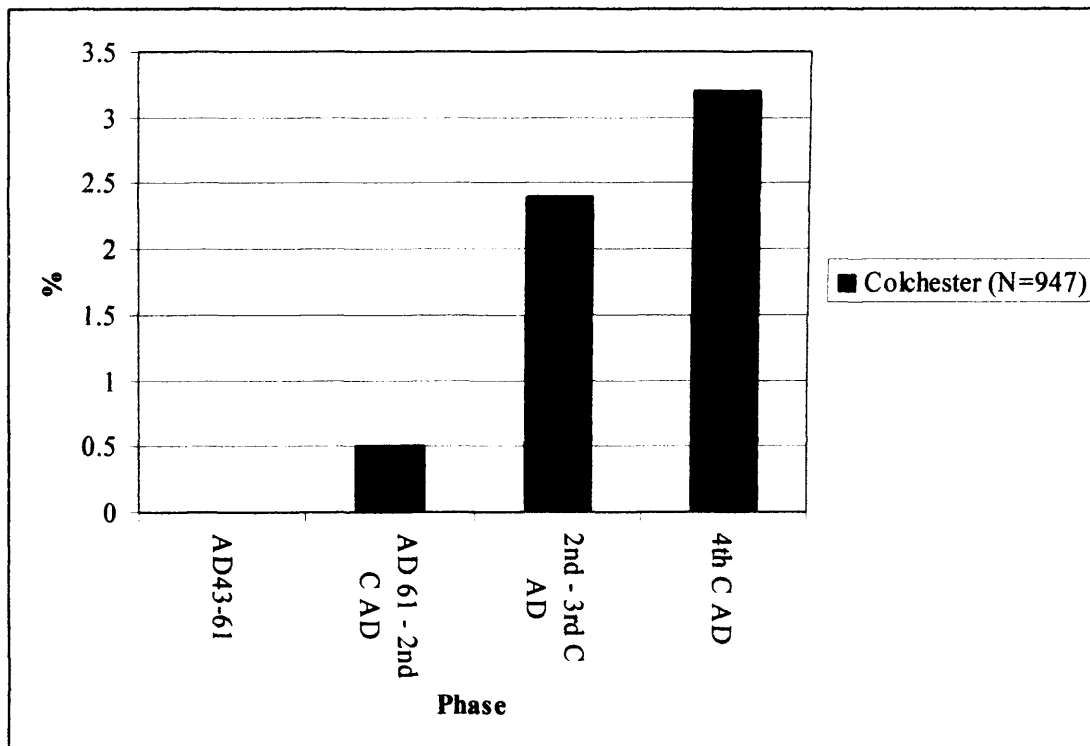


Fig 6.2: Relative proportions of palaeopathological lesions by phase at Colchester

Phase	Total No.	No. of Pathologies	% Pathologies of Total Assemblage
AD 43- 61	5	0	0%
AD 61 – 2 nd C AD	35	5	0.5%
2 nd – 3 rd C AD	413	23	2.4%
4 th C AD	494	30	3.2%
TOTAL	947	58	6.1%

Table 6.4: Relative proportions of palaeopathological lesions by phase at Colchester

The relative proportions of palaeopathological lesions among the different species at each site are represented in figure 6.3 and table 6.5. These results, which exclude those specimens that could not be securely identified to an individual species, show that at both sites the vast majority of palaeopathological lesions are found on cattle. Dogs, caprines (sheep/goat) and birds were affected with the next greatest frequency, although the dog data for Alchester is biased by the inclusion of partial skeletons; when those remains are excluded, the relative proportion of affected dog bones is significantly lower. Palaeopathological lesions on pig, horse and red deer bones were only found at one site, not both.

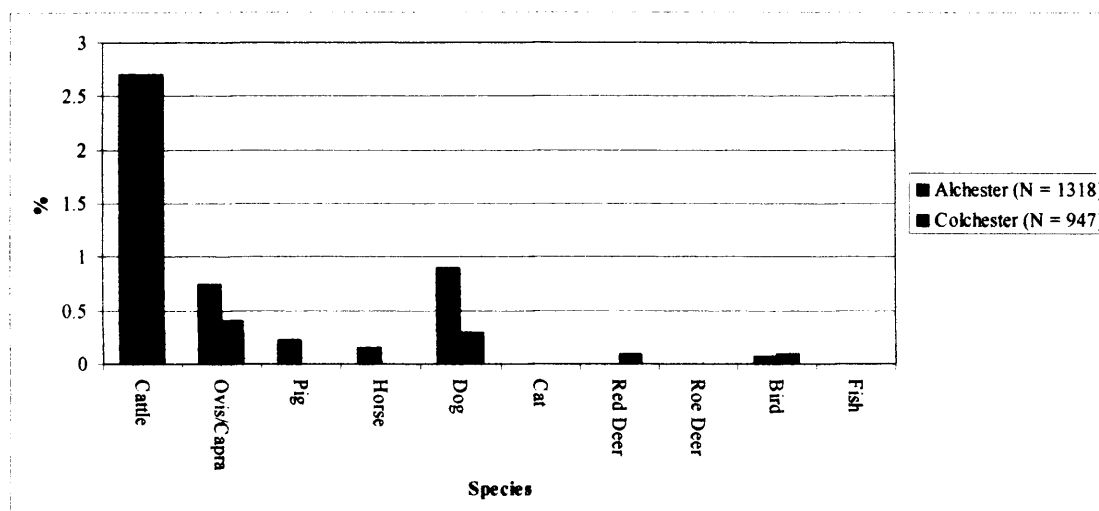


Fig 6.3: Relative proportions of palaeopathological lesions by different species

Species	Alchester			Colchester		
	Total No.	No. of Pathologies	% Pathologies of Total Assemblage	Total No.	No. of Pathologies	% Pathologies of Total Assemblage
Cattle	293	36	2.7%	332	26	2.7%
Ovis/Capra	260	10	0.75%	178	4	0.4%
Pig	120	3	0.22%	236	0	0%
Horse	55	2	0.15%	0	0	0%
Dog	58	12	0.9%	35	3	0.3%
Cat	1	0	0%	28	0	0%
Red Deer	1	0	0%	19	1	0.1%
Roe Deer	2	0	0%	4	0	0%
Bird	16	1	0.07%	7	1	0.01%
Fish	0	0	0%	2	0	0%
Unidentified	512	4	0.3%	106	0	0%
TOTAL	1318	64	4.9%	947	35	3.6%

Table 6.5: Relative proportions of palaeopathological lesions by different species

The prevalence of palaeopathological lesions on different skeletal elements by species at each site demonstrated both inter-site and inter-species variation. At Alchester (figure 6.4), most major skeletal elements were represented. Of the

limb bones, only the femur showed no pathological alteration in any species. In cattle, the vast majority of lesions were found in the feet – particularly the metapodials and phalanges. In caprines, pathological alteration was most frequent in the humerus, which was followed by teeth and then elements of the feet in order of frequency. Pathological alteration in pigs was concentrated in elements of the forelimb, whilst horses only showed alteration to the axial skeleton – specifically the pelvis and vertebrae. Lesions were also most frequent in the axial skeleton of dogs although, as previously stated, these results may be skewed due to the prevalence of articulated material.

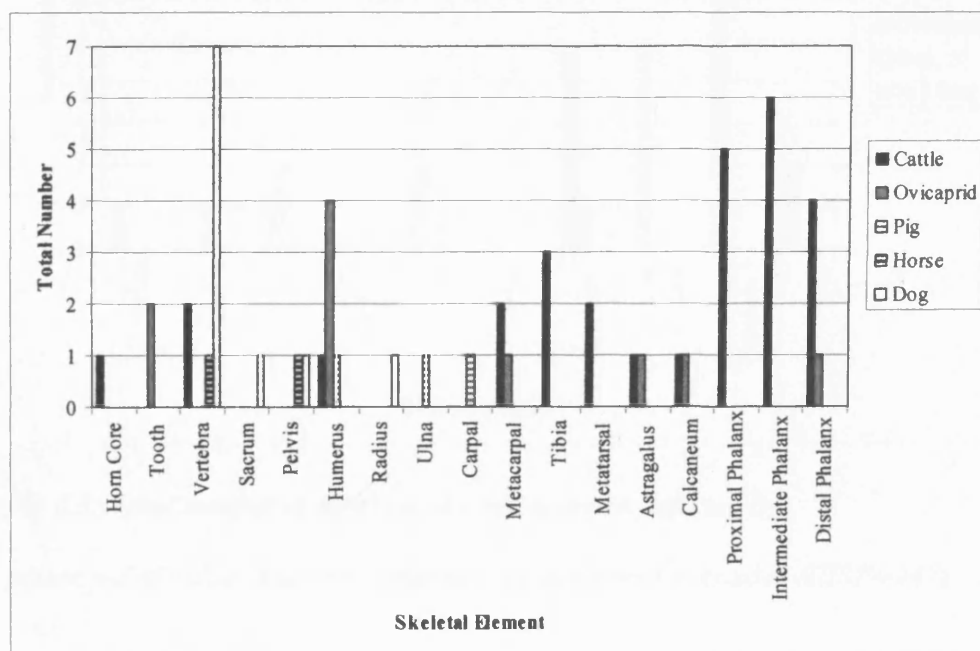


Fig 6.4: Total number of different skeletal elements affected by palaeopathological lesions by different species from Alchester (NISP=1318)

At Colchester (figure 6.5), however, only elements of the axial skeleton and forelimbs were affected by palaeopathological lesions. The vast majority of palaeopathological lesions on cattle bones were shown to be present in the fore

feet – specifically the metacarpal and anterior phalanges. This is comparable with the results gained from the cattle bones at Alchester where the bones of the feet also showed the most alteration. Palaeopathological lesions in caprines were fewer in number and had less discernible trends, whilst lesions on dog bones were focused entirely on the bones of the forelimb – in particular, the humerus, radius and ulna. Red deer was represented by an individual radius.

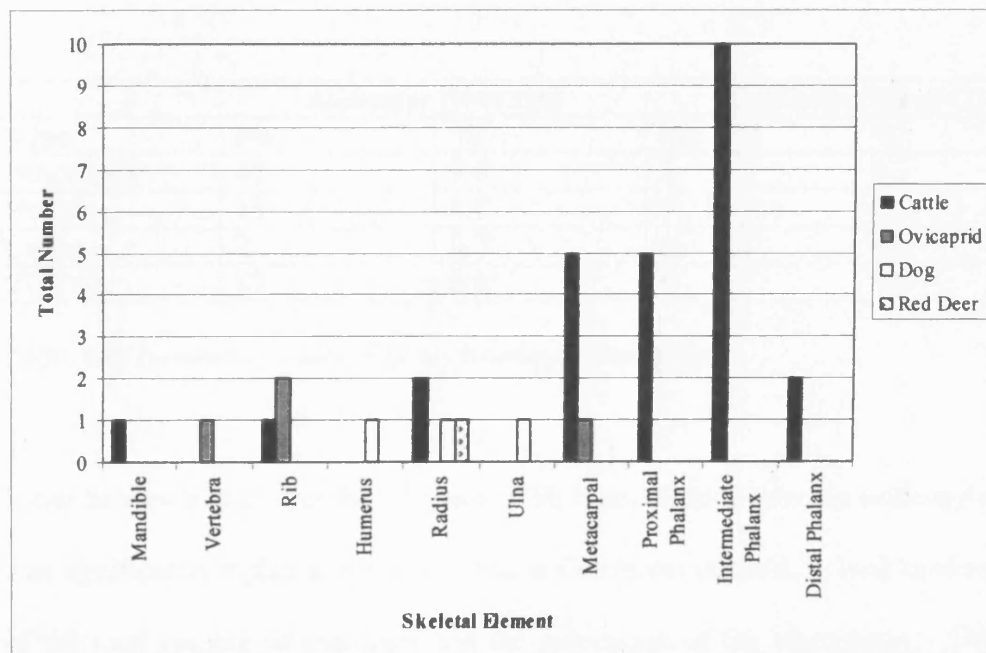


Fig 6.5: Total number of different skeletal elements affected by palaeopathological lesions by different species from Colchester (NISP=947)

In summary, it can be seen that the prevalence of palaeopathological lesions at both sites was greater in domesticated mammals than in wild species and birds. The number of cases of palaeopathology was significantly higher at Alchester than at Colchester, both in terms of the total number of examples and the relative frequency by species. However, both inter-site and inter-species variation affected the prevalence and skeletal distribution of palaeopathological

lesions. Such conclusions have also been drawn by a recent review of palaeopathology at prehistoric and historic sites in Ireland (Murphy, 2005). However, at those sites, greater incidences of trauma were noted in both caprines and dogs (Murphy, 2005: 21).

6.4 Bone formation

6.4.1 Introduction

Type	Alchester (N=1318)		Colchester (N=947)	
	No.	%	No.	%
Periostosis	47	3.6	3	0.3
Nodule	18	1.4	5	0.5
Callus	2	0.2	1	0.1
TOTAL	67	5.1	9	0.9

Table 6.6: Number of cases of bone-forming pathologies

It can be seen that the number of cases of all types of bone-forming pathologies was significantly higher at Alchester than at Colchester (table 6.6), both in terms of the total number of examples and the percentage of the assemblage. This variation may reflect differences between the two sites – one largely military and one largely urban – and the nature of the supply of animals to them, an issue discussed in greater depth later in the chapter.

6.4.2 Periostosis

Lesions due to abnormal bone formation on the periosteal layer at both sites were generally irregularly shaped with indeterminate margins, ranging from less than 100mm² up to 3696mm² in area. This was the most prevalent type of bone-forming pathology at Alchester. However, periostosis was less common than

nodular bone formation in the Colchester assemblage, and was present on a much lower percentage of the bones than in the Alchester material.

At Alchester, periostosis was identified on skeletal elements of *Bos taurus* and *Ovis/Capra*, and the majority (61.7% of the total elements displaying periostosis) were found on the visceral surface of ribs (table 6.7). However, at Colchester these were found on other skeletal elements: two radii (one from a red deer, *Cervus elaphus*, and one from a pig, *Sus scrofa*) and a small-ungulate-sized vertebra.

Element	Species	Number of Affected Elements	Total Number of Element
Cranium	Unidentified	5	11
Rib	Unidentified	29	692
Vertebrae	<i>Bos taurus</i>	3	43
Scapula	Unidentified	1	35
Humerus	<i>Ovis/Capra</i>	2	24
Tibia	<i>Bos taurus</i>	2	11
Calcaneum	<i>Bos taurus</i>	1	16
	<i>Ovis/Capra</i>	1	18
Astragalus	<i>Bos taurus</i>	1	11
Unidentified	<i>Bos taurus</i>	2	-
TOTAL		47	861

Table 6.7: Number of cases of periostosis by skeletal element in the Alchester assemblage

These probably represent a variety of infection or inflammation processes, which may result from a wide range of causes; for example, trauma on the tibia, perhaps due to a kick from another individual, could cause inflammation of the periosteum, and could provide insight into stocking conditions. Those examples on ribs and vertebrae may represent respiratory conditions such as tuberculosis. As previously noted (section 4.4), in domestic mammals, tuberculosis generally affects vascular cancellous bone. In order of decreasing importance, these

lesions can be found in the vertebral bodies, extremities of long bones, ribs, sternum, skull and other flat bones (coxal bone) (Lignereux and Peters, 1999: 341). Ribs and vertebrae are, therefore, key sites for the identification of tuberculosis within faunal assemblages (Wakely *et al.*, 1991). It is not, however, possible to be more specific in the diagnosis than ‘infection and/or inflammation’ for these specimens as it is not possible to see the skeletal distribution of the lesions for each individual. Skeletal distribution is of particular importance when diagnosing infectious and inflammatory diseases as it is often only the elements affected that distinguish one condition from another.

6.4.3 Nodule

Element	Species	Number of Affected Elements	Total Number of Element
Axis	<i>Canis familiaris</i>	1	1
Vertebrae	<i>Canis familiaris</i>	6	17
	<i>Equus caballus</i>	1	19
Sacrum	<i>Canis familiaris</i>	1	2
Pelvis	<i>Canis familiaris</i>	1	4
	<i>Equus caballus</i>	1	5
Humerus	<i>Ovis/Capra</i>	1	24
Radius	<i>Canis familiaris</i>	1	2
Intermediate Phalanx	<i>Bos taurus</i>	3	31
Distal Phalanx	<i>Bos taurus</i>	2	20
TOTAL		18	125

Table 6.8: Number of cases of nodular bone growth by skeletal element in the Alchester assemblage

The second most common type of pathological bone formation in the Alchester assemblage was nodular bone growth. These were generally smooth protrusions of bone with a poorly defined margin, and of irregular or round/oval shape.

Most lesions were of a small size, ranging from c. 6mm² to 250mm² in area. By comparison, this type of osteoblastic response was the most frequent type of bone formation-related pathology in the Colchester assemblage. As with the Alchester material, these were smooth protrusions of bone, irregular in shape, with a poorly defined margin. They ranged from 300 mm² to 3500 mm² in area.

At both sites, this type of pathology was most common on dogs. However, in contrast to the Alchester assemblage where the majority of these were found on vertebrae (table 6.8), the Colchester cases were found on a humerus, radius and ulna, all from the same context and possibly from the same individual. In addition, there was a small-ungulate-sized rib and an unidentified bird bone, probably *Gallus sp.*, that exhibited this condition. The dog bones represent osteophytic bone formation around the margins of articular surfaces. Osteophytosis, the formation of branching spicules ('lipping') of new bone on a pre-existing bone surface (see glossary), is most likely to occur at the margins of vertebral bodies, and this is also seen in the material from context 41.161 (late 2nd – mid 3rd century AD) of the Alchester assemblage. From a single, articulated canid skeleton, the vertebrae, sacrum and pelvis all show evidence of osteophytosis (figure 6.6).

It is possible that this is due to vertebral spondylosis. Usually associated with degenerative changes in the joints between vertebral bodies, this condition results in new bone formation on the ventral and lateral aspects of the centra and sometimes results in vertebral fusion (Baker, 1978: 110), suggesting an attempt to stabilise the vertebral column. In veterinary texts, this has been considered to

be primarily a degenerative condition, with trauma being an identifiable causal factor in at least some cases (Davies, 2003:62). In dogs, the incidence of this condition has also been shown to increase with age (Morgan, 1967: 53).



Fig 6.6:
Osteophytosis of a
canid vertebra from
Alchester

6.5 Bone destruction

6.5.1 Introduction

As was the case with bone-forming pathology, it can be seen that the number of cases of all types of bone-destroying pathologies was significantly higher at Alchester than at Colchester (table 6.9), both in terms of the total number of examples and the percentage of the assemblage. Once again, this variation may reflect differences in the nature of the two sites and the manner of the supply of animals to them, an issue explored in greater depth below.

	Alchester (N=1318)		Colchester (N=947)	
Type	No.	%	No.	%
Porosity	13	0.9	2	0.2
Cavity	7	0.5	2	0.2
Articular Depression or Groove	6	0.4	8	0.8
TOTAL	26	1.9	12	1.2

Table 6.9: Number of cases of bone- destroying pathologies

6.5.2 Porosity

Type	Species	Number of Affected Elements	Total Number of Elements
Cranium	<i>Bos taurus</i>	2	4
Horn Core	<i>Bos taurus</i>	2	6
Axis	<i>Canis familiaris</i>	1	1
Humerus	<i>Ovis/Capra</i>	1	24
Pelvis	Unidentified	1	35
Tibia	<i>Bos taurus</i>	1	11
Calcaneum	<i>Bos taurus</i>	1	16
Tarsal	<i>Bos taurus</i>	1	6
Metatarsal	<i>Bos taurus</i>	1	12
Intermediate Phalanx	<i>Bos taurus</i>	1	31
Unidentified	<i>Bos taurus</i>	1	-
TOTAL		13	146

Table 6.10: Number of cases of porosity by skeletal element in the Alchester assemblage

Increased porosity was the most common type of bone destruction-related pathology in the Alchester assemblage and was most frequently seen in skeletal elements of cattle (*Bos taurus*). In most instances, these lesions were irregular in shape with poorly defined margins, ranging from less than 100mm² up to 3696mm² in area. These were found throughout the skeleton (table 6.10). Porosity was also found in association with other pathological manifestations

such as periostosis and nodular bone formation (section 6.2) and eburnation (section 6.5).

In the Colchester assemblage, the prevalence of this condition was significantly lower; only two bones out of a total of 947 exhibited pathological porosity. Both cases were small – only 300mm² in area – and were round/oval in shape with poorly defined margins. Both cases involved cattle (*Bos taurus*) bones; a radius and a metacarpal.

At both sites, all of these lesions are of unknown aetiology, although those in association with other conditions may represent additional symptoms of inflammation, infection or joint degeneration due to age, weight-bearing or activity.

6.5.3 Cavity

Type	Species	No. of Affected Elements	Total No. of Elements
Humerus	<i>Ovis/Capra</i>	1	24
	<i>Sus scrofa</i>	1	13
Radius	<i>Canis familiaris</i>	1	2
Carpal	<i>Sus scrofa</i>	1	6
Metacarpal	<i>Bos taurus</i>	1	10
	<i>Ovis/Capra</i>	1	15
Metatarsal	<i>Bos taurus</i>	1	12
TOTAL		7	82

Table 6.11: Number of cases of cavity formation by skeletal element in the Alchester assemblage

The second most common type of bone destruction-related pathology in the Alchester assemblage was cavity formation. These were defined simply as a

hollow area within a bone. These displayed no real pattern, being either linear, round/oval or irregular in shape, with examples of both poorly and well defined margins. They ranged in area from 4 mm² up to 60 mm², and were found throughout the skeleton (table 6.11). Examples were identified on all three major domestic species: cattle (*Bos taurus*), sheep/goat (*Ovis/Capra*) and pig (*Sus scrofa*), as well as dog (*Canis familiaris*).

Once again, these had a significantly lower prevalence in the Colchester assemblage. The two examples discovered at Cups Hotel were both round/oval in shape; however, one had a poorly-defined margin and the other a well-defined margin. That with a poorly-defined margin was found on the exterior surface of a rib from a large mammal such as an ox or a horse, and was of unknown aetiology. The other was found on a dog humerus, which also exhibited nodular bone formation and patches of eburnation, suggesting a potential link to osteoarthritis.

The precise aetiology of the Alchester cavities is difficult to establish. That on the dog (*Canis familiaris*) radius was a circular depression with a sharp remodelled ridge proximal to the ulna notch that appeared to be associated with a syndesmophyte (a bony bridge linking a fibrous joint). The cavity on the caprine humerus, however, was a linear cleft, most likely developmental in origin, on the edge of the proximal aspect of the trochlea. This cleft had a well-defined margin and a smooth surface and interior. It was apparently associated with a lesion of osteochondritic type, a condition discussed further in relation to depressions in the articular surface (section 6.5.3). Other examples were harder

to ascribe an aetiology to. Some, such as those on the metacarpals, were potentially taphonomic. Others, such as that on the pig humerus, were well remodelled and had poorly defined margins. It was, therefore, likely to have been inactive at the time of death.

6.5.4 Articular depressions

Type	Species	No. of Affected Elements	Total No. of Elements
Ulna	<i>Sus scrofa</i>	1	14
Astragalus	<i>Ovis/Capra</i>	1	6
Tarsal	<i>Bos taurus</i>	2	6
Proximal Phalange	<i>Bos taurus</i>	2	38
TOTAL		6	64

Table 6.12: Number of cases of articular depressions by skeletal element and species in the Alchester assemblage

Within the Alchester assemblage, four out of the six identified articular depressions (table 6.12) were found on cattle (*Bos taurus*) bones; two on tarsals and two on phalanges. These had well-defined margins, and ranged in area from 4mm² up to 44mm². Of the three types of depressions commonly seen on the articular surfaces of cattle phalanges described by Baker and Brothwell (1980: 110), those found in the Alchester assemblage most resemble those classified as types two and three. Type two are “of variable length between the articular facets and are more common on the lower extremity of the second phalanx than at other sites” (Baker and Brothwell, 1980: 110). Type three “take the form of a slit of variable length and not inconsiderable depth running across the articular facets in a line slightly oblique to the mediolateral axis,” and are typically found on the third phalanx (Baker and Brothwell, 1980: 110). The phalanges from Alchester exhibit one type two and one type three depression; the type two on

the proximal articulation and the type three on the distal articulation. That on the cattle central tarsal (figure 6.7) is, however, most comparable to type one. That is a rounder depression occurring on either articular facet, with a medio-lateral orientation (Baker and Brothwell, 1980: 110). The other two articular depressions were found on the proximal articulation of a pig (*Sus scrofa*) ulna (figure 6.8) and the distal articulation of a caprine astragalus (figure 6.9). The first bone exhibited a single type three lesion, which could be developmental in origin (Thomas, pers. comm.). The second displayed three small, deep type two lesions with one type one lesion close to the edge of the distal articulation.

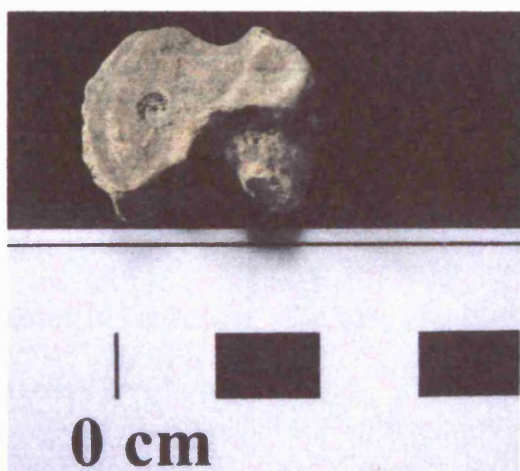


Fig 6.7: Type 1 articular lesion on cattle central tarsal from Alchester



Fig 6.8: Type 3 articular lesion on pig ulna from Alchester



Fig 6.9: Caprine astragalus with three small, deep type 2 lesions and one type 1 lesion close to the edge of the distal articulation from Alchester

Articular depressions are also seen in the Colchester assemblage, representing the most prevalent form of pathological response at that site. However, unlike the Alchester assemblage, these were not found on phalanges or tarsals. Instead, they were found on the articular surfaces of radii and metacarpals (table 6.13). Nor were they found solely on cattle (*Bos taurus*) bones. Examples were also seen in red deer (*Cervus elaphus*), pig (*Sus scrofa*) and sheep/goat (*Ovis/Capra*).

Element	Species	No. Affected Elements	Total No. of Elements
Radius	<i>Cervus elaphus</i>	1	2
	<i>Sus scrofa</i>	1	6
	<i>Bos taurus</i>	1	11
Metacarpal	<i>Ovis/Capra</i>	1	10
	<i>Bos taurus</i>	4	21
TOTAL		8	50

Table 6.13: Number of cases of articular depressions by skeletal element and species in the Colchester assemblage

With the exception of their location, these would also appear to conform to types two and three as previously defined (Baker and Brothwell, 1980: 110). It is possible though that the type two lesions could be due to other conditions such as osteochondritis dessicans. This is a condition of the joint, in which fragments of bone or cartilage have come loose, leading to pain and inflammation (see glossary), and one that is relatively common in larger breeds of dog, pigs and horses (Baker and Brothwell, 1980: 129). Whilst these fragments were not noted, either loose or subsequently re-fused to other parts of the bone, it is not impossible that at least some of these depressions might represent sites from which such fragments have been removed.

6.6 Fractures

Three fractured bones were found in the Alchester assemblage. The first of these was an oblique healed fracture of a probable dog (*Canis familiaris*) metapodial from context 20.83 (AD 40 – AD 60/65). The callus was irregular in shape with a smooth surface and an indeterminate margin. It covered an area of c. 221 mm². The fracture had an angle of displacement of c. 10° and had caused foreshortening of c. 10 mm. The prevalence was one out of a total of three dog metapodials found in the assemblage.

The second example was a fractured dog lumbar vertebra (figure 6.10) from context 41.161 (late 2nd – mid 3rd century AD). This was a well-healed transverse fracture of the vertebral spine, evident from the angle of the spine (which deviated from perpendicular c. 5°) although the callus had been remodelled. This condition had a prevalence of one out of a total of seven canid

lumbar vertebrae found at this site, of which a total of six came from the same context (41.161). As this vertebra was associated with a number of other dog bones from the same context, it is likely that these belonged to the same individual. Of those bones, a number also displayed other pathological alterations such as osteophytosis (see section 6.1). The fracture of the vertebral process might or might not, therefore, be associated with the vertebral spondylosis. Trauma can sometimes be a factor in secondary osteoarthritis in the same region (Roberts and Manchester, 1995: 106), however this could not be stated definitively in this instance. The healed nature of the fracture would imply that this was an old injury.

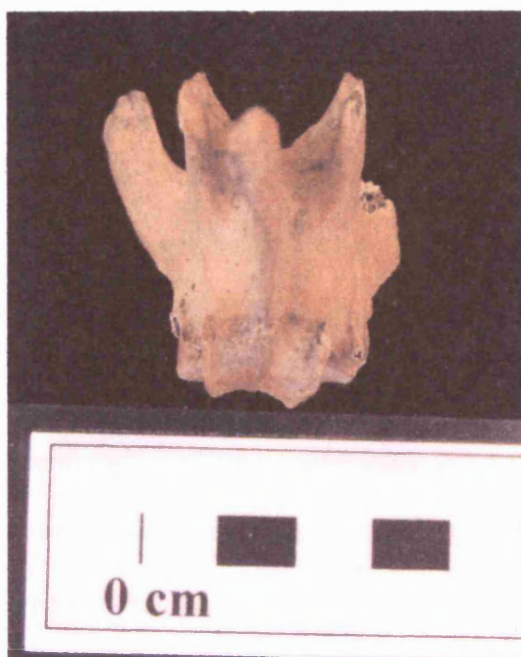


Fig 6.10: Transverse fracture of a canid vertebra from Alchester

Finally, an unidentifiable bird bone from context 42.27 (late 4th century AD) displayed a possible oblique fracture. The callus was round/oval in shape, with a smooth surface and well-defined margin that demarcated an area of *c.* 230 mm².

There was no evidence of displacement or foreshortening. The prevalence of this condition was one out of a total of fourteen bird bones identified at the site.

Only a single example of a fractured bone was discovered at Cups Hotel, Colchester. This was a probable transverse fracture of a rib comparable in size to a sheep/goat. The fracture had been healed for some time by the time of death, the bone having completely remodelled, leaving a smooth surface and indeterminate margins to the injury. The angle of bone displacement was slight (*c.* 2° from perpendicular). The prevalence of this condition was one out of a total of fifteen ribs of this type identified at the site.

6.7 Miscellaneous

A small number of other miscellaneous conditions, which did not fit into any of the above three major categories, were also identified (table 6.14). The most prevalent of these was eburnation, found on three bones in the Alchester assemblage and one in the Colchester assemblage. This term describes the degeneration of bone into a hard, polished, ivory-like mass (see glossary). It is therefore not surprising to find it in association with other conditions such as porosity and nodular bone formation, which in combination provide evidence for degenerative joint disease (as discussed in section 4.2). The slight broadening of the distal articulation of a cattle (*Bos taurus*) metacarpal from context 32.103 (AD 40 – AD 60/65) of the Alchester (figure 6.11) assemblage may also represent an early stage (stage 2 as described by Bartosiewicz *et al.*,

1997) of degenerative joint disease. The prevalence of this condition was one out of a total of ten cattle metacarpals identified within the assemblage.

Type	Alchester (N=1318)		Colchester (N=947)	
	No.	%	No.	%
Eburnation	3	0.2	1	0.1
Enlarged Size	1	0.1	0	0.0
Extension of Articular Surface	1	0.1	0	0.0
TOTAL	5	0.4	1	0.1

Table 6.14: Number of cases of other miscellaneous pathologies



Fig 6.11: Stage 2 (Bartosiewicz et al., 1997) broadening of the distal articulation of a cattle metacarpal from Alchester

6.8 Pathological index

The pathological index devised by Bartosiewicz *et al.* (1997) was tested on all cattle metapodia and phalanges that were complete enough to permit all variables to be recorded. No differentiation was made between those that were obviously pathological and those that were not. The aim was to investigate whether or not the cattle at these sites showed any evidence of pathological alteration that might be related to activity such as traction.

As can be seen from the results summarised in table 6.15, the majority (79%) of those cattle (*Bos taurus*) bones from the Alchester assemblage recorded using this methodology devised showed no pathological alteration, having a pathological index (PI) of 0.000. Few showed significant deformation, with only one bone, a distal phalanx, displaying a PI of more than 0.200.

PI	Metacarpal	Metatarsal	Proximal Phalanx	Intermediate Phalanx	Distal Phalanx	TOTAL
0.000	3	1	20	14	10	48
0.091	0	0	3	4	0	7
0.143	0	0	0	0	3	3
0.181	0	0	0	2	0	2
0.272	0	0	0	0	0	0
0.285	0	0	0	0	1	1
TOTAL	3	1	23	20	14	61

Table 6.15: Summary of results from Alchester, based on methodology devised by Bartosiewicz et al. (1997)

These results are comparable to those from the Colchester assemblage (table 6.16). At that site the majority (64%) of those cattle (*Bos taurus*) bones recorded also showed no pathological alteration. Few showed significant deformation,

with only one bone, an intermediate phalanx, displaying a PI of more than 0.200.

PI	Metacarpal	Metatarsal	Proximal Phalanx	Intermediate Phalanx	Distal Phalanx	TOTAL
0.000	0	0	19	5	8	32
0.091	0	0	4	6	0	10
0.143	0	0	0	0	3	3
0.181	0	0	1	3	0	4
0.272	0	0	0	1	0	1
0.285	0	0	0	0	0	0
TOTAL	0	0	24	15	11	50

Table 6.16: Summary of results from Colchester, based on methodology devised by Bartosiewicz et al. (1997)

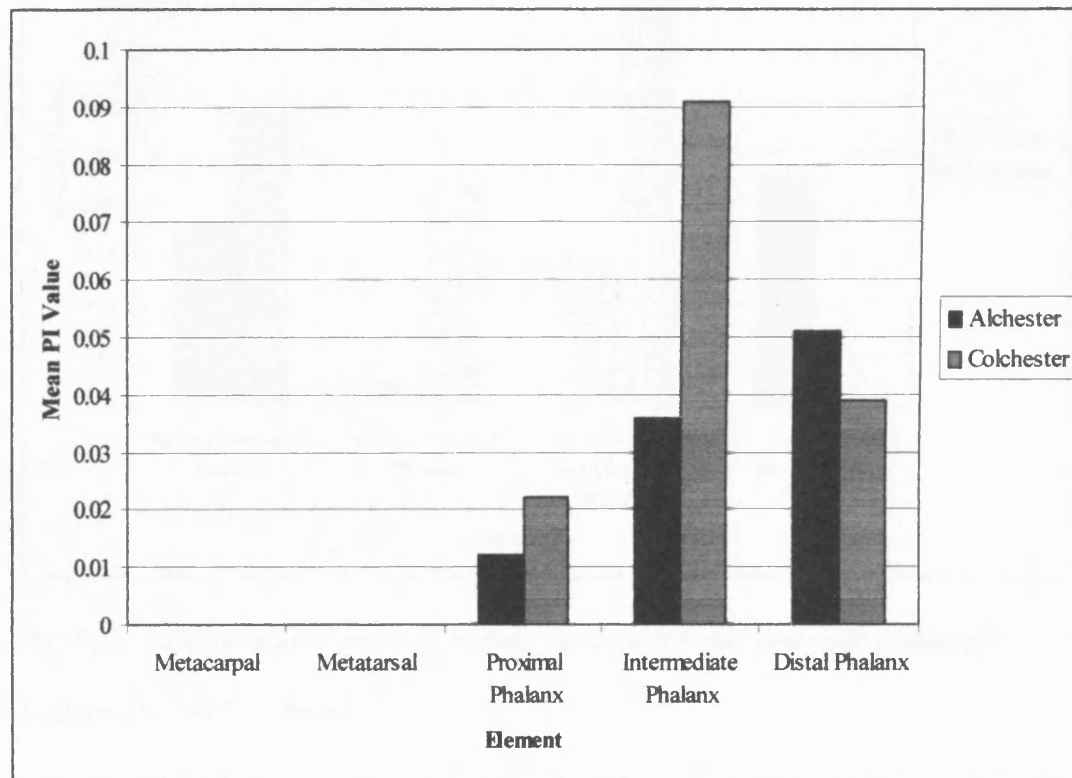


Fig. 6.12: Comparison of mean PI values by skeletal element at Alchester and Colchester

The average PI value was calculated for each skeletal element and these results are displayed in figure 6.12. It can be seen that the distal phalanx exhibited the highest average PI value in the Alchester assemblage, whilst in the Colchester assemblage the average PI value for the intermediate phalanx is significantly higher than any that for any other element. Neither site showed any pathological alteration in the metapodials using this methodology.

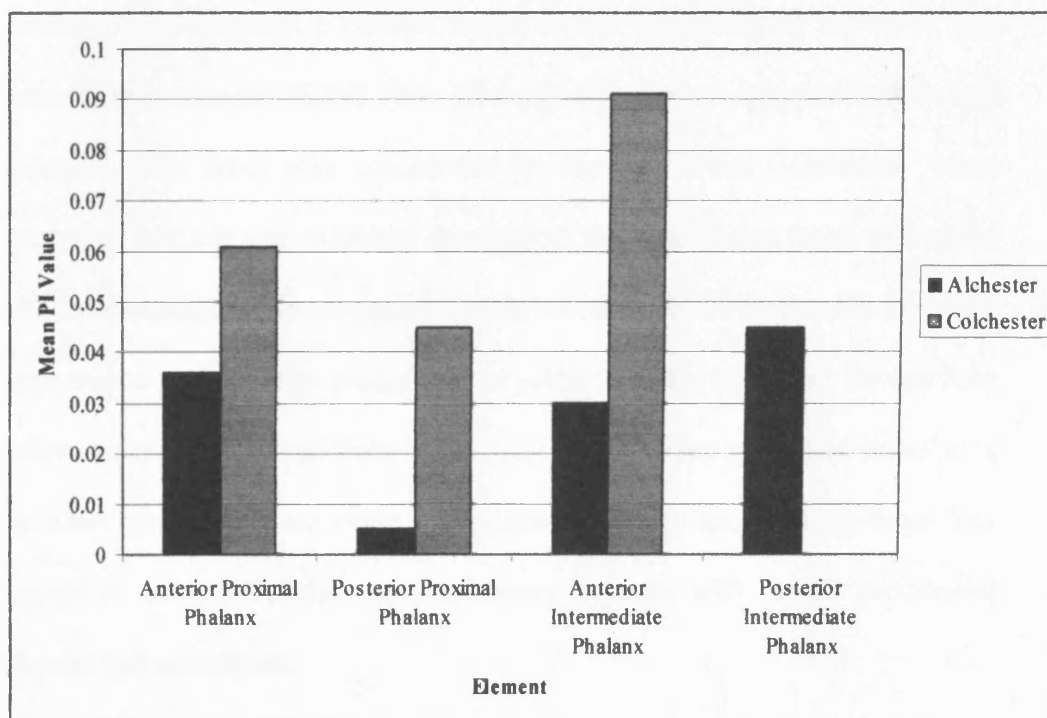


Fig. 6.13: Comparison of mean PI values for anterior and posterior phalanges at Alchester and Colchester

Differentiation between anterior and posterior elements for the proximal and intermediate phalanges demonstrated that the mean PI value was high for the anterior elements than the posterior elements at Colchester. However, a clear distribution pattern was less evident at Alchester (figure 6.13). Distal phalanges

were not included due to the difficulty in discriminating between anterior and posterior (Dottrens, 1946).

6.9 Oral pathology

Only two examples of oral pathology were found in the Alchester assemblage and one in the Colchester assemblage. Both of the Alchester cases were recorded on caprine teeth. The first, from context 39.04 (late 2nd – mid 3rd century AD), exhibited a carious lesion on the labial side of the tooth. The second, from context 41.195 (late 1st – mid 2nd century AD), exhibited slight calculus. This latter was comparable to the case from Colchester, where moderate calculus was exhibited around both the lingual and labial side of the two teeth represented in the cattle (*Bos taurus*) mandible. The alveolar bone also appeared to be unusually porous with possible alveolar recession. Research by other workers (Baker and Britt, 1984: 412) suggests that such mild deposits of calculus have little or no effect on the animal during life, although there does appear to be a correlation between heavy deposits with severe periodontal disease and emaciation.

6.10 Summary of results

- Pathological change was more common at Alchester than Colchester.
- Domestic animals demonstrate more pathological alteration than wild animals in both assemblages.
- Periostosis was the most common pathology in the Alchester assemblage.
- Articular depressions and grooves were the most common pathology in the Colchester assemblage.

- Osteophytosis was the second most prevalent condition in both assemblages.
- The prevalence of oral pathology from both sites was very low, and those conditions that were present were relatively minor.
- The mean PI values for the Alchester assemblage of 0.028 and for the Colchester assemblage of 0.046 are significantly lower than previously published data (de Cupere *et al.*, 2000: 261).

6.11 Discussion

6.11.1 Introduction

Whilst it is true that there are isolated instances of certain pathologies, *e.g.* the single example of eburnation from Colchester or the individual example of broadening of the articular surface from Alchester, from which it is not possible to reveal anything meaningful, it is nonetheless apparent that the results from the preceding analysis reveal some discernible trends. It is these that will be now be the subjects of further discussion, and which will form the basis of the interpretation of the two sites.

6.11.2 The economic significance of cattle

The greater proportion of pathological alteration in cattle in comparison to other species, as previously demonstrated in figure 6.3, made a closer examination of the significance of that species at the two sites worthwhile. In particular, in light of recent research into the use of cattle as draught animals (section 4.3.2), it seemed appropriate to discuss the economic significance of that species at Alchester and Colchester.

At both sites the majority of pathological alterations affected the lower limb bones – particularly the metapodials and phalanges. This may in part be a function of taphonomy since the elements associated with locomotion undergo more stresses than other elements and are thus composed of denser bone (Shaffer and Baker, 1997: 259), which might, therefore, bias analyses. However, the nature of the pathological alteration was not the same at both sites.

Osteophytosis was the second most prevalent condition overall in both assemblages. However, in cattle specifically, osteophytosis and eburnation, both often associated with degenerative joint disease, were noted at Alchester, but not Colchester. Deformation of these types has been linked (Bartosiewicz *et al.*, 1997; de Cupere *et al.*, 2000; Fabiš, 2005; Higham *et al.*, 1981; Johannsen, 2005) to the use of cattle for traction. This variation may thus reflect differences in the supply of animals to the two sites.

This is supported by the results from those bones recorded using the methodology devised by Bartosiewicz *et al.* (1997). When compared with the results of other studies discussed in section 4.2.1, we can see that the mean PI values for the Alchester assemblage of 0.028 and for the Colchester assemblage of 0.046 are significantly lower than the sites studied by de Cupere *et al.* (2000: 261). This suggests that these animals were generally subject to less strenuous activity during their lifetimes than was the case for those from the other assemblages studied using this system so far. What is interesting, however, is that the Colchester value is higher than that for Alchester given that it is only at Alchester that conditions such as osteophytosis and eburnation are noted in

cattle. This suggests that the PI value for Colchester reflects different forms of deformation in the cattle metapodials and phalanges from that site.

One factor that could determine the severity of deformation in the limbs is the landscape that the cattle inhabited. The physiography of the region around Alchester is dominated by clay lowland, lying mostly at less than 80m above OD (Ordnance Datum). This is divided into two north-eastward-trending vales separated by a range of hills capped by the limestones and sands of the Corallian, Portland, Purbeck and Whitchurch Sand formations, which cross diagonally from near Oxford to Aylesbury (British Geological Survey, 1995: 1-2). Further to the east, around Colchester, Quaternary deposits are more commonplace, particularly Pre-Anglian fluvial deposits (British Geological Survey, 1996: Fig. 29), whilst the central part of the London Basin is infilled with Palaeogene deposits, dominated by sand and mudstone, the London Clay Formation being the thickest and most widespread of these (British Geological Survey, 1996: 3-4). Even today, this district is largely agricultural (British Geological Survey, 1995: Preface), and it does not seem unreasonable to suppose that these lowlands were also exploited in this manner during earlier periods. If so, such terrain would presumably put less stress upon the limbs of an individual animal than would be seen at the other study sites, such as that of Sagalassos on the rocky hill slope of the western Taurus range, or Liberchies, Namur and Torgny, where the topography is also generally hilly (section 4.2.1). It is possible, therefore, that this may contribute in some way to the observed differences at Alchester and Colchester.

Nutritional deficiency has been implicated as a factor in other large mammals such as moose (Peterson, 1988). The 'early nutrition hypothesis' suggests that subtle developmental abnormalities in cartilage due to under-nutrition subsequently results in a higher frequency of degenerative lesions in later life (Peterson, 1988: 465). Poor nutrition can also result in a greater susceptibility to infection, something seen at Alchester but not Colchester. The fact that the PI value at Colchester was higher than that at Alchester would seem to contradict this hypothesis. If poor nutrition were a factor, the greater susceptibility it provided to other conditions such as infection would lead to the expectation that the prevalence of those would also be high as well as the prevalence of degenerative joint disease (as indicated by the PI value). However, this does not appear to be the case at these sites.

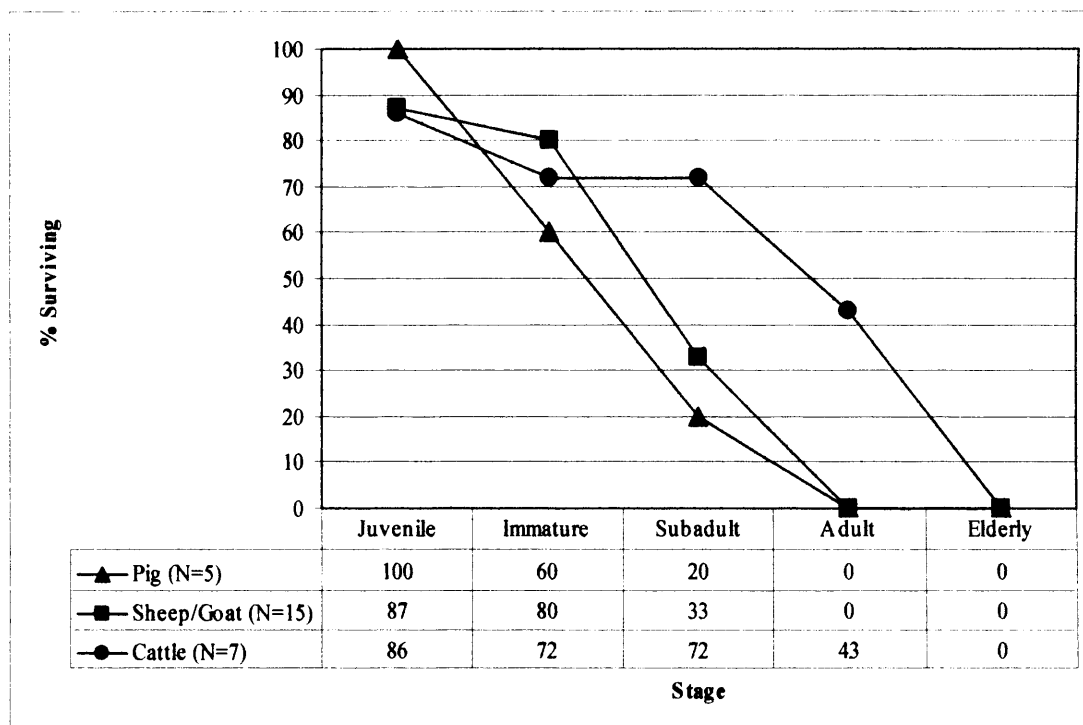


Fig. 6.14: Mortality profiles of main domestic species at Alchester

Age can also be an important factor: degenerative change occurs less frequently amongst younger individuals (Armour-Chelu and Clutton-Brock, 1985: 300). In order to explore the link between lower limb pathology in cattle and age, the mortality profiles of the three main domestic species (cattle, sheep/goat and pig) based upon tooth eruption and wear were examined for the two sites. The stages were based upon those defined by O'Connor (2003: Table 31). The total number of mandibles recorded from Alchester (figure 6.14) was too low to draw any definitive conclusions. However, five cattle mandibles, five sheep/goat mandibles and one pig mandible could definitely be said to have belonged to adult or elderly animals whose third molar showed evidence of wear. There was a greater frequency of adult or elderly cattle mandibles than there were mandibles belonging to younger individuals. This is in contrast to pig and sheep/goat where the majority were sub-adult or younger.

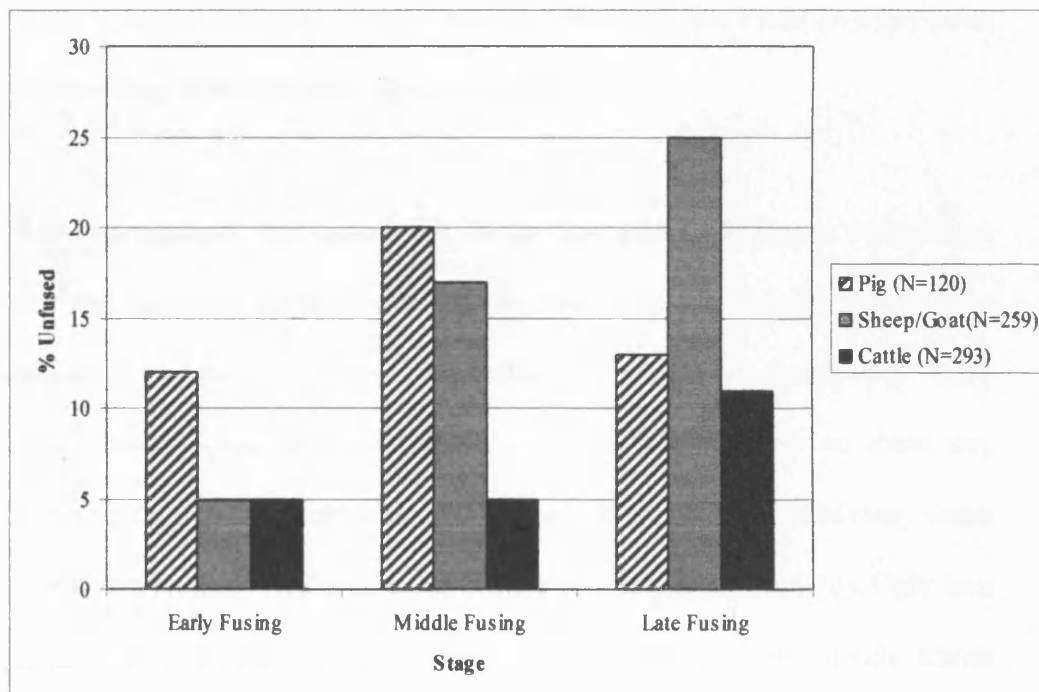


Fig. 6.15: Frequency of unfused elements by main domestic species at Alchester

Since the low numbers of recordable mandibles had almost certainly biased the results, mortality profiles were also constructed using post-cranial fusion data (figure 6.15). The stages were based upon those set out in Reitz and Wing (1999: Table 3.5). This demonstrates that the frequency of unfused skeletal elements was lower for cattle than for either pig or sheep/goat. Only 11% of the total number of elements identified as belonging to this species were still unfused by the late-fusing stage. This would indicate that the majority was above 42 months (3.5 years) of age (Reitz and Wing, 1999: Table 3.5) when they were slaughtered. In contrast, 25% of the total number of elements identified as belonging to caprines remained unfused by the same stage. This would indicate that these individuals were below 36 months (3 years) of age (Reitz and Wing, 1999: Table 3.5) when they were slaughtered. This supports the suggestion that more immature pig and sheep/goat were represented in the Alchester assemblage than immature cattle. The cattle at Alchester would appear to be predominantly mature animals, something that could be a key point in unravelling their economic significance.

The same approach was undertaken on the Cups Hotel, Colchester assemblage with the intention of both determining the economic significance at that individual site, and also of permitting comparison with the Alchester data. Once again, the total number of mandibles recorded was too low to draw any definitive conclusions, especially for cattle and sheep/goat. However, some patterns are revealed by the mortality profile of this site (figure 6.16). Only four pig mandibles could definitely be said to have belonged to adult animals, whose third molar showed evidence of wear. No adult sheep/goat or cattle were

recorded. This would suggest that the majority of all three domestic species at this site were sub-adult or younger.

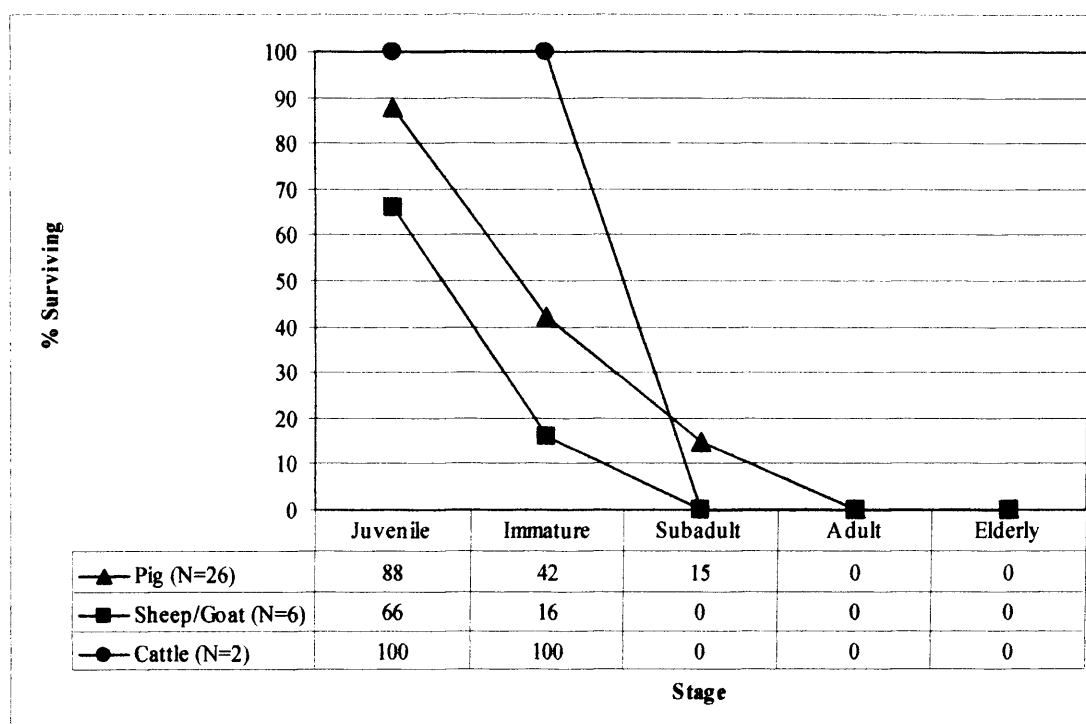


Fig. 6.16: Mortality profiles of main domestic species at Colchester

However, it is only reasonable to note that the low numbers of recordable mandibles may well bias the results, particularly for cattle and sheep/goat. Therefore, the mortality profile based on tooth eruption and wear was compared to the frequency of unfused post-cranial skeletal elements (figure 6.17). This demonstrates that, as at Alchester, the frequency of unfused skeletal elements was lower for cattle than for either pig or sheep/goat. Only 2.5% of the total number of elements identified as belonging to this species at Colchester were still unfused by the late-fusing stage. This would indicate that the majority was above 42 months (3.5 years) of age (Reitz and Wing, 1999: Table 3.5) when they were slaughtered. This would suggest that a greater number of mature animals are present within the Colchester assemblage than is indicated by the

tooth eruption and wear data. This would appear to be particularly the case with cattle.

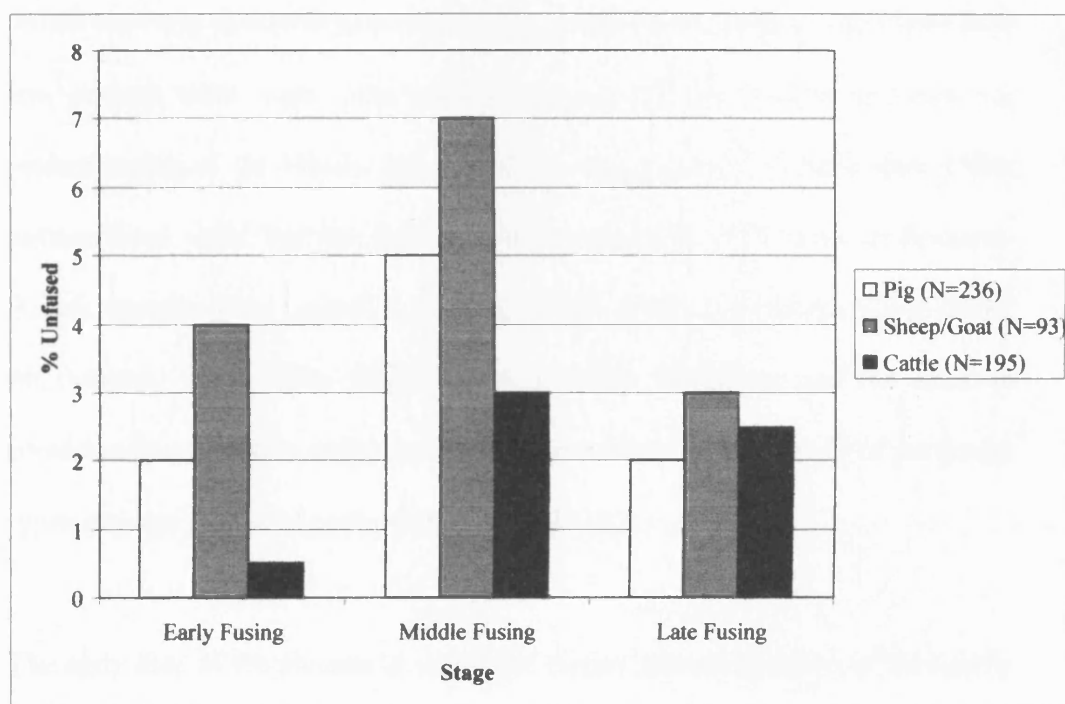


Fig. 6.17: Frequency of unfused elements by main domestic species at Colchester

Whilst it is true that immature animals are present at both sites, it would appear that in both instances the majority of individuals were adult at the time of their death. Few animals had been killed in the earliest stages of life, although the proportion of younger animals killed off was greater at Alchester than Colchester. This was interesting in view of the lower rate of pathology present among the cattle at Alchester and Colchester given that conditions such as degenerative joint disease is linked to age. However, post-cranial fusion data does not have the resolution to determine whether the cattle were slaughtered soon after they had reached their maximum size or kept for many years beyond.

The PI evidence may also reflect the lifestyle of the individual animals present within the Alchester and Colchester populations. The use of cattle for traction, which has been shown to exacerbate degenerative joint disease, may have been low at both these sites. This information can also be used to enhance our understanding of the way in which animals were supplied to these sites. Other authors have noted that the highest concentrations of adult cattle in Romano-British samples have appeared on military and urban settlements (Cool, 2006: 80; Maltby, 1981: 182). Organisation of cattle marketing and the need to provision these centres with meat may have resulted in the supply of particular types and age groups of cattle (Maltby, 1981: 182).

The early date of the fortress at Alchester means that examination of the nature of meat supply has the potential to shed light on the nature of relations with indigenous communities. Unable to supply its own meat, the garrison would have had to rely on local supply, but what was the nature of that supply? Did the Romans forcibly requisition, was it taxed, or was a system of market exchange in operation at the very earliest conquest period? (Thomas, in press)

Evidence from other sites suggests that the earliest Roman settlements were established rapidly following the Claudian invasion in AD 43, and one of the first tasks of the invading force must have been to ensure they had adequate food supplies (Grant, 2004: 372). According to Tacitus, every Roman fort in Britain, when Agricola was governor in AD78-84, was provided with sufficient supplies to last for a year (Davies, 1971: 122-123). Calculations show that each Roman soldier would eat approximately one-third of a ton of corn each year

(Davies, 1971: 123). The establishment of a new, demanding and powerful group of consumers within local farming communities therefore had the potential to bring about considerable disruption (Grant, 2004: 372). However, if the army intended to remain for any length of time, they would need to ensure that local animal husbandry and agriculture were not fatally undermined (Grant, 2004: 372).

In peacetime the army used various sources from which to obtain its food supplies. One major source was the civilians of the province; this could take the form of requisitions or compulsory purchase at a fixed price (Davies, 1971: 123). Another important source was food produced on military land (*territorium* or *prata*), which extended for a considerable distance around each fort; this was sometimes grown by the military themselves, at other times by civilians to whom the land was leased (Davies, 1971: 123). Contracts for supplies in bulk were also used (Davies, 1971: 123).

Assemblages from early fortresses included higher proportions of cattle than were common at contemporary native settlements (Cool, 2006: 80; Grant, 2004: 372; King, 1999: 179-180), but the beef consumed was mainly from old or even elderly animals (Grant, 2004: 372). Sites such as the Flavio-Trajanic (c. AD 75 – c. AD 120) auxiliary fort of Leucarum at Loughor in West Wales have shown that cereals and vegetable products provided the basis of the army diet, but cereal cultivation required cattle for ploughing and other agricultural tasks (Grant, 2004: 372). Thus, full-grown cattle may have been preferentially chosen

for slaughter, both to ensure herds remained viable and to permit animals to be trained for the plough (Grant, 2004: 372).

The mortality profile of the cattle from Alchester is consistent with the pattern established at other early fortress sites. However, the low PI values and minimal evidence for pathological deformation of the metapodials challenges the assumption that such activity was a major role for local cattle herds and the reason for their mature age of slaughter. Whilst the evidence does not entirely rule out their use for traction in this area, such activity, if it occurred, would have had to have been so infrequent that it caused little or no associated pathological change. It would seem more likely that the mortality profile reflects the demand for hides to be manufactured into leather, something that the military required in significant quantities (Grant, 2004: 372) and which others (*e.g.* Applebaum, 1958: 74-75) have suggested was, along with beef, the main economic use for cattle during this period. Alternatively, the Roman military may have been selective, demanding the supply of cattle not crippled by activity such as traction from the local population.

Cattle were also the most important species in respect to their contribution to the Romano-British diet at urban centres (Grant, 2004: 377). Deposits from towns such as Chichester, Winchester, Silchester, Leicester and Lincoln point to the development of centralised processing and distribution (Grant, 2004: 377). The growth of large urban centres made the rearing of cattle for beef an increasingly viable strategy (Grant, 2004: 377). Concentrated human populations could share the meat and offal provided by each of these large animals. However, large-

scale exploitation required an efficient system for carcass processing, meat distribution and preservation (Grant, 2004: 377). Networks that had been established by the military as a means of provisioning early settlements, such as that at Alchester, would doubtless have been subsequently exploited to supply growing urban populations (Grant, 2004: 377). Evidence for this can be seen in the mortality profiles of many urban deposits that exhibit narrow age ranges which reflect a continuation of the culling practices used by the military (Grant, 2004: 377).

An increased investment in cattle could also reflect an expansion of cereal cultivation and the increased use of cattle as draught animals (Grant, 2004: 377). Dumps of primary butchery waste from urban sites such as Dorchester, Cirencester and Lincoln demonstrate that the majority of the cattle being slaughtered were mature, *i.e.* older than four years, suggesting that they may have had a working life prior to being eaten (Cool, 2006: 85). This would be comparable with the data from the extramural settlement at Alchester (Powell and Clark, 2001: 401-402), which observed a high proportion of old animals in the assemblage. In addition, pathological alteration of cattle phalanges, including articular extension and lesions in the articular surface, were linked to sustained high levels of stress upon the animals (Powell and Clark, 2001: 413-414). However, whilst the PI value for Colchester was higher than that of Alchester – indicating greater pathological alteration at the urban site – the value was still very low in comparison to previously published comparative data (de Cupere *et al.*, 2000: 261). This may be due to inter-site variation and reflect aforementioned differences in topography or age, Sagalassos in particular is

noted as having an “old slaughter age” (de Cupere *et al.*, 2000: 259). Nonetheless, it was not possible to see the increased use of cattle for traction in the data set.

The results from Cups Hotel were comparable to other Colchester assemblages of the Roman period. At those sites the cattle were also mainly mature. However, approximately 1% exhibited lesions along the medial edge of the acetabulum, which were considered to stem from over-rotation of the hip during traction (Luff and Brothwell, 1993: 105). This was not seen on the cattle at Cups Hotel. This suggests that at least some cattle were used for traction in the Colchester area, even if these animals were not found at the Cups Hotel site. Such inter-site variation may reflect variations in supply and demand in different parts of the town.

6.11.3 Infection and inflammation

Periostosis was the most common pathology in the Alchester assemblage. In contrast, in the Colchester assemblage, this was only the third most prevalent pathological condition. In particular, the prevalence of periostosis was significantly higher in cattle at Alchester than at Colchester. This would suggest that the prevalence of infection or inflammation was also higher at Alchester than at Colchester, something that may relate to variation in herd management, the quality of the animals or environmental conditions.

Increased susceptibility to disease can be a consequence of poor nutrition, as can increased intervals between offspring and an increase in the time taken to reach maturity (Davies, 2005: 85). It is therefore possible that the higher rate of periostosis at Alchester may reflect a higher rate of nutritional deficiency. Such under-nutrition may reflect the degree of access to grazing or surplus feed, as well as the prevalence of parasites (O'Connor, 2000: 101-102). The presence of parasites in the alimentary canal reduces the efficiency with which food is digested and interferes with the absorption of the products of digestion (O'Connor, 2000: 102).

Other potential causes of increased rates of infection and inflammation include trauma and environmental conditions. An examination of the evidence from historic period sites in Ireland, for example, demonstrated that infection was most common on lower leg bones, suggesting that these elements were most susceptible to infectious diseases including foot rot (Murphy, 2005: 16). Such infections have been linked by other authors to prolonged stalling or keeping animals on soft and muddy pastures (Baker and Brothwell, 1980: 73) and this could explain the periosteal lesions found on some lower limb bones found at Alchester and Colchester, particularly those on the cattle and caprine bones which were found at Alchester as these two species are frequently stalled or kept in fields.

Plaques of woven periosteal bone demonstrating inflammation might also relate to trauma, infection or both (Murphy, 2005: 16). When found on relatively exposed bones that are not protected by large amounts of muscle or fat, *e.g.* the

tibia, such trauma may be entirely accidental and reflect inadvertent contact with stalls or other animals, for example. It has been suggested that such reactions of the periosteal bone when found on the inner surfaces of ribs may be an indicator of respiratory conditions such as tuberculosis (section 4.4), and this could potentially explain the periosteal lesions found on the visceral surfaces of ribs at Alchester. As has been noted earlier in this volume, greater investigation into conditions such as tuberculosis is required by archaeozoologists, a point emphasised by human palaeopathologists (Roberts and Buikstra, 2003: 270-271). Sites where this could be positively identified would be of great value to researchers examining questions such as domestication or stocking conditions. However, whilst DNA analysis would be required for confirmation in the absence of complete skeletons, it seems unlikely that tuberculosis is the 'culprit' in this instance as no tuberculous lesions were seen on other skeletal elements. That does not, however, rule out other pleural infections such as brucellosis *etc.* (Bendrey, 2004).

6.11.4 The social status of dogs

The status of dogs in Roman Britain may have been low if some of the pathological conditions exhibited (*e.g.* fractures) are a genuine reflection of neglect or abuse. Comparisons with other sites suggest that such injuries may not have been uncommon. The presence of a number of healed injuries on dog bones from the Iron Age and Romano-British settlement at Dragonby led to the suggestion that these animals were not particularly well treated (May, 1996: 161). Some may have been used for hunting and herding, and some could have been pets; others may have been tolerated as scavengers around the settlement.

That the partial dog skeleton from Alchester (late 2nd – mid 3rd century AD) was found in the upper fill of a ditch is perhaps more suggestive of functional disposal than reverential burial (Thomas, 2005). Analysis of the ribs and vertebrae from the medieval sites of Haithabu, Starigard and Schleswig in Northern Germany support a similar interpretation. It is acknowledged, however, that other causes, such as fights between animals, accidental falls or stress fractures due to cardiopulmonary, neuromuscular or metabolic disease do also have to be taken into consideration (Teegan, 2005b: 36-37), although there is no supporting evidence for these at Alchester.

It is possible that the osteophytosis recorded on the dog (*Canis familiaris*) skeleton from context 41.161 (late 2nd – mid 3rd century AD) at Alchester is due to vertebral spondylosis. As the incidence of this condition has also been shown to increase with age in dogs (Morgan, 1967: 53), it is possible that the Alchester specimen represents an aged individual. A dog from medieval Perth (Smith, 1998: 870, 879-880) was hypothesised to be an elderly cosseted pet or lapdog on the basis of its small size and the evidence of chronic osteoarthritis with localised osteoporosis. This suggested an animal that had been cared for despite its infirmities.

Documentary sources indicate that the Romans kept dogs, not just as pets, but also for sporting (*Canes Venatici*), guarding (*Canes Villatici*) and shepherding (*Canes Pastorales*) purposes (Zedda *et al.*, 2006: 319). Roman towns in Britain regularly yield the bones of both cats and dogs, and the keeping of both species as pets is noted in contemporary documents (O'Connor, 1992: 109). Vegetius,

following the example of earlier Greek writers such as Aeneas Tacticus, recommends their employment as guards, for example (Forster, 1941: 116), as does Columella (*De Re Rustica*, VII: XII), who says:

“What servant is more attached to his master than is a dog? What companion more faithful? What guardian more incorruptible? What more wakeful nightwatchman can be found? Lastly, what more steadfast avenger or defender?”

It does not seem unreasonable, therefore, to suggest that the animals may have had a social role, which might have encouraged humans to look after them beyond their natural working lifespan. However, this social role may also have made them more susceptible to traumatic injury through human contact or work-related activity.

6.11.5 Nutritional health

The numbers of examples of oral pathology from both sites were very low, and those conditions that were present were relatively minor and probably had little or no effect on the animal during life. The absence of linear enamel hypoplasia indicated that the nutritional health of animals during the period of dental development was relatively balanced. This is particularly interesting when compared to the results of previous studies of other Roman sites in Colchester which found approximately 50% of the pig second molars showed evidence of enamel hypoplasia (Luff and Brothwell, 1993: 103). At these sites, it was

apparent that most of the defects were concentrated in bands around the top half of the crown surface in the second mandibular molar (Luff and Brothwell, 1993: 103). This suggested that the lesions had formed two to four months after birth, leading to the proposal that there were two farrowings at Colchester; the piglets of the second litter suffering stress after weaning that was not exhibited by those of the first litter (Luff and Brothwell, 1993: 103).

6.12 Conclusion

The case studies illustrated in this chapter demonstrate the potential of a systematic approach to recording animal palaeopathology. Both of these sites were typical assemblages such as any archaeozoologist might investigate. The prevalence of pathologies within the assemblages was not unusually high. Nonetheless, their study has provided fresh insights into the human-animal relationships at two sites of interest to Roman archaeology, as well as demonstrated the value of applying the methodology to several modest-sized bone assemblages in order to gather cumulative data. The calculation of the pathological index alone produced some very interesting conclusions that contribute to our understanding of meat supply to these sites. There is little evidence for the use of cattle as draught animals at either site, suggesting that they were primarily intended for consumption or leather manufacture. However, it is also possible that the assemblage represents animals that were deliberately selected by the Romans because they did not exhibit pathological change due to traction or that draught usage was too light at the sites to cause osteological damage.

In general it can be seen the animals found at both Alchester and Colchester were of reasonable skeletal health, although some may have been subject to infection, which resulted in the periosteal reaction seen on certain elements. Several of those conditions that were found were, however, so minor that they would probably not have impacted significantly upon their quality of life.

In many cases, the absence of certain pathologies was as interesting as their presence. The apparent good skeletal health of most animals at these sites, as well as the lack of evidence for nutritional disorders such as linear enamel hypoplasia, contributes to our knowledge of the general health and well being of animals at this period in British history. It would appear that times of stress such as birth and weaning did not cause significant deficiencies within the population, suggesting perhaps not only that their health was good, but also that a certain amount of human care and attention was taking place to ensure their diet was adequate.

In the next chapter those conclusions that can be drawn from this case study will be examined and discussed in light of the success or otherwise of this project and their potential for future research.

Chapter Seven: Conclusion

7.1 Introduction

Animal palaeopathology is a significant topic in archaeology. Because of disease's all-pervading nature, the study of it can contribute towards a broad range of questions, not only in archaeology, but also in many other disciplines (section 1.2), the answers to which can provide helpful insights into human-animal interactions, as well as the environment in which both are living (Vann and Thomas, 2006: 2.0). However, despite this significance, the potential of animal palaeopathological research had not been fully realised; something which can be attributed, at least in part, to the inconsistent manner in which incidences of palaeopathology have been collected, recorded and interpreted in the past. This fact, together with the typically low incidence of specimens per site, has precluded any detailed studies of regional or temporal trends, and resulted instead in a focus on individual specimens that often display extreme deformity. The aim of this project was to unlock the previously untapped potential of animal palaeopathology to resolve archaeological questions and enable the past impact of animal disease to be better understood. This was to be achieved by designing, developing and implementing a system by which all types of animal palaeopathology could be simply and consistently recorded.

Three primary objectives were defined at the beginning of this thesis:

1. Design and develop a generic methodology to enable the consistent recognition, recording and description of animal palaeopathological data;

2. Implement the methodology using a database-driven system;
3. Apply and critically evaluate the methodology, using assemblages from the Roman legionary fort at Alchester and the Roman town of Colchester, to demonstrate the benefits of adopting a systematic approach to recording animal palaeopathology.

This chapter will reflect upon whether or not these objectives were met and the success of the methodological system devised during the period of this research. Further conclusions gained during this time will also be drawn, and future applications and research agendas will be considered.

7.2 Review of objectives

The first objective, to design and develop a generic methodology to enable the consistent recognition, recording and description of animal palaeopathological data, was successfully met. The protocol that resulted was independently tested by both commercial and university-based archaeozoologists, and was proven to be simple and straight-forward to use, making it accessible to a wide audience, with terminology that is defined to ensure it can be understood by all researchers, regardless of academic background or nationality. It encourages consistency between researchers, reduces inter-observer variability, and permits the calculation of prevalence when used in conjunction with standard recording methodologies.

The second objective, to implement the methodology using a database-driven system, was achieved. The methodology has been implemented using Access

2000. This software is widely available and can be integrated with other programs such as Excel, Word, SPSS, Quattro Pro *etc.* It is thus compatible with the aim of making the finished methodology available to a broad research body.

The third objective, which sought to apply and critically evaluate the methodology and to demonstrate the benefits of adopting a systematic approach to recording animal palaeopathology using assemblages from the Roman legionary fort at Alchester and the Roman town of Colchester, was also accomplished. Both of these sites were in many ways typical of commercial faunal assemblages: they were small in size and the prevalence of pathologies within the assemblages was low. Nonetheless, their study provided fresh insights into the human-animal relationships at two sites of interest to Roman archaeologists. They also demonstrated the value of multiple applications of the methodology to modest-sized bone assemblages in order to provide cumulative information regarding issues such as the prevalence of pathologies.

7.3 Potential improvements to the methodology

There are areas within the protocol that could be improved with further work. At present, the system is a stand-alone database, which requires users to employ it in conjunction with existing recording systems. To calculate prevalence in particular, it is necessary to record pathological data in conjunction with non-pathological data. To increase user-friendliness, future research could turn the current independent database into a 'plug-in' for pre-existing systems, *e.g.* the

York System (Harland *et al.*, 2003). This would reduce the number of computer programs required to be open at once whilst recording was in progress. Alternatively, the current protocol could be expanded to include additional fields so that non-pathological archaeozoological material could be recorded alongside pathological data. This would, however, require decisions to be made regarding what should and should not be recorded for archaeozoological remains. Such decisions would contribute to debates concerning the standardisation of recording within archaeozoology, something which has been a hotly contested topic in recent years and is not popular with all researchers in the field. As noted earlier in this thesis, recording should not be a result in itself and, as other authors (O'Connor, 2003: 125) have rightly stated, it should be driven by the needs of the research in hand. An expanded generic methodology would undoubtedly reduce the number of computer programs required to be in operation at one time, something which researchers might well appreciate, but it would only be of value if the methodology permitted the answering of questions that individual researchers were interested in.

7.4 Future research agendas

The study of palaeopathology is not a means to an end. Material should not be analysed purely to produce a report. If it is to contribute to archaeology as a whole then it is necessary to frame research questions, raise hypotheses and consider all of these whilst collecting data (Roberts and Cox, 2003: 383). Much of the archaeology in Britain in recent years has been conducted under the auspices of PPG16 (1990) and contract archaeology, and consequently palaeopathology and osteoarchaeology is generally undertaken by people

working within tight budgets and short time schedules. This has an inevitable effect on post-excavation analysis. Many reports do not contain basic site and preservation data that would facilitate calculation of meaningful prevalence rates, and descriptions are often not sufficient to support diagnoses, something that compromises later comparisons between sites (Roberts and Cox, 2003: 384).

Through the adoption of this methodology, such problems can be avoided and any future research will be founded on a set of consistently recorded data. This addresses some of the issues raised by earlier authors concerning inter-user variability and the typically small sample sizes that palaeopathologists work with by introducing a degree of comparability to description and terminology. This is of benefit to those wishing to undertake research that involves comparisons between sites, both at a local, regional and national level. As noted at the beginning of this volume, detailed studies of regional or temporal trends have been effectively precluded to date due to a lack of consistency and comparability between workers. The methodology laid out in this thesis improves this situation significantly. However, it will only contribute towards future studies of epidemiological trends within animal palaeopathology and their effect on human-animal interactions if the protocol is used. To this end, the recording protocol will be published in a peer-reviewed journal, following up the co-authored paper published in *Internet Archaeology* (Vann and Thomas, 2006), to not only promote this methodology to archaeozoologists, but also to the archaeologists that commission bone reports and consume their results. Whilst it is true that this recording protocol represents an additional

methodology to be employed during the assessment and analysis of faunal assemblages, the demonstrated and potential benefits (chapter 5), far outweigh any additional cost or time that may be incurred. Indeed, the prevalence of pathological lesions within an assemblage is typically low; thus, the majority of bones would not require recording via this methodology. Even where sites present unusually high proportions of pathological alteration, exploring the cause of this phenomenon should be amongst the key research questions and therefore of direct interest to all archaeologists. In addition, this methodology has been developed with a user-friendly interface, which in personal experience is simple to use and enables rapid recording of all types of pathological lesions.

Meanwhile, the sets of consistently recorded data, made possible by the recording protocol, will contribute to future research agendas. Gathering data in such a cumulative fashion permits even small faunal assemblages to contribute towards reviews of regional and temporal trends. Analysis of palaeopathological trends within these data sets is vital for our understanding of changing human-animal interactions in the past. It is only through these that animal palaeopathologists will be able to contribute to wider questions, such as those discussed in earlier chapters, that are of interest to archaeologists as well as researchers in other disciplines.

In summary, systematic recording will:

- Enable the distribution of pathologies by species, skeletal element, age, sex and other variables to reveal epidemiological information;

- Enable the significance of particular lesions and non-metric traits (section 2.4.2) to be determined;
- Reveal trends that can be linked with other evidence to elucidate their significance *e.g.* the increased pathological deformations observed in cattle metapodia and phalanges from Dudley Castle, West Midlands, could be linked to an increase in cattle size that occurred during the 14th century, by exclusion of other contributing factors (*e.g.* age and sex) (Thomas, 2007b);
- Enable comparisons to be made between sites that will permit animal palaeopathologists to identify those areas where, at present, information is sparse and where further research is required to increase our understanding.

As demonstrated in chapter six, the systematic analysis of many forms of pathology can provide fresh insights into the human-animal relationships even at sites where the relative prevalence rates are low. For example, returning to some of the issues raised both there and in chapter one, the investigation of degenerative joint disease in cattle contributed towards the discussion about agricultural practices. The calculation of the pathological index alone produced some very interesting conclusions that contribute to our understanding of meat supply to Alchester and Colchester. There is little evidence for the use of cattle as draught animals at either site, suggesting that they were primarily intended for consumption or leather manufacture. However, comparison of a larger range of Roman period sites is necessary in order to see how characteristic these sites were in relation to others of the period.

The sex of the cattle being employed as draught animals could also be of potential interest. As noted in chapter four, the cattle at Tiel-Passewaaij challenge the assumption that draught cattle must always be male oxen or castrates. This use of cows, rather than bulls, for draught purposes is also noted by Armour-Chelu and Clutton-Brock (1985) in their examination of the evidence from Etton, Cambridgeshire, and by Isaakidou (2006) in the analysis of the cattle from Neolithic Knossos. As with the evidence from Tiel-Passewaaij, the diagnosis of traction-related change was based upon degeneration of the acetabulum that seemed far more advanced than was usual given the age of the animals at slaughter (Armour-Chelu and Clutton-Brock, 1985: 302). In addition, the association with female pelves argued against larger body size as a major cause of the observed pathologies (Isaakidou, 2006: 108).

The use of female bovines for draught power is well documented in developed and developing countries. Their use has often been out of need rather than choice. In many crop-livestock systems the preferred animal for draught is the ox. However, pressures such as those of increasing population numbers and diminishing land resources can erode the ability to sustain large herds. Under those circumstances, the use of cows allows the same animals to be used both for work and for milk production, reducing the need to maintain a large number of animals for different tasks (Pearson *et al.*, 1999: 5). This raises interesting questions about the nature of human society during periods when the use of female bovines is commonplace.

The systematic analysis of many forms of pathology during the case study (chapter six) also revealed clear differences in the prevalence of particular types of pathology, *e.g.* inflammation and infection, although it was not possible to conclusively establish the cause of the condition and many were so minor that they would probably not have impacted significantly upon their quality of life. As observed in chapter six, in many cases, the absence of certain pathologies was as interesting as their presence. The apparent good skeletal health of most animals at these sites, as well as the lack of evidence for nutritional disorders such as linear enamel hypoplasia, for example, suggests that seasonality and times of stress did not affect teeth at these sites. However, as noted above, it is not yet known how characteristic these sites were in relation to others of the same period. Hopefully, future applications of a systematic approach will provide further population-based studies with which the data from Alchester and Colchester can be compared. Such comparisons would not only provide further insight into animal husbandry in Roman Britain and elsewhere, but would also enable the significance of particular lesions to be assessed and thus stimulate more detailed research into those conditions which reveal interesting patterning.

Nor would such comparisons be limited to questions regarding domestic animals. As discussed in section 1.2, wild animals too can be investigated using palaeopathological data. Systematic analysis of data recorded using this protocol could contribute, amongst other things, towards investigations into hunting strategies and behaviour in both prehistoric and historic populations: were diseased animals hunted or avoided, for example, and did such attitudes change over time as lifestyles became more sedentary? What do injury patterns and

prevalence indicate about the terrain? What evidence is there for inter- and intra-species conflict? Consistently recorded data from appropriate sites could help to answer all of these questions.

7.5 Conclusion

In conclusion, it is considered that this recording protocol should be used by individuals involved with archaeozoological research. Data is only useful if collected in a manner that enables questions to be addressed. This first attempt may require some refining, but nonetheless it represents significant progress in the field as it is only with a sound methodological basis that the discipline can move forward. Hopefully, the same problems that have been aired regularly over the last thirty years (section 2.2) will not still be being heard in another thirty years time.

Appendix One: Glossary

- A -

Abscess: a collection of pus or other matter contained in a localised area of the body. Acute or chronic forms may occur.

Actinomycosis: An inflammatory disease of cattle, pigs, and sometimes humans, caused by micro-organisms of the genus *Actinomyces* and characterised by lumpy tumours of the mouth, neck, chest, and abdomen. Also called lumpy jaw.

Alveolar: Relating to the jaw section containing the tooth sockets, the alveolar ridge.

Alveolar recession: Reduction of the bone of the jaw section containing the tooth sockets, the alveolar ridge.

Ankylosing spondylitis: Also known as Marie-Strumpell's disease, this is a progressive inflammatory disease of unknown aetiology. Characterised by the fusion of the small joints of the vertebrae, the vertebral bodies begin to fuse from the lumbar vertebrae upwards, not only via the joints, but also through the ossification of the inter- and super-spinous ligaments.

Ankylosis: The stiffening or immobility of a joint resulting from disease, trauma, surgery, or bone fusion. The rigidity may be complete or partial and may be due to inflammation of the tendinous or muscular structures outside the joint or of the tissues of the joint itself. When inflammation has caused the joint-ends of the bones to be fused together the ankylosis is termed osseous or complete.

Anterior: The front surface of the body or a part thereof.

Apposition: The condition of being placed or fitted together.

Arthropathy: An abnormality of a joint.

Articular Depression: A smooth circular or ovoid pit located on the articular surface of a bone

Articular Extension: The extension or widening of the articular surface of a bone.

Articular Groove: A smooth linear feature located on the articular surface of a bone

Atrophy: The wasting away of living tissue, including bone.

- B -

Bevel: A surface having a sloped or slanting edge.

Bowed: Characterised by smooth, gradual curvature.

Bowing: Curvature of the bone shaft due to a pathological disorder or deficiency.

Brucellosis: Also known as undulant fever or Mediterranean fever, this is a zoonotic disease caused by the bacterium *Brucella*. *Brucella* usually infects animals, and humans can become infected by direct contact with infected animals or their milk.

Buccal: Pertaining to, adjacent to, or in the direction of the cheek.

- C -

Calculus: The calcified remains of dental plaque, one of the commonest types of ectopic concretions affecting teeth.

Callus: A mass of bone tissue, usually of woven bone, formed in response to a need to support the bone or joint, *e.g.* after a fracture.

Cancellous bone: Osseous tissue which consists of a network of rods, plates, or tubes (trabeculae), with the spaces between the trabeculae filled with marrow, characteristically located in the epiphyses of long bones.

Caries: Decay of bones or teeth resulting in the softening, discoloration and destruction of the original material.

Cartilage: A specialised connective tissue that forms tough, but flexible, parts of the vertebrate skeleton.

Cavity: A hollow area within a bone.

Cloaca: A cavity or sinus through which pus drains, such as in osteomyelitis.

Collagen: An important connective tissue protein *e.g.* in vertebrate tendon, the organic matrix of bone, and fish scales.

Compact bone: Dense, osseous tissue. Forms the cortex of all bones, and consists largely of concentric lamellar osteons and interstitial lamellae.

Coronal: Of, relating to, or having the direction of the coronal suture or of the plane dividing the body into front and back portions.

Cortex: The outer layer of bone that is harder and denser than the cancellous bone it encases.

Cyst: An abnormal sac in the body, filled with a fluid or semi-solid and enclosed in a membrane.

- D -

Dental attrition: Dental wear; the natural process of wearing down the occlusal surfaces of teeth by chewing abrasive foods.

Dental calculus: Tartar; a hard, stone-like concretion, varying in colour from creamy yellow to brown or black, that forms on the teeth through the calcification of dental plaque.

Dentine: A material that forms the bulk of the tooth and is similar in structure to bone. Yellowish in colour and composed of inorganic hydroxyapatite crystals and collagen. (See also enamel).

Dentition: A set of teeth.

Diaphysis: The middle section, or shaft, of a bone.

Displacement: Removal of a bone or segment of bone from its normal position.

Distal: The end of the bone furthest from the point of attachment or articulation, or the side of the tooth furthest from the midline of the jaw; opposite of proximal.

Dorsal: Towards the back or upper surface of the body; opposite of ventral.

- E -

Eburnation: Degeneration of bone into a hard, polished, ivory-like mass, such as occurs at articular surfaces of bones in osteoarthritis.

Ectopic: Out of place, as of an organ not in its proper position, or of a pregnancy occurring elsewhere than in the cavity of the uterus.

Enamel: Forms the occlusal cap on most teeth; hardest substance in vertebrate body, consisting almost entirely of calcium salts as apatite crystals.

Enamel hypoplasia: Defects in the teeth observed as lines, pits or grooves on the enamel surface, that form as a result of arrests in the growth process.

Endochondral ossification: One of two types of bone formation (ossification) and the process responsible for much of the bone growth in vertebrate skeletons, especially in long bones. As the name might suggest (*endo* - within, *chondro* - root for cartilage), endochondral ossification occurs by replacement of hyaline cartilage.

Endocrine: Relating to the endocrine glands, which secrete hormones directly into blood vessels.

Endoskeleton: An internal skeleton, *e.g.* the cartilage or bony skeleton of vertebrates.

Endosteum: Connective tissue which lines the bone marrow cavities as well as the trabeculae of spongy bone and the vascular canals of compact bone (see also periosteum).

Enthesophytes: Projections or spicules of bone at sites of tendinous or ligamentous attachment.

Epidemiology: The study of the incidence (or prevalence), distribution and determinants of disease in populations.

Epiphysis: The end segments of a bone.

Exoskeleton: An external skeleton, *e.g.* an arthropod cuticle.

Exostoses: Formations of new, abnormal, osseous tissue on the outside of the bone.

Expansion of diaphysis: An abnormal increase in the dimensions of the diaphysis.

Expansion of metaphysis: An abnormal increase in the dimensions of the metaphysis.

Extensor: A muscle that extends or straightens a limb or body part.

- F -

Fibrocartilage: Fibrocartilage (also called white cartilage) is a specialised type of cartilage found in areas requiring tough support or great tensile strength, such as between intervertebral disks, the pubic and other symphyses, and at sites connecting tendons or ligaments to bones.

Flexor: A muscle that when contracted acts to bend a joint or limb in the body.

Foramen: An aperture or perforation through a bone or a membranous structure.

Foot-and-mouth disease: A highly contagious and sometimes fatal viral disease of cattle and pigs. It can also infect deer, goats, sheep, and other animals with cloven hooves, as well as elephants, rats, and hedgehogs. Humans are affected only very rarely.

Fracture: Structural failure (breakage) of bone or cartilage.

Fusion: The unification of two or more bones into a single entity by the growth of new bone across a joint.

- H -

Haematoma: A swelling containing blood.

Haversian system: see Osteon.

Histology: The branch of biology that studies the microscopic structure of animal or plant tissues.

Hypermineralisation: An increase in mineralisation.

Hyperostosis: An increase in bone formation.

Hyperplasia: An increase in the number of cells as a result of cell proliferation; usually occurs in response to stress or increased activity.

Hypertrophic osteopathy: A pathological condition, which demonstrates an increase in bone density.

Hypoplasia: A decrease in the number of cells.

Hypsodont: Hypsodont dentition is characterised by high-crowned teeth, which provide lots of extra material for wear and tear. Some examples of animals with hypsodont dentition are cows and deer.

- I -

Increased Density: Bone density is the amount of bone tissue in a certain volume of bone. Increased density indicates that this level is higher than is normal for bones from that site, something usually indicated by the bone appearing heavier and/or thicker than normal.

Intra-membranous ossification: One of two types of bone formation and the process responsible for the development of flat bones, especially those found in the skull. Unlike endochondral ossification, cartilage is not involved or present in this process.

- K -

Kinesis: Movement.

Kyphosis: The forward curvature of the upper spine, which can result in a hunch-backed appearance.

- L -

Labial: The side of the tooth that faces the lips.

Lamella: A thin sheet or layer. In compact bone, lamellae are arranged in a concentric fashion around a central Haversian canal.

Lesion: A broad term referring to any pathological or traumatic discontinuity of tissue or loss of function of a part, including wounds, sores, ulcers, tumours and any other tissue damage; one of the individual points or patches of a multi-focal disease.

Ligament: A collagenous connective tissue that attaches bones to other bones.

Lingual: The side of the tooth that faces the tongue.

Lipping: The formation of an overgrowth of bone, which projects beyond the margin of the affected articular surface.

Lordosis: Excessive curvature in the lumbar portion of the spine, which gives a swayback appearance.

Lysis (adj. Lytic): Disintegration or dissolution of tissue.

- M -

Malocclusion: The lack of occlusion, or the abnormal occlusion, existing between the teeth of the upper and lower jaws.

Matrix: The material between animal or plant cells, or the material (or tissue) in which more specialised structures are embedded, The internal structure of connective tissues is an extra-cellular matrix.

Meatus: A canal or opening.

Median: The mid-line of the palate.

Medullary cavity: The cavity in the middle of bone shafts in which bone marrow (or medulla ossea) is found.

Mesenchyme: Loosely associated cells of mesodermal origin.

Mesial: The side of the tooth closer to the midline of the jaw.

Mesoderm: The 'middle layer' of tissue, which forms in triploblastic animals.

Metabolism: The sum of all physical and chemical reactions that are used by animals for anabolic synthesis of macromolecules for cell assembly and catabolic degradation of macromolecules for energy production.

Metaphysis: Also known as the epiphyseal plate, this is the region that separates the epiphysis from the diaphysis of a bone, and the region in which growth takes place.

Mycobacteria: A genus of acid-fast bacteria.

Myeloma: A tumour of the bone marrow and related cells, which can produce multiple spongy growths of bone simultaneously in a number of sites.

- N -

Necrosis: Bone death resulting from the loss of blood supply to a bone or region of bone.

Neoplasia: An abnormal growth uncontrolled by normal body mechanisms, and independent of adjacent tissues.

Neurotrophic factors: Also called neurotrophins, these are a family of protein growth factors (secreted proteins, usually found in the blood stream, that signal particular cells to survive, or differentiate, or grow) that induce the survival of neurons (nerve cells). Neurotrophic factors are secreted by target tissue (such as muscle), and act by prohibiting the neuron from initiating apoptosis - thus signalling the neurons to survive. Neurotrophins also induce differentiation of progenitor cells, to form neurons.

Nodule: A small mass of bone tissue

Non-metric trait: Dichotomous, discontinuous, epigenetic traits; non-pathological variations of skeletal tissues that can be better classified as present or absent (or as a point on a morphological gradient *e.g.* small to large) rather than quantified by a measurement.

- O -

Occipital: Relating to the back and lower part of the cranium.

Occlusal: The chewing surface of the tooth; also refers to a position toward the hypothetical plane passing between the maxillary and mandibular teeth when the upper and lower jaws are brought together.

Occlusion: The contact between upper and lower teeth that occurs when the jaws close.

Odontome: A neoplastic developmental anomaly, which contains enamel and dentine.

Osteoarthritis: A degenerative disease primarily affecting the articular cartilage

Osteoblastic: Relating to bone formation.

Osteochondritis dessicans: A condition of the joint, in which fragments of bone or cartilage have come loose, leading to pain and inflammation.

Osteoclastic: Relating to bone destruction.

Osteocyte: Cells inside the bone.

Osteogenesis: The formation of bone.

Osteoma: A benign bony tumour.

Osteomyelitis: Inflammation of the marrow cavity of a bone due to pyogenic infection.

Osteon: The basic structural unit of compact bone, composed of a central, vascular canal (Haversian canal) and the concentric osseous lamellae, which surround it.

Osteopenia: A decrease in bone matrix formation, used to describe thin bones in radiographs, a general term to describe a loss in the amount of bone.

Osteopetrosis: A condition in which bones harden and become abnormally dense.

Osteophyte: A small abnormal bony outgrowth or protuberance around the joint margin.

Osteophytosis: Formation of branching spicules ('lipping') of new bone on a pre-existing bone surface. They are most likely to occur at the margins of vertebral bodies.

Osteoporosis: Abnormal rarefaction of bone.

Osteosarcoma: A common type of malignant bone tumour.

- P -

Palmar: Of, relating to, or corresponding to the palm of the hand.

Periodontal disease: Infection of the alveolar bone surrounding the teeth and the periodontal membrane of each socket, leading to the loosening and eventual shedding of the teeth involved.

Periosteal: Relating to the periosteum.

Periosteum: The membrane that invests bone. Increase in bone diameter is accompanied by new bone formation on its internal surface. (See also endosteum).

Periostitis: Inflammation of the periosteal layer.

Periostosis: Abnormal bone formation on the periosteal layer.

Plantar: Of, relating to, or occurring on the sole.

Polydactyly: An increase in the number of digits over the basic pentidactylous number.

Porosity: An area of bone surface that possesses numerous small pits or pores created by pathological activity.

Posterior: Directed toward or situated near the back surface of the body.

Proximal: The end of the bone nearest to the point of attachment or articulation, or the side of the tooth furthest from the midline of the jaw; opposite of distal.

Pyogenic: Pus forming.

- S -

Sclerosis: Pathological hardening or thickening of tissue.

Serology: The study of blood serum.

Sero-negative: Showing a negative reaction to a test on blood serum for a disease, especially syphilis or AIDS.

Sesamoid bone: A bone that develops directly in a tendon, *e.g.* the patella (kneecap).

Sesamoiditis: Inflammation of a sesamoid bone.

Spondylosis deformans: A condition in which vertebral processes degenerate and osteophytes form.

Stenosis: An abnormal narrowing in a blood vessel or other tubular organ or structure, *e.g.* the spinal column. It is also sometimes called a "stricture".

Striation: A minute groove, scratch, or channel especially when one of a parallel series.

Subchondral bone: Bone underlying cartilage.

Supernumerary: Exceeding the normal amount.

Synarthrosis: A joint through which little or no movement is permitted between the articulated skeletal elements.

Synchondrosis: A synarthrosis of cartilage.

Syndesmosis: A synarthrosis of fibrous tissue.

Synostosis: A synarthrosis of bones.

Synovial joint: A freely movable joint, characterised by the presence of lubricated articular cartilage on the opposing bony surfaces and an articular cavity that is bound by a fibrous joint capsule lined with fluid-secreting synovial membrane.

- T -

Thickening of Epiphyseal Plates: An abnormal increase in the dimensions of the bone around the junction of the epiphysis and metaphysis in which growth of a juvenile bone takes place.

Trabecular bone: see Cancellous bone.

Transverse: At right angles to the long axis of the body.

- U -

Ungulate: Of, or belonging to, the former order Ungulata, now divided into the orders Perissodactyla and Artiodactyla and composed of the hoofed mammals such as horses, cattle, deer, swine, and elephants.

- V -

Ventral: Toward the belly; opposite of dorsal.

- W -

Woven bone: Fibrous or non-lamellar bone, which consists of an irregular network of intermingled trabeculae. Found wherever bone is being rapidly formed.

Appendix 2: Users Guide

Introduction:

The legends on the tabs within the recording protocol are designed to be self-explanatory. However, what follows is a basic user guide to the system.

Opening the database:

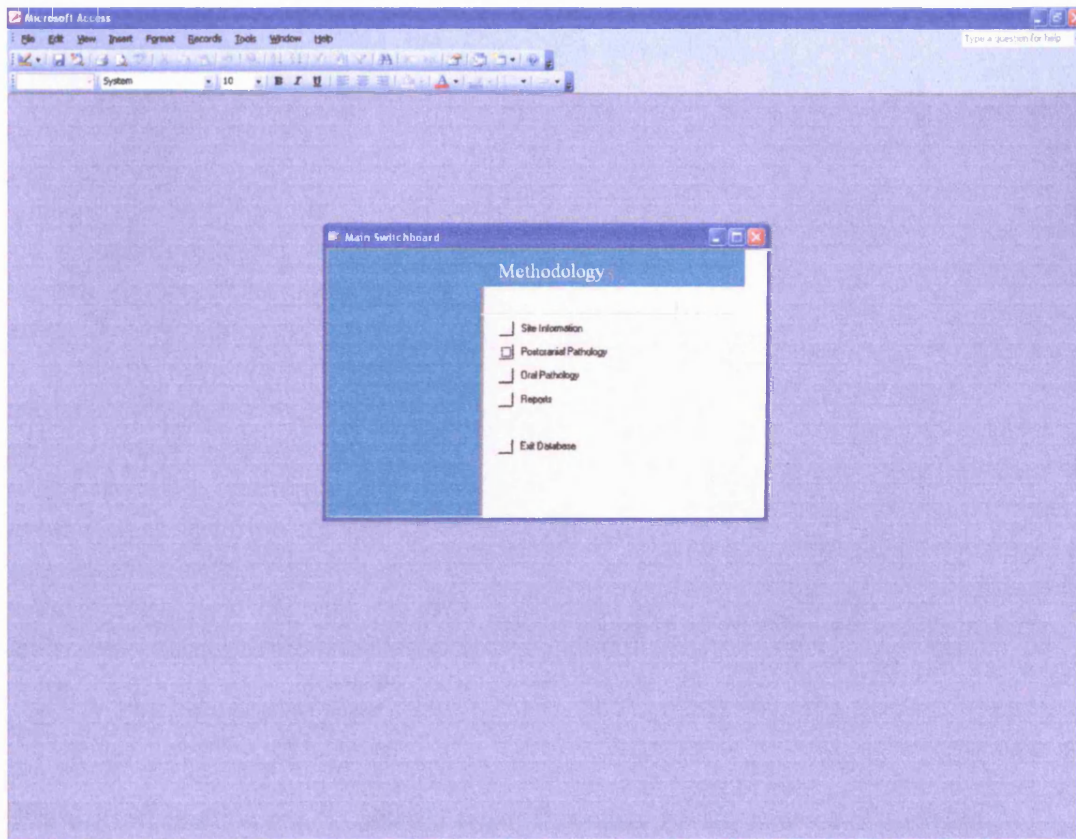


Fig 9.1: Switchboard form

The database opens with a switchboard menu screen giving five options:

1. Site Information
2. Post-Cranial Pathology
3. Oral Pathology
4. Reports
5. Exit Database

Option 1 leads to the site information recording form.

Options 2 and 3 lead to recording forms for particular types of pathology.

Option 4 leads to the report section.

Option 5 closes the database.

Site Information:

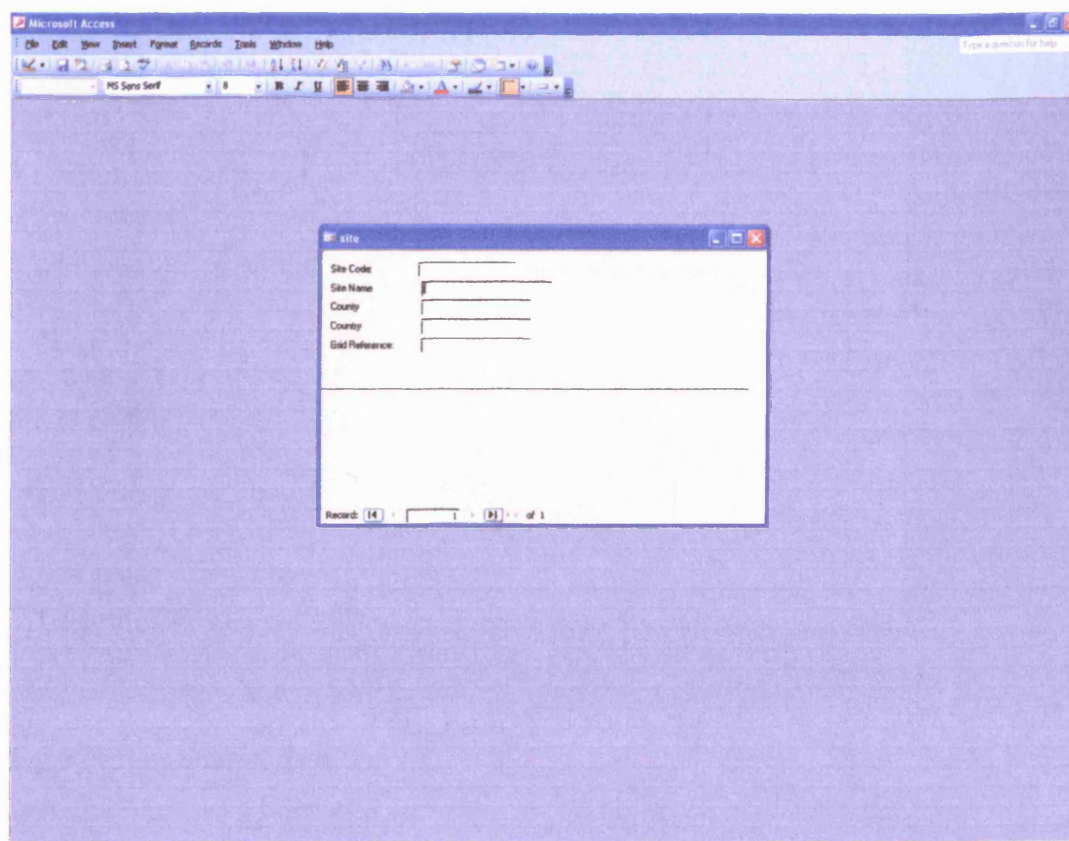
The image is a screenshot of a Microsoft Access database window. The main window has a blue title bar and a menu bar with options like File, Edit, View, Insert, Format, Records, Tools, Window, and Help. Below the menu bar is a toolbar with various icons. The main area of the window is a light blue grid. In the center of the grid is a smaller window titled 'site'. This window has a white background and contains five text input fields with labels: 'Site Code', 'Site Name', 'County', 'Country', and 'Grid Reference'. At the bottom of the 'site' window, there is a status bar that says 'Records: 14' and a small table icon with '1' and '91' and 'of 1'.

Fig 9.2: Site information form

The site information can be entered either through entering a new site code (as described below) or by filling the information directly into this form. This should only be entered once for each site. Both recording forms link to the same table.

Site Code: Alphanumeric code indicating which site is being recorded.

Site Name: Name of site.

County: County in which site is located.

Country: Country in which site is located.

Grid Reference: Grid reference of site.

Recording post-cranial pathologies:

The screenshot shows a Microsoft Access database window titled "Postcranial - Form". The window has a menu bar (File, Edit, View, Insert, Format, Records, Tools, Window, Help) and a toolbar. The form itself has three tabs: "Post Cranial Bones", "Lesion", and "Pathological Index". The "Post Cranial Bones" tab is selected. It contains several data entry fields: "Bone Id" (with a "(Number)" hint), "Site Code", "Context No.", "Specimen No.", "Species", "Element", "Zone", "Side", and "Illustration Location". There are also dropdown menus for "Preservation (Harland, 2003)", "Skeleton Identification No.", "Non-Macroscopic Techniques", and "Additional Information". The form is displayed within a Microsoft Access window titled "Postcranial - Form".

Fig 9.3: Post-cranial form

The post-cranial form has three tabs: post-cranial bones, lesion and pathological index. Above these can be found the bone ID. This automatically generated number is unique to each bone.

Site Code: Alphanumeric code indicating which site data is from. Select from previously entered codes or enter new code. If unrecognised code is entered, pop-up will open. If code is correct, but new, complete site information data form and confirm.

Context No.: Alphanumeric code indicating context to which material belongs.

Specimen No.: Alphanumeric code indicating exact specimen.

Species: Enter the species in the text field.

Element: Select from the predetermined list in the drop down box.

Zone: Enter the appropriate code for that element in the zoning system that you are using. Remember to state which system was used in any subsequent reports.

Side: Select the appropriate option from left, right, anterior, posterior or unknown from the drop down box to indicate which side of the animal the element is from.

Illustration location: record the web address, photo identification number or other code by which any illustrations of the pathology can be found.

Preservation: Select from excellent, good, fair, and poor (based on Harland *et al.*, 2003) in the drop down box.

Skeleton identification no.: Alphanumeric code linking individual elements that all belong to a single articulated or semi-articulated skeleton. Leave blank if not appropriate.

Non-macroscopic techniques: Indicate the type of technique applied to the bone in question and any results gained. Leave blank if no relevant information exists.

Additional information: additional relevant information that seems appropriate. Leave blank if no relevant information exists.

Lesions:

Microsoft Access

Postcranial: Form

Bone ID: [Placeholder]

Post Cranial Bones | Lesion | Pathological Index

Lesion | Bone Formation | Bone Destruction | Fracture | Size | Shape | Diagnosis

Bone Formation ☐

Bone Destruction ☐

Fracture ☐

Alteration of Size ☐

Alteration of Shape ☐

Other: 0

Record: 1 of 1

Fig 9.4: Lesion tab on the post-cranial form

The lesion tab itself has six tabbed forms contained within it. The first of these is for general information.

Bone Formation: Tick if applicable.

Bone Destruction: Tick if applicable.

Fracture: Tick if applicable.

Alteration of Size: Tick if applicable.

Alteration of Shape: Tick if applicable.

Other: Insert name of other condition which does not fit any of the above categories e.g. failure to form bone, eburnation.

Bone formation:

Microsoft Access

Postcranial: Form

Bone Id [Number]

Post Cranial Bones Lesson Pathological Index

Lesion Bone Formation Bone Destruction Fracture Size Shape Diagnosis

Type [v]

If other, please name [v]

Size [0]

Surface [v]

Margin [v]

Active at Death: [v]

Record: 1 of 1

Fig 9.5: Bone formation tab

Type: Select from nodule, callus, periostosis, increased density, fusion, and other. If other is selected, please state what this is in the box below. Also use this box for entering more specific categories if desired e.g. enthesophyte or osteophyte if nodule has been selected.

Size: Record the size of the lesion in millimetres.

Surface: Select from smooth or irregular.

Margin: Select from well defined, or poorly defined.

Active at Death: Select from active, inactive or unknown.

Bone destruction:

The screenshot shows a Microsoft Access database window titled 'Postcranial Form'. The 'Bone ID' field is at the top, followed by a tab bar with 'Post Cranial Bones', 'Lesion', and 'Pathological Index'. The 'Bone Destruction' tab is selected. The form contains several fields with dropdown menus: 'Type' (with a note 'If other, please name:'), 'Size (mm)', 'Shape', 'Margin', 'Interior', 'Sclerosis', and 'Active at Death'. At the bottom, the record count is shown as 'Record: 1 of 1'.

Fig 9.6: Bone destruction tab

Type: Select from cavity, porosity, osteopenia, articular depression, articular groove, necrosis, and other. If other is selected, please state what this is in the box below. Also use this box for entering more specific categories if desired e.g. abscess, cyst or cloaca if cavity has been selected.

Size: Record the size of the lesion in millimetres.

Shape: Select from linear, round/oval or irregular to describe the shape of the lesion.

Margin: Select from well defined or poorly defined to describe the margin of the lesion.

Interior: Select from smooth or irregular to describe the interior of the lesion.

Sclerosis: Select from yes, no or unknown.

Active at Death: Select from active, inactive or unknown.

Fractures:

The screenshot displays the Microsoft Access application window. At the top, the menu bar includes File, Edit, View, Insert, Format, Records, Tools, Window, and Help. Below the menu is a toolbar with various icons. The main window shows a form titled 'Postcranial: Form'. The form has three tabs: 'Post Cranial Bones', 'Lesion', and 'Pathological Index'. The 'Lesion' tab is currently selected. Within the 'Lesion' tab, there are sub-tabs: 'Lesion', 'Bone Formation', 'Bone Destruction', 'Fracture', 'Size', 'Shape', and 'Diagnosis'. The 'Fracture' sub-tab is active, showing four fields: 'Type', 'Condition', 'Angle', and 'Foreshortening'. Each field has a dropdown arrow. The 'Record: 14 of 1' is displayed at the bottom of the form.

Fig 9.7: Fractures tab

Type: Select the type of fracture present from transverse, comminuted, oblique, hairline, impacted, incomplete, spiral, and greenstick.

- a) transverse – fracture in which the bone is broken perpendicular to its long axis;
- b) comminuted – fracture in which the bone is broken into many pieces or fragments;
- c) oblique and displaced – fracture in which the bone is completely broken at an angle diagonal to its long axis;
- d) hairline – minor fracture in which bone fragments remain in perfect alignment;

- e) impacted – fracturing and subsequent wedging of one bone end into the interior of another;
 - f) incomplete – fracture more severe than hairline, but less severe than a complete with no separation of bone fragments;
 - g) segmental – fracture in which a significant portion (intact segment) of the bone is displaced;
 - h) spiral – oblique fracture commonly associated with ‘fresh’ bone
- (Mann and Murphy, 1990: 158-159).

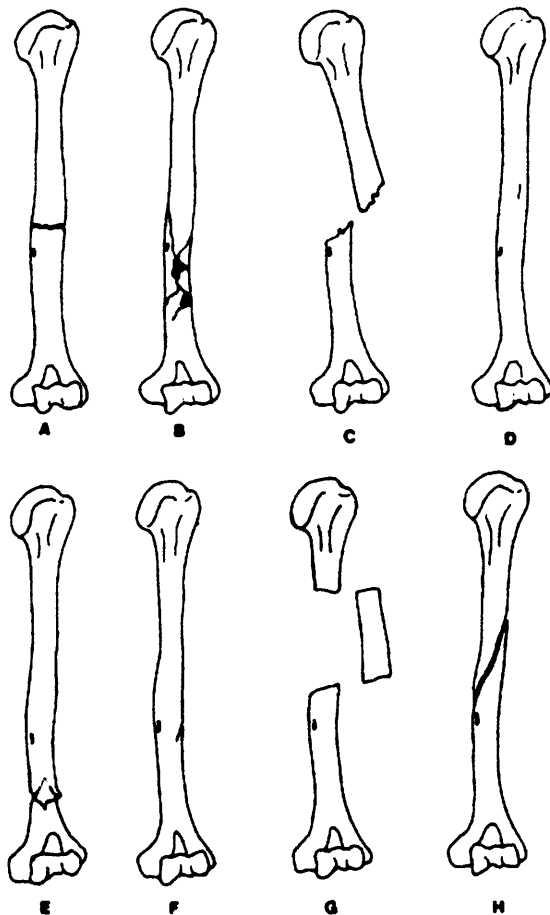


Fig 9.8: Types of long bone fractures (Mann and Murphy, 1990: Fig 97).

Condition: Select from fresh, healing or healed.

Angle: Record the angle of displacement due to the fracture in degrees.

Foreshortening: Record the amount in millimetres that the bone has been shortened due to the injury.

Alterations in size:

The screenshot shows a Microsoft Access window titled 'MS Sans Serif'. Inside, a form titled 'Postcranial: Form' is open. The form has a tabbed interface with the following tabs: 'Post Cranial Bones', 'Lesion', 'Pathological Index', 'Lesion', 'Bone Formation', 'Bone Destruction', 'Fracture', 'Size', 'Shape', and 'Diagnosis'. The 'Size' tab is currently selected. Within the 'Size' tab, there is a 'Type' label followed by a dropdown menu. The dropdown menu is open, showing a list of options. At the bottom of the form, there are two record navigation controls. The first one shows 'Records: 14' and '1' of 1'. The second one shows 'Records: 14' and '1' of 1'.

Fig 9.9: Alterations in size tab

Type: Select from reduced or enlarged in comparison to the site norm.

Alterations in shape:

Microsoft Access

File Edit View Insert Format Records Tools Window Help

MS Sans Serif

Postcranial: Form

Bone Id: [Humerus]

Post Cranial Bones Lesion Pathological Index

Lesion Bone Formation Bone Destruction Fracture Size Shape Diagnosis

Type: []

If other, please name: []

Angle: [0]

Direction: []

Record: 14 1 of 1

Fig 9.10: Alterations in shape tab

Type: Select from bowing, expansion of the diaphysis, expansion of the metaphysis, articular extension, displacement, thickening of epiphyseal plates and other. If other is selected, please state what this is in the box below.

Angle: Record the angle of any shape change in degrees.

Direction: Record the direction of any shape change using anatomical terminology.

Diagnosis:

Microsoft Access

File Edit View Insert Format Records Index Window Help

Post Cranial Bones

Post Cranial Bones Lesion Pathological Index

Lesion Bone Formation Bone Destruction Fracture Size Shape Diagnosis

Suggested Diagnosis:

Record: 14 1 of 1

Fig 9.11: Diagnosis box

Enter all potential diagnoses and reasons for them into the text box.

Pathological Index:

Microsoft Access

Postcranial - Form

Form ID: [Preamble]

Post Cranial Bones | Lesions | Pathological Index

Note: 0 = non-recordable

Element	
Proximal Extremity	0
Proximal Limb	0
Distal Extremity	0
Distal Limb	0
Distal Depression	0
Proximal Extension	0
Distal Extension	0
Fusion	0
Fracture	0
Stabilization	0
Pathological Index	0

Calculate PI

Record: 14 of 1

Fig 9.12: Pathological index tab

For recording information based upon the Bartosiewicz *et al.* (1997) methodology. This is only applicable to certain skeletal elements: the metacarpal, metatarsal, proximal phalanx, medial phalanx, and distal phalanx.

Element: Select element to be recorded.

Record the degree of each specific condition listed, selecting from the numerical options in the drop down boxes. Note that 0 = non-recordable.

Proximal Exostosis: Record for all elements.



Fig 9.13.: Different stages of exostosis development of the proximal end of the metacarpal.

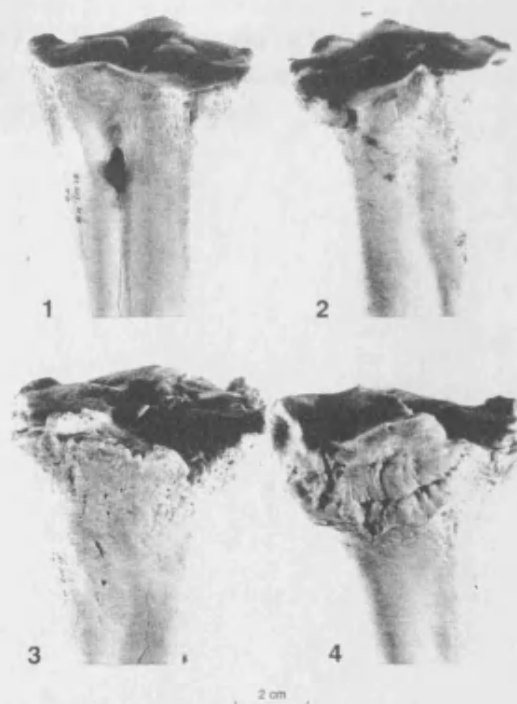


Fig 9.14.: Different stages of exostosis development of the proximal end of the metatarsal.



Fig 9.15.: Different stages of exostosis development of the proximal end of the proximal phalanx.



Fig 9.16.: Different stages of exostosis development of the proximal end of the medial phalanx.

Proximal Lipping: Record for all elements.

Fig 9.17.: Different stages of lipping at the proximal articular surface of the metacarpal.

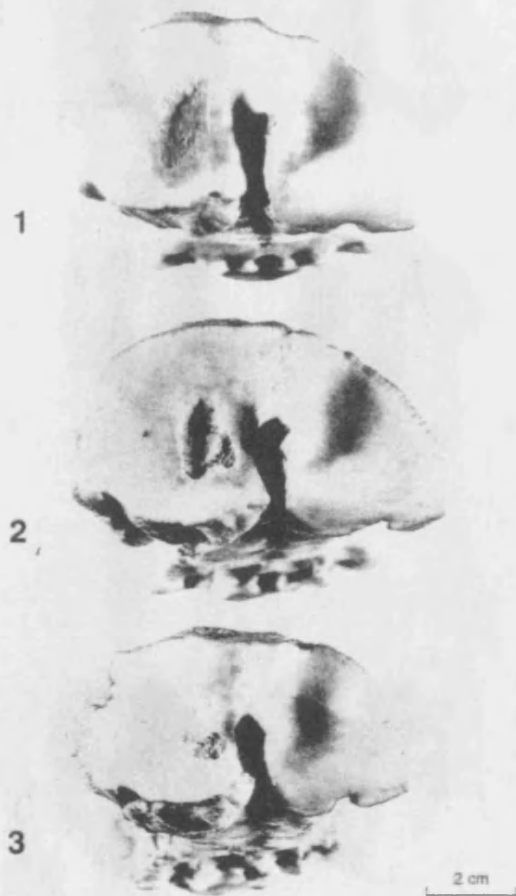
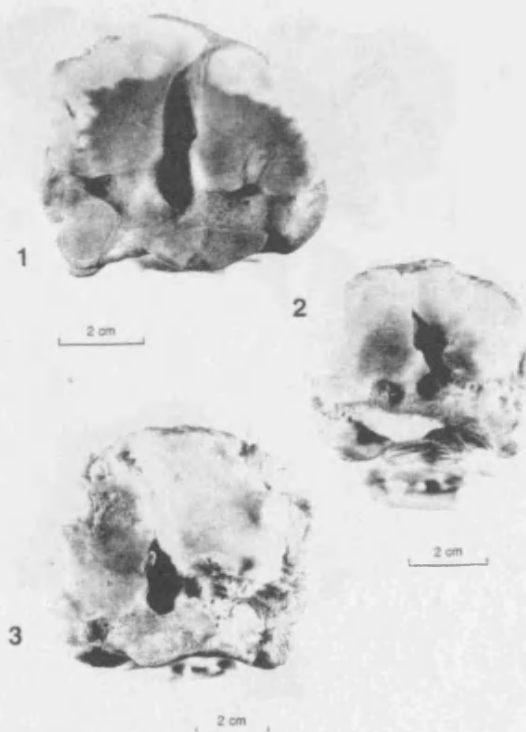


Fig 9.18.: Different stages of lipping at the proximal articular surface of the metatarsal.



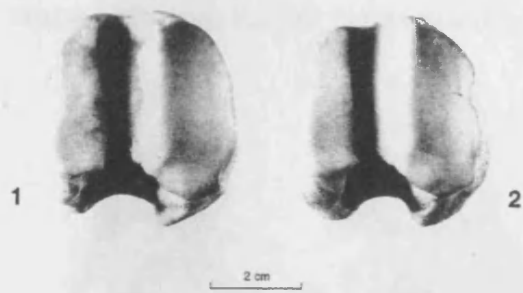


Fig 9.19.: Different stages of lipping at the proximal articular surface of the proximal phalanx.

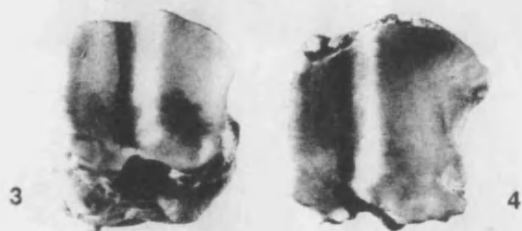


Fig 9.20.: Different stages of lipping at the proximal articular surface of the medial phalanx.

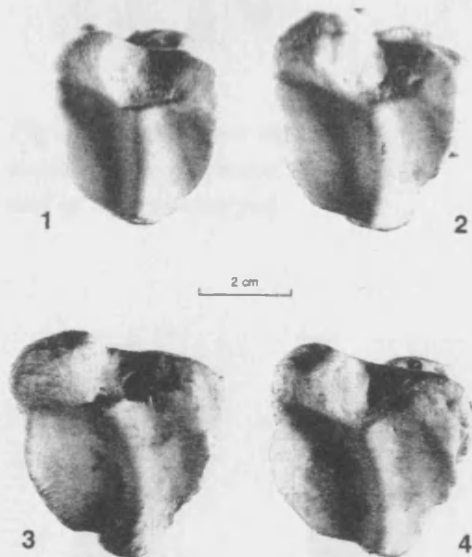


Fig 9.21.: Different stages of lipping at the distal articular surface of the medial phalanx.

Distal Exostosis: Record for every element except distal phalanx.

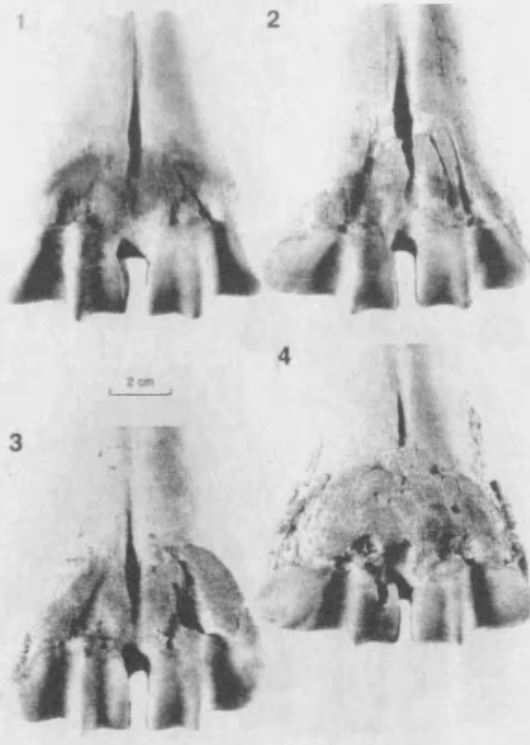


Fig 9.21.: Different stages of exostosis development at the distal end of the metacarpal.



Fig 9.22.: Different stages of exostosis development at the distal end of the proximal phalanx.

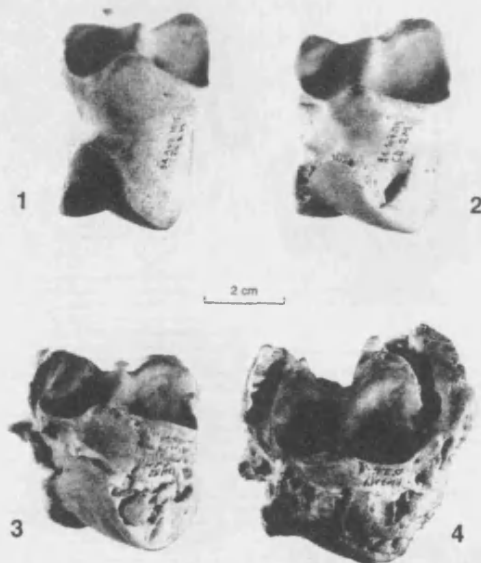
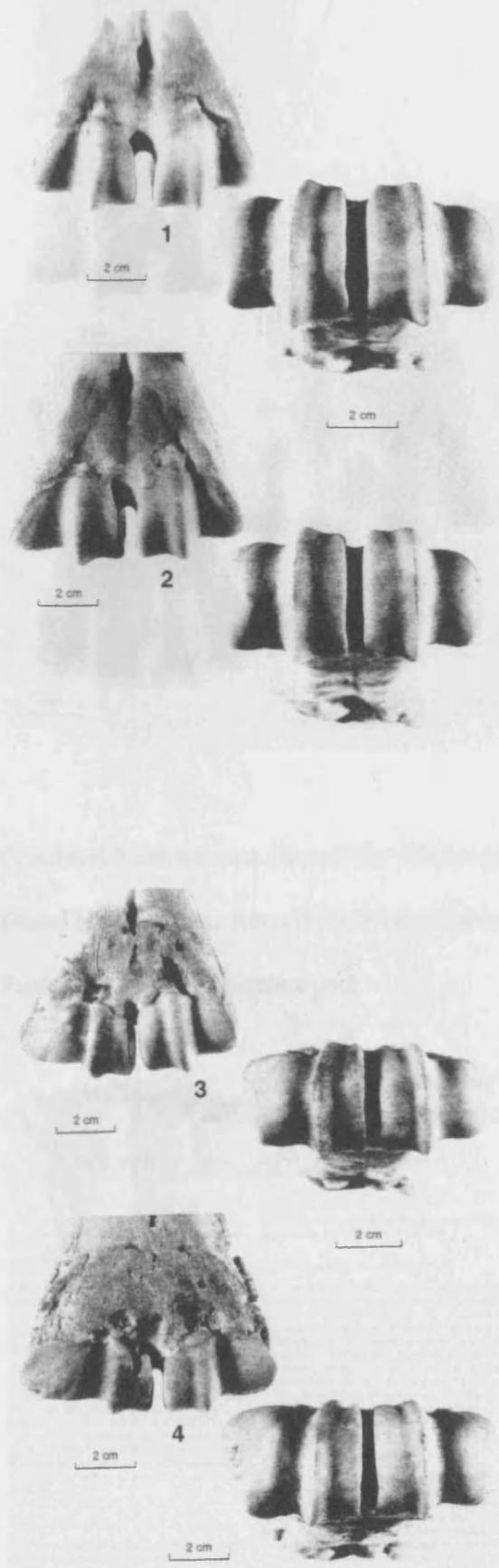


Fig 9.23.: Different stages of exostosis development at the distal end of the medial phalanx.

Distal Broadening: Record for metacarpals and metatarsals.

Fig 9.24.: Different stages of broadening at the distal epiphysis of the metacarpal.



Distal Depressions: Record for metacarpals and metatarsals.

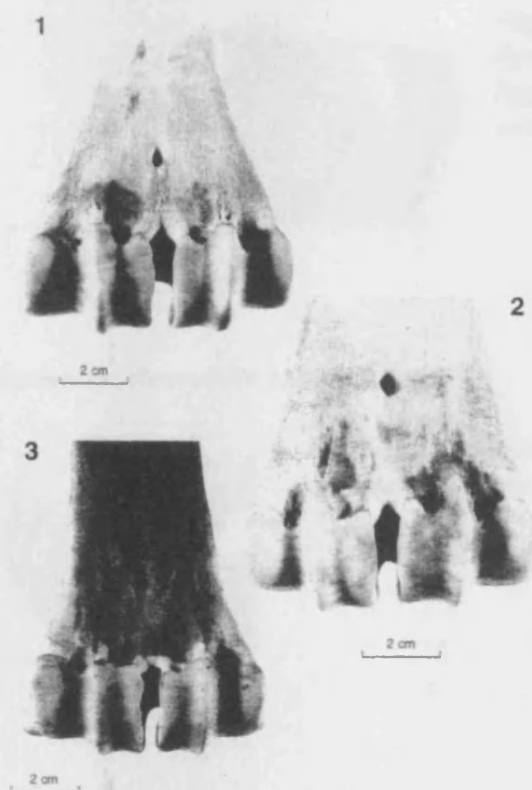


Fig 9.25.: Different stages of palmar depressions in metacarpals.

Proximal Eburnation: Record for all elements.

Distal Eburnation: Record for every element except distal phalanx.

Fusion: Record for metacarpals.



Fig 9.26.: Fusion of the second metacarpal with the third metacarpal stage 2.

Facet: Record for metacarpals.



Fig 9.27.: Striation of the triangular facet serving for the attachment of the ligamentum accessorium of the metacarpal stage 2.

Striation: Record for metatarsals.



Fig 9.28.: Transverse striations on the medio-proximal surface of the metatarsal stage 2.

Once all of the relevant specifics have been recorded, press the 'calculate PI' button to automatically generate the result for that element based upon the equation given by Bartosiewicz *et al.* (1997; also in chapter 2 of this volume):

$$PI = (\text{sum of scores} - \text{number of variables}) / (\text{maximum score} - \text{number of variables})$$

$$PI (Mc) = (\text{sum of scores} - 9) / 17$$

$$PI (Mt) = (\text{sum of scores} - 8) / 16$$

$$PI (Ph1) = (\text{sum of scores} - 5) / 11$$

$$PI (Ph 2) = (\text{sum of scores} - 5) / 11$$

$$PI (Ph 3) = (\text{sum of scores} - 3) / 7$$

Recording oral pathology:

The screenshot shows a Microsoft Access database window titled 'Microsoft Access'. Inside, there is a form titled 'Oral Pathology Form'. The form has five tabs: 'Oral Pathology', 'Cavity', 'Enamel Hypoplasia', 'Malocclusion', and 'Diagnosis'. The 'Oral Pathology' tab is currently selected. The form contains the following fields and controls:

- Tooth Id:** A text box with a value that appears to be '100-100-100'.
- Site Code:** A text box with a dropdown arrow.
- Context No.:** A text box with a dropdown arrow.
- Tooth Wear Stage:** A text box with a dropdown arrow.
- Attrition:** A text box with a dropdown arrow.
- Enamel Hypoplasia:** A checkbox that is checked.
- Calculus:** A text box with a dropdown arrow.
- Alveolar Recession:** A text box with a dropdown arrow.
- Cavity:** A text box with a dropdown arrow.
- Supernumerary Teeth:** A text box with a dropdown arrow.
- Absent Teeth:** A text box with a dropdown arrow.
- Absent Cusps or Pylars:** A text box with a dropdown arrow.
- Tooth Rotation:** A text box with a dropdown arrow.
- Malocclusion:** A text box with a dropdown arrow.

At the bottom of the form, it says 'Record: 14' and '1 of 1'.

Fig 9.29: Oral pathology form

The oral pathology form has five tabs: oral pathology, cavity, enamel hypoplasia, malocclusion and diagnosis.

The first form is for recording general information. At the top of the list is an automatically generated tooth ID. This is a unique identifier.

Site Code: Alphanumeric code indicating which site is being recorded. Select from previously entered codes or enter new code. If unrecognised code is entered, a pop-up will open. If the code is correct, but new, complete site information data form and confirm.

Context No.: Alphanumeric code indicating context to which material belongs.

Tooth Wear Stage: Alphanumeric code indicating wear stage based on recognised recording systems e.g. Grant (1982).

Attrition: Record the angle and direction of any abnormal tooth wear.

Enamel hypoplasia: Check box if this is present.

Calculus: Select from slight, moderate, and severe.

Alveolar recession: Select from slight, moderate, and severe.

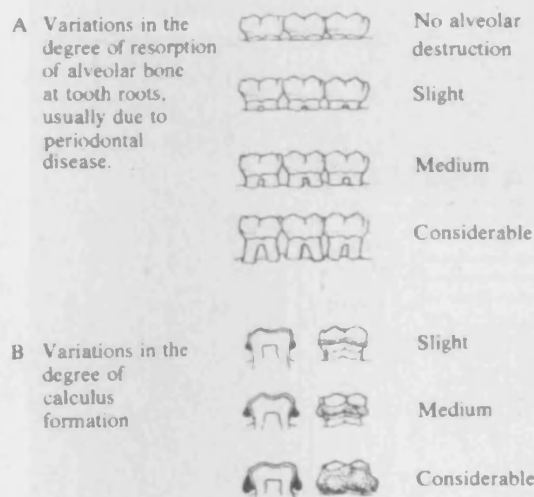


Fig 9.30: Stages of A) Alveolar Resorption and B) Calculus Formation (Brothwell, 1981: fig 6.14)

Cavity: Check box if this is present.

Supernumerary teeth: Record which additional teeth are present.

Absent teeth: Select from none, congenital loss, or premortem loss.

Absent cusps or pillars: Record which cusps or pillars are absent.

Tooth rotation: Insert the degree of rotation, if appropriate.

Malocclusion: Check box if this is present.

Cavity:

The screenshot shows a Microsoft Access window titled 'MS Sans Serif'. Inside, there's a form titled 'Oral Pathology' with a tabbed interface. The 'Cavity' tab is selected. The form has four input fields with dropdown arrows: 'Cavity Type', 'Abscess Stage', 'Caries Type', and 'Caries Stage'. Below these fields is a large empty text area. At the bottom of the form, there are record navigation controls showing 'Records: 14' and '1 of 1'.

Fig 9.31: Cavity tab

Type: Select from abscess or caries.

Abscess stage: Record the stage based on Levitan (1985), from the options of low, medium or severe.

1. Low: obvious disturbance to the pulp cavity and/or alveolus, but this is not discernable from the exterior (X-rays must be used).
2. Medium: disturbance has spread to the extent that the condition is obvious externally; there is severe root disfigurement, but the tooth is retained.
3. Severe: The tooth has been shed ante-mortem.

(Levitan, 1985: 45)

Caries Type: Select from mesial, distal, occlusal, lingual, and labial. This records the location on the tooth of the carious cavity.

Caries Stage: Select from low, medium, or severe to record the stage of severity.

1. Low: less than half the tooth crown destroyed.
2. Medium: more than half the tooth crown destroyed.

3. Severe: all the tooth crown destroyed.

Enamel hypoplasia:

Microsoft Access

File Edit View Insert Format Records Tools Window Help

Type a question for help

MS Sans Serif

Oral : Form

Oral Pathology Cavity Enamel Hypoplasia Malocclusion Diagnosis

Enamel Hypoplasia

Severity

Measurement (mm) perpendicular distance between CEJ and lowest point of line

0.00

Record: 14 1 of 1

Fig 9.32: Enamel hypoplasia tab

Type: Select from line or pit.

Severity: Select from mild, moderate or severe to record the severity.

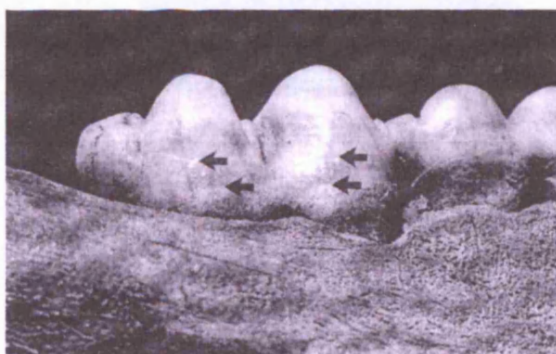


Fig 9.33.: Slight linear enamel hypoplasia (Dobney and Eryvnick, 1998: Figure 7).

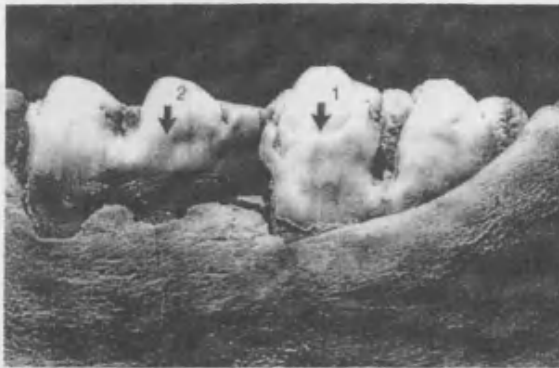


Fig 9.34.: Moderate linear enamel hypoplasia (Dobney and Ervynck, 1998: Figure 8).

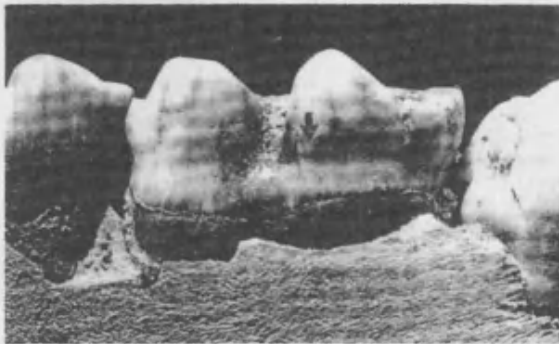


Fig 9.35.: Severe linear enamel hypoplasia (Dobney and Ervynck, 1998: Figure 9).

Measurement: Record the measurement in millimetres of the perpendicular distance between the cemento-enamel junction and the lowest point of the line in the enamel.

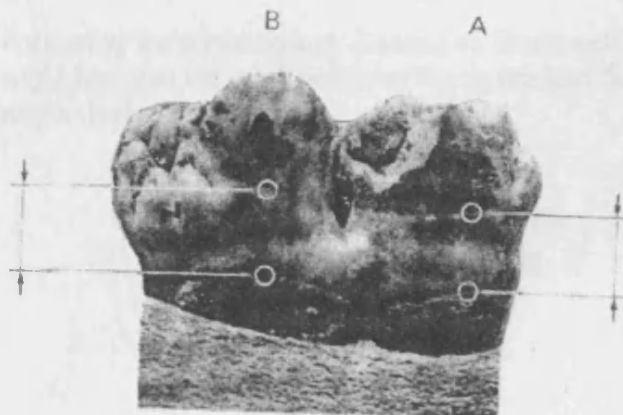


Fig 9.36.: Schematic diagram to show where measurements of LEH lines should be taken from (Dobney and Ervynck, 1998: Figure 10).

Malocclusion:

Microsoft Access

File Edit View Insert Format Records Tools Window Help

MS Sans Serif

Oral Form

Oral Pathology Cavity Enamel Hypoplasia Malocclusion Diagnosis

Median P2

Median P3

Median P4

Median M1

Record: 1 of 1

Records: 1 of 1

Fig 9.37: Malocclusion tab

Following the methodology devised by Brothwell (1991), in each box record the angle between the median line of the palate and the p_2 , p_3 , p_4 , and $M1$ respectively.

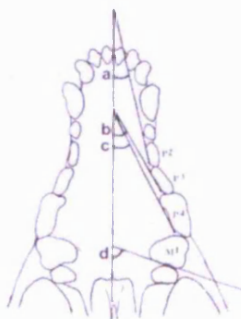


Fig 9.38.: Details of the construction of angles used (Brothwell, 1991: Fig. 3)

Diagnosis:

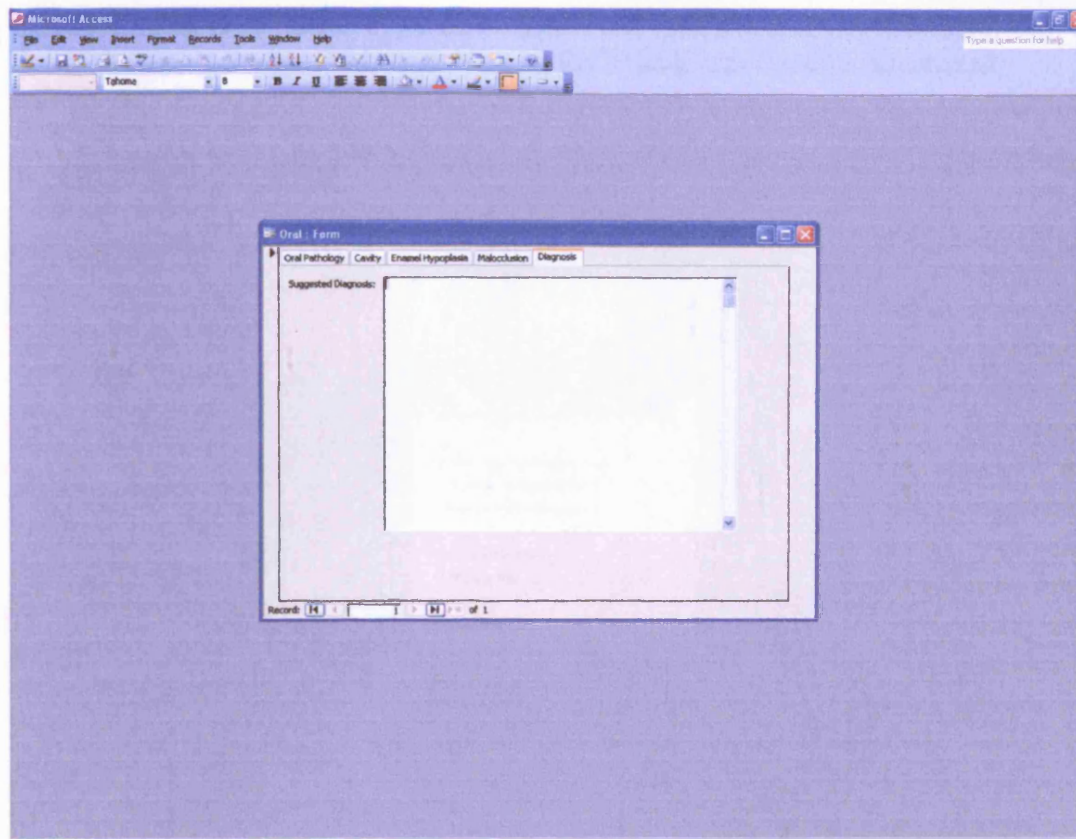


Fig 9.39: Oral pathology diagnosis box

Enter all potential diagnoses and the reasons for them into the text box.

Reports:

Once recording is complete, close down forms and return to main switchboard. Select the reports button. This will open up the default report menu (illustrated below).

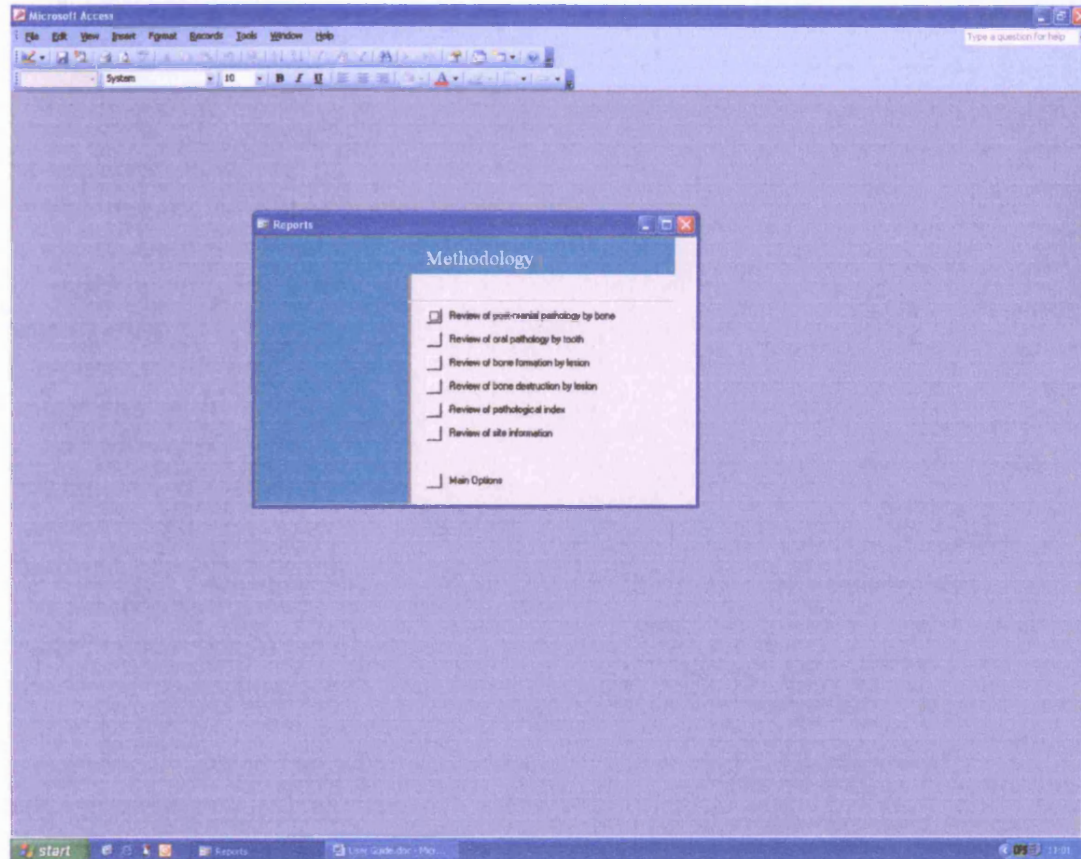


Fig 9.40: Reports menu

Review of post-cranial pathology by bone: Creates a report displaying the types of post-cranial pathology exhibited on each bone.

Review of oral pathology by tooth: Creates a report displaying the types of oral pathology exhibited on each tooth.

Review of bone formation by lesion: Creates a report displaying bone formation related pathologies by lesion ID.

Review of bone destruction by lesion: Creates a report displaying bone destruction related pathologies by lesion ID.

Review of pathological index: Creates a report displaying the pathological index data.

Review of site information: Creates a report giving the site information for all sites recorded on the database.

Select 'Main Options' to return to Main Switchboard.

Select 'exit database' on the Main Switchboard to close down the database.

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