ASPECTS OF HEALTH AND POPULATION STUDIES IN NORTHERN EUROPE BETWEEN THE TENTH AND TWELFTH CENTURIES

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Thesis submitted for the degree of doctor of philosophy

School of Archaeology and Ancient History

University of Leicester 2004

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Sarah Patricia Tatham

Aspects of Health and Population Studies in Northern Europe between the Tenth and Twelfth Centuries

Thesis: 86,406 (including bibliography)

Abstract

This research project is an international study of certain aspects of health and population studies in 10-12th century populations of northern Europe by using skeletal remains from nearby European regions. They include England, France and Sweden. A total of 2,718 adult skeletons were analysed (and an additional 41 individuals were used for isotope analysis). Through the analysis of the skeletal remains and/or archival reports, information pertaining to health and diseases through contact and exposure was collected by the process of calculating sex ratios and the age at death structure of each population. Prevalence rates of non-specific infections (periostitis, enamel hypoplasia and cribra orbitalia) and specific infections including tuberculosis, leprosy and chronic chest disease provided direct evidence of health.

The disease and lesion prevalence rates showed that there were no distinctive health differences between the regions, only a range of variation in the experience of health. The differences that were apparent were more to do with the nature of the settlements and their historical and socio-economic context, rather than their geographical location in Europe. Although current methodologies used to diagnose diseases have not proved to be applicable to their assessment of prevalence rates at the population level, this project has demonstrated that the northern European region could be perceived as a single geographical unit when assessing health in the past. It has provided a unique outlook on the range of past human life experience and identified evidence of the diversity that is potentially present in early medieval European populations.

To assess potential exposure to pathogens through contact, population movement was investigated using isotope analysis in two skeletal assemblages. Although no immigrant component was detected, the use of this new tool to identify population profiles and local variability was established.

Acknowledgements

I would like foremost to express my gratitude to my supervisors Jenny Wakely (Medical School) and Deirdre O'Sullivan (School of Archaeology and Ancient History), who supported and guided me through this project. Many thanks are also due to the Anglo-Danish society for funding the first year of my PhD and to the NIGSF Steering committee for funding the isotope research.

I would like to thank staff and student from the archaeology department, notably fellow PhD students: Dr Clare Duncan for her help with statistics and giving me access to some of her files, Mr Stan Chapman for the DXA scans and Mr Nigel James (from the medical school) for advice on teeth and his steady encouragement. I would also like to thank Prof. Marilyn Palmer for her constant support and all the references!

I am especially grateful to the following people for access to skeletons and archives, general information, assistance and advice. They did so with with great kindness and were very helpful:

In France to Miss Isabelle Catteddu (AFAN) and Mr Philippe Vidal for information archaeology and collections, Dr Joel Blondieux (Centre Paleopathologique du Nord) for information on Arras and his advice on paleopathology, Dr Armelle Alduc-Le Bagousse and Mrs Cecile Niel (CRAHM-CNRS) for giving me access to the skeletons and the archives of Cherbourg and Rouen, as well as making my stay in Caen very pleasant.

In Denmark to Prof. Jesper Boldsen, who helped me start this PhD, and his ADBOU unit at the University of Odense, Dr Pia Bennike and Dr Niels Lynnerup (Panum Institute) at Copenhagen for giving me access to the skeletons and archives, as well as letting me roam free in their fascinating labs. In Sweden to Dr Caroline Arcini (RAA) who provided me the information on Lund.

In Germany to Prof. Michael Schultz and the Göttingen Paleohistopathology Course 2002.

In England to Mr Tom Loader and Keith Wade (Suffolk Archaeological Unit) for archaeological information for Ipswich and Dr Simon Mays (English Heritage Monuments) for osteological data on Ipswich and Empingham II and advice for Wing, Mr Iain Meadows and Mr Stephen Parry (both Northamptonshire Archaeological Unit) for archaeological information on Ketton, Mr Iain Soden and Mr Mark Holmes (Northamptonshire Archaeological Unit) for information on Wing, Ms Christine Kyriacou (York Archaeological Trust) for information on Fishergate, Dr Bill White (MoLAS) for his help with St Nicholas Shambles, Prof. Don Ortner and the Bradford Paleopathology Course group 2001 who listened, advised and encouraged me at a crucial time and Dr Jenny Wakely (University of Leicester) for access to the Ketton and Abingdon material, Mr George McTurk for technical assistance on the SEM.

For the isotope analysis I would like to thank Dr Jane Evans for introducing me to isotopes and for the strontium analysis, Mrs Carolyn Chenery for teaching me oxygen and silver phosphate analysis and mentoring me throughout. Also thanks Dr Simon Chenery, Dr Tiffany Barry and Dr Craig Storey.

I would also like to thank all my colleagues from the Heritage Conservation Group at Kent County Council for their encouragement, patience and good discussions. I am very grateful to Mrs Veronica Griffiths for providing me with study space this last year and unending support. I am hugely indebted to Mr Neil Anderson for scientific and computer assistance and correcting thesis drafts.

The biggest thanks must go to my family for their never-ending moral and financial support, without which this PhD would never have been started, let alone finished. Dad, you once told me a story about radios, maybe you would like to hear one about bones…

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Chapter 1. Introduction

1.1. Context of the project

The development of the study of the biological anthropology of past humans and the establishment of paleopathology as a discipline has been protracted in Britain. In the past, paleopathology suffered from the lack of a multidisciplinary approach and a disregard for the accompanying cultural context (Mays 2000a). In the last two decades, however, biological anthropology and paleopathology have attempted to progress from a purely diagnostic/clinical approach of individual cases to the population-based studies. This was largely influenced by the American concept of a 'biocultural approach', whereby biological evidence is linked to cultural determinants (Mays 2000a; Roberts and Cox 2003:24). In the more recent years in Britain, groups such as the British Association for Biological Anthropology and Osteoarchaeology (established in 1998) have been striving for a coherent adoption of diagnostic criteria and standards as well as more rigorous recording methods. In addition, biological anthropology has often had to struggle to gain support or indeed acknowledgement as a useful discipline from archaeologists, and in the light of the financial restrictions that surround the field the post-excavation analysis of human remains often suffers. Biological anthropology is nevertheless an increasingly popular and respected discipline today, whose finds, in spite of the lack of appropriate funding, have undeniably contributed to our knowledge and understanding of the past.

These are recent developments though and there are still various schools of thought that have influenced scholars in their approach of the assessment of health in the past using paleopathology. Looking at populations as a whole rather than just individual skeletons is a very recent phenomenon. Although most scholars seem to agree on the validity of large-scale studies, few exist, mostly because the cost and time limitations are rarely compatible with the nature and reality of today's requirements of anthropological work and research. Some efforts have been made to make nation-wide analyses, for example Bennike and Brade's *Paleopathology of Danish Skeletons* (1985) and more recently the excellent volume by Roberts and Cox, *Health and Disease in Britain* (2003), which also includes a

critical assessment of paleopathology as a discipline in this country. Even fewer published works, however, investigate comparative health on an international basis (e.g. Buikstra 1999, Jacob in progress). The need for it has nevertheless been identified, since a new project called a '*History of Health in Europe*', based in the United States, was initiated in 2001, just over two years after the beginning of this research project.

This present research project endeavours to address this void in comparative health by using skeletal collections from England and modern France and Sweden. Such a project was greatly facilitated by my language skills, which enabled me to work abroad. Once permission was granted to visit various laboratories and institutions in England, France, Germany and Denmark, and use their collections and facilities, I had unique access to skeletons and data that might not have been available otherwise to fellow scholars. This access formed the basis of the international outlook of this research project. There were limiting factors though in the breadth and scope of the project, mainly relating to the availability and access to skeletal collections, the cost and the time frame of the project. The period investigated is therefore a short one, spanning between the 10th and 12th centuries, and the geographical area examined is the north-west of Europe, composed of England, the north and west of France and southern Sweden. Skeletal assemblages from Greenland, the south of France and Denmark, despite being available for study, were not included in this project in an attempt to restrict it to a manageable size.

The assessment of health and a comparison between the regions was the main drive of the project and it was attempted to investigate whether northern Europe could be treated as a single geographical unit when assessing health. Health, however, is a widely encompassing term and many health indicators could be used to provide as full a picture as possible. This was not possible here, and the research was limited to analysing certain aspects of health in the form of the analysis of primarily infectious diseases. To place health data in context, population studies were also used in the form of age and sex profiles, and isotope analysis.

A deciding factor at the beginning of this project was Northamptonshire Archaeology's request for an analysis and report of the late Anglo-Saxon cemetery of Wing in

Buckinghamshire, excavated in 1999. Permission was granted to use the skeletons for this research project, which included authorisation for destructive sampling. The skeletons were stored at the University of Leicester for part of this project. To a large extent, the human remains from the Wing excavation formed the starting point for this PhD. Other sites were selected according to availability and adequate bone preservation and included Fishergate 4 (York), St Nicholas Shambles (London), Ipswich, Abingdon (Oxon) and Raunds Furnells (Northampton).

It was originally intended for the project to be an early medieval comparison of health in England and southern Scandinavia. To this purpose, six months were spent in Denmark gathering data from the collections Lille Skt Mikkel and Hesselbjerggård in Odense (under the guidance of Professor Boldsen) and in Copenhagen (with Dr Bennike). The investigation of Fjälkinge, a Swedish site, was also planned. The Scandinavian material, however, did not match expectations. The skeletal preservation of the Danish material was worse than anticipated, with bones very fragmented and the majority of the skeletons were incomplete. Access to Fjälkinge also proved difficult. Regrettably, these sites could no longer be included in the project. At this point it was decided to modify the project and include two other Swedish sites and some French sites.

Spending weeks at a time in France, Denmark and Germany in various laboratories was not only useful to access data and archives, but also an opportunity to learn new skills (for example a new method of lifting very fragmentary skeletal material from the ground, working with mummies, learning paleohistological techniques). Attendance of local conferences and seminars challenge views and offer the opportunity to participate in other research projects and be aware of new research directions. When I was at the Anthropological Data Base Laboratory at the Odense University in Denmark (ADBOU). The group had just started working on a large research project assessing the prevalence of leprosy in early medieval southern Scandinavia. Soon an overall picture emerged: 1) there was a higher prevalence of leprosy in Scandinavia than expected from the 10th century onwards, and 2) there were very few cases of tuberculosis during that period (ADBOU, unpublished data). These finds would tend to contradict the British experience of those

diseases. In Britain, leprosy only became a significant disease from the mid to late-11th century (Orme and Webster 1995; Roberts 2000) and tuberculosis, although at a low prevalence, was constant during the medieval period (Roberts and Cox 2003: 390-1).

To make up for the limited Scandinavian material, new options were pursued. Co-operation with Professor Blondiaux and Dr Alduc-Le Bagousse offered access to a selection of sites in France. The skeletal collections of Rouen and Cherbourg, stored at the University of Caen, were suitable for this project and full access to the skeletal material and archives was subsequently granted. Access to the skeletal material and the archives of Arras, stored at the Centre d'Etudes Paléopathologique du Nord was also made available, although there was virtually no archaeological information obtainable. The research team led by Armelle Alduc-Le Bagousse was, at that time, working on a very large (950 individuals) Merovingian necropolis called Lisieux-Michelet. A number of cases of congenital syphilis in juveniles had been diagnosed. This was surprising because no evidence of syphilis has been found in England before the 15th century, and even after this date the skeletal evidence is rare, and no osteological cases of congenital syphilis have been so far reported in Britain (Roberts and Cox 2003: 272, 341).

It was clear that there were different patterns of infectious diseases between at least these three regions in northern Europe and that an attempt to assess differences in mortality and morbidity between neighbouring contemporary regions in the Middle Ages was a valid undertaking. The apparent lack of international comparative work in paleopathology meant that this type of research was necessary and would bridge a gap in our knowledge by establishing if these differences were widespread and suggestions for the causes behind them. It would also establish whether the European region observed could be perceived as one geographical unit.

Roberts and Cox (2003:218) put forward a possible explanation for the variability found in infectious disease prevalence. They suggested that the increased prevalence of leprosy in the medieval period in Britain was possibly a reflection of the influx of people with the disease from the continent and a rise in population density. Indeed, it is reasonable to presume that the development of trade and commerce must have meant increased

population movement, and that we might have underestimated its extent and magnitude. The potential of isotope analysis soon emerged as a means to test the theory of extensive migration and population movement. Isotope analysis of human remains is increasingly used in archaeology and anthropology to determine place of origin and migration patterns (e.g. Grupe *et al.* 1997). Isotopes act as a geochemical marker in bones and teeth while they are formed and can thus place individuals in a geographical context when oxygen and/or strontium isotope ratios are analysed.

After an initial discussion with Dr Jane Evans from the NERC Isotope Geochemistry Laboratories (NIGL) at the British Geological Survey in Keyworth on the prospects of this technique for the project, we applied for and were granted a NERC scholarship to undertake oxygen isotope analysis on English skeletal assemblages. We selected two Anglo-Saxon sites: Ketton and Empingham II and analysed the tooth enamel. The bone preservation of the two assemblages was so poor that permission was willingly granted to sample the teeth, the only well-preserved parts of the skeleton. The grant was only provided for oxygen isotope analysis, which I undertook under the supervision of Ms Carolyn Chenery after being trained in the technique and the use of machinery. Strontium isotope analysis is also a major tool used to assess migration, and Jane Evans was able to secure additional funding enabling her to conduct analyses on some of the teeth used for the oxygen work, therefore supplementing the information obtained from the oxygen work. The isotope analysis part of the research was mostly developed in the last two years of the research project, at the NIGL facilities at the British Geological Survey in Keyworth (Nottinghamshire), under the supervision of Dr Evans.

1.2. Difficulties associated with access to skeletal material, archives and reports

Human skeletons from burials are the primary evidence used to reconstruct past health and disease. There are, however, various limiting factors involved in their preservation, discovery, careful excavation and curation, meaning that the quality of the data can be highly variable (Roberts and Cox 2003:13). Firstly, there is the issue of the preservation of the inhumed bodies, the location of the burial ground and the eventual excavation of the

site. The quality and completeness of the skeletal tissues are dictated by the various methods of disposal of the dead (Roberts and Cox 2003:15). The preservation of these tissues is regulated both by intrinsic factors (e.g. abdominal content, obesity, etc.) and by extrinsic factors (e.g. embalming, time lapsed between death and burial, exposure, etc.) (Henderson 1987). Methods of excavation and post-excavation treatment of the remains will also affect the quality and quantity of information available to the human bones specialist (McKinley and Roberts 1993).

Archaeology suffers from a chronic lack of resources, and the added constraints of PPG 16 (Department of Environment 1990), means that it is often the post-excavation work which suffers when not enough funding is available to cover all aspects of an archaeological excavation (Roberts and Cox 2003). The human bone specialists are not blameless themselves either. The lack of standards for recording and reporting data means that the quality and usefulness of the reports are highly variable. In addition, no up-to-date central database of published and unpublished reports (the latter being more common) exists, meaning that access to them is limited (when it is at all available) and consequently leads to an inability to identify gaps in knowledge and understanding (Roberts and Cox 2003). This further hinders comparative work, whether they be intra- or inter-period assessments, as well as the swift advancement of the discipline.

Some bone specialists have bypassed this problem by re-analysing the material completely each time information is needed and ignoring any published and unpublished records. This approach, although widespread (e.g. Tyrell 2000), is very costly and time-consuming. It is not realistic (or feasible) though for one person, given the time and financial constraints of most research projects, to go back to the primary sources. We have to rely on reports, even if they are often incomplete, so that comparative work is not restricted to just a couple of sites. This is done with the full knowledge that access to reliable sources will severely restrict which sites can be included in a project.

1.3. The period of study and choice of sites

Since the mid-1990s, studies analysing regional trends in health or population studies have started to appear, mostly in the form of PhDs (e.g. Duncan 2000, Owens 2003). Very few studies, however, have attempted to introduce an inter-regional approach, and this project is an attempt to redress this apparent deficiency.

It is essential, however, that only sites sharing common denominators are selected, so as to provide a comparative basis without introducing too many variables. The sites chosen for this project were restricted to the northern European areas of England, Normandy and Flanders, which had been transformed by Viking activity and which shared a common cultural heritage through political unity and/or extensive trade links. The period observed was set between the 10th and 12th century, a time of widespread expansion during fairly stable times when trade, local and international, was thriving. Population was growing in response to agrarian success and the relative political stability of post-Conquest politics further obliterated the damages that had been brought on by the Viking raids. By the 14th century, however, a crisis point was reached when food supplies, exacerbated by famine and wars between England, Scotland and France, became insufficient to feed the overstretched population and facilitated the impact of the Black Death (Cartwright and Biddiss 2000).

Some variables were brought in with a mixture of inland and coastal, rural and urban sites. The majority of sites came from urban settings apart from Wing, Raunds, Löddeköpinge and the sites used for isotope analysis. Towns played a major role in trade and international contact, either as coastal towns (Ipswich, Rouen and Cherbourg) or as river towns (London, York and Arras). They were all established sites of at least regional (e.g. Cherbourg), national (e.g. Arras) or even international importance (London, York and Rouen). The rural sites provide a contrast with minimal, mainly local contact at a regional level.

Access and availability of reports, archives and skeletal material largely dictated which sites could be used in this project. Data were gathered using the published reports of York

Fishergate, London St Nicholas Shambles, Empingham II and Raunds Furnells, and from the unpublished reports of Ipswich, Arras and Abingdon Abbey. For Cherbourg, Rouen, Wing and Ketton, data were collected by primary analysis of the skeletal material. For Cherbourg and Rouen, this was complemented by access to the archives. In total, 2,718 adults from eleven sites (and 41 individuals from an additional two sited for the isotope analysis work) have been included in this research project.

Only adult skeletons (i.e. aged 18 years old and over) were analysed, even though childhood mortality and morbidity has been recognised to provide a measure of population health (Lewis 2000). There are many difficulties associated with under-representation, small sample sizes and poor preservation of skeletons of children (Buckberry 2000). It was felt that a different approach and methodology would be required to assess sub-adult health. In addition, changes to the bones, such as periosteal lesions in children, are often difficult to identify and therefore require more specialised experience in examining bones. As reports and archives were heavily relied on for this project, it was felt that there might be uneven quality in the observations, and therefore that adult data might be more reliable. For these reasons, adult skeletal material was preferred to provide insights on population health. It does not follow that our results are any less complete or valid as a result of the exclusion of the sub-adult populations.

The sites investigated for this project were selected because they had extensive contact with other populations. This was the case for the large urban settlements such as York and London, some of the more minor towns, such as Cherbourg, and to some extent for the rural settlements such as Raunds due to their location. Coastal and fluvial towns are likely to have widespread contact with other settlements and individual outsiders, which can lead to the increased infectious disease prevalence.

1.4. Aims and methods

The aim of this project is to assess some aspects of adult health and population profiles in Northern Europe between the 10th-12th century using skeletal material from England, the

north and west France (the historical regions of Normandy and Flanders) and southern Sweden (formally part of the Danish kingdom).

The following criteria were applied to select the sites for the purposes of the comparative study:

- Access to data through archives, published and unpublished reports and primary analysis of the skeletons. Although primary analysis would have reduced inter-observer variability, too few skeletons could have been observed in timeframe and cost limitations of the project. Standardisation in recording methods could resolve this.
- Representativity of the selection of the sites for study and in the case of the use of reports and archives, the reliability of the data. Due to the nature of archaeological investigations, fully excavated cemeteries were only available for two skeletal assemblages (Raunds in England and Rouen in France).
- Comparability of the sites, which were all of the same period (10th-12th century), lay, and a mixture of urban and rural, although with more urban sites (rural ones are often too small). Sites had to be comparable not only in nature (monastic/lay; urban/rural, etc.) but also in the approaches and quality of the excavation, recording, analysis and presentation of the data in the reports.

The analysis of health was accomplished using the following methods:

- **Paleopathological analysis**, with specific emphasis on infectious diseases. Infectious diseases that affect the skeleton only reflect a fraction of the total infectious load populations would have been exposed to in the past (Roberts and Cox 2003:18-19). By selecting some disease markers, however, levels of health can be assessed and compared between sites. This was achieved by analysing a selection of "non-specific stress indicators" (a term coined by Goodman *et al.* 1988:169): here periostitis, enamel hypoplasia and cribra orbitalia; and infectious diseases through lesions suggestive of leprosy, tuberculosis and non-specific chest infections. Non-specific stress indicators complement the study of specific diseases as they indicate chronic conditions and childhood diseases. The analysis of injuries, diet-related diseases and osteoarthritis can also provide useful information and a fuller understanding of health; however, such an

extensive investigation was not possible given the time limitations of the project. The diagnosis of lesions was made using macroscopic observation and for some of the Wing skeletons the scanning electron microscope assisted diagnosis.

- **Paleodemographical investigation**. The assessment of age and sex distribution of a cemetery provides information on the mortality and morbidity of a population as well as offering an insight on the composition of the population during a given period. Paleodemography is a complex discipline which is currently attracting renewed attention in population studies (e.g. Buchet and Séguy, forthcoming).
- **Isotope analysis** was conducted on two sites of Anglo-Saxon date, one early (5th –7th centuries) and the other late (10th-12th century), to assess potential population movement in rural central England. Isotope analysis for migration studies is in its infancy in its application to archaeological questions. Before being able to isolate the migrant component in a given a population, it is necessary to establish the natural variation and means to ascertain maximum and minimum values for native populations. Hence, the work presented in the isotope chapter is an attempt to establish a basic methodology as well as the study of a particular region.

The following objectives were determined:

1. To assess whether northern Europe could be perceived as a single geographical unit when assessing health in the 10th-12th century.
2. To consider the available techniques for the recording of lesions and assess their application to health enquiries at the population level.
3. To detect patterns or differences in disease prevalence and demographic profiles between the investigated populations and assess what factors are involved in producing them.
4. In the case of infectious diseases, to investigate the link between population density and infection.
5. In the case of demography to examine whether the use of partially excavated cemeteries can still provide us with exploitable information.

6. To find out if isotope analysis is a valid tool in the investigation of population movement in the past, and whether it is able to detect immigrant components in an observed population.

Chapter 2. Historical and Archaeological Description of the Skeletal Material

2.1 Introduction

The selected sites from England (see map p.256), France and Sweden share a common historical heritage that is intrinsically linked, providing an interesting basis for the comparison of their populations. Danes and their descendants ruled in part at least both Normandy and England in the 9th – 10th century, and included most of Sweden in their kingdom. The Vikings raids and subsequent colonisation had brought much political and social disruption to northern Europe in the late 8th, 9th and 10th centuries first in England, then in France and the Low Countries (Nicholas 1997:54). As the southern cities of France were being undermined by Muslim attacks, trade routes shifted away from the Mediterranean towards the North Sea. Recovery was perceptible by the 10th century, and the major cities of northern France prospered swiftly. Rouen grew more rapidly than Paris and its prosperity was attributed to its handling the Seine trade with England (Nicholas 1997:65-6). In England, political turbulence and general unrest still marked the country in the 10th and early 11th century. Recovery followed, however, and by the end of the 11th century England became united and relatively secure, an empire with political bases in Caen, Rouen, Winchester and London (Sawyer 1998).

The Norman Conquest of England in 1066 could be perceived as a re-establishment of Viking-descent rule in England, joining the Duchy of Normandy and the Kingdom of England under the authority of one leader. One of the important results of the Norman Conquest in England was the strengthening of close links between England and Normandy, now part of a common political unit. Colonisation and exploitation followed the Conquest, and much wealth was at first transported to Normandy. As the Normans settled in the country in the later part of the 11th century, the deportation of wealth was replaced with investment in the country and landscape, and a revival of trade was observed on both sides of the Channel and port towns prospered (Rowley 1997:10). In the 11th century London was already an important European city with trading links all over the continent whose first call

of port was Rouen, and other English towns were thriving from the export of wool to the growing industries of Flanders (Sawyer 1998:251). Towns were growing and expanding in the 10th-12th century. Buildings, principally churches but also noble residences and castles flourished (Nicholas 1997:88-9), and the colonization by Normans of some Anglo-Saxon *burhs* such as in Shrewsbury and Southampton contributed to the development of urbanization (Rowley 1997:11, Rowley 1983:106).

Flanders had agricultural and commercial strengths rather than industrial ones, but still emerged as an urban region after the Viking attacks (Nicholas 1997:56,80), although cities grew modestly in the 10th century. It enjoyed extensive commercial links with, amongst other nations, Britain for wool and cloth, rendering it very attractive to its neighbours, particularly the French kings, of which it was a vassal. Indeed, the Dukes of Normandy (and by extension the king of England after the Conquest) and the Counts of Flanders were vassals to the King of France.

In southern Scandinavia, urban development began in earnest in the 11th century. Some towns grew from already established trading places such as Ribe, while others such as Lund were founded in areas that had not been previously associated with a particular activity. Denmark, at the time, was attempting to unite Scandinavia into one kingdom and this was achieved by creating new towns such as Lund with administrative and religious centres (Arcini 1999:19). The Vikings had not only been raiders, but also keen on trade and commercial activity (Nicholas 1997:55). The settlements of the period bear witness to imported goods of English, German and Slavic origin, and in the late 11th century King Canute declared that foreigners, irrespective of where they come from, should be granted the same rights as the natives (Arcini 1999:29-33).

For all three regions, the 10th-12th centuries are a period of transition and establishment, and one of prosperity as well, mostly generated by commerce, and of growth with the development of urban centres (Nicholas 1997:64-8, 81). In the 10th century, Flanders was created as an independent *Comté* and Normandy thrived under Viking rule. Denmark was asserting itself as the Scandinavian kingdom. In England, the 10th century saw the

establishment of an identifiable English cultural identity (Sawyer 1998), born of the creation of a sense of English unity, primarily by way of military allegiance (Reynolds 1985:403).

The expansion was seen both in rural and urban England. During the late Anglo-Saxon period there was a gradual coalescence of rural settlement from isolated farmsteads and hamlets to nucleated villages (Nicholas 1997:56; Rowley 1997). Agriculture was well established by the late 11th century and the Normans were not perceived to have been directly responsible for any major agrarian changes (Rowley 1997:29). Settlement patterns that had been established by the time of the Norman Conquest did not change substantially; however, the rising population trends continued and accelerated after the Conquest (Rowley 1997:28) and as the pattern of cultivation changed to produce the cereal needs, new settlements were created (Sawyer 1998:142). Sheep were the most popular form of livestock as they produced meat as well as wool, of prime mercantile importance. Districts such as Essex and East Anglia were dedicated to sheep farming and sheep pasture occupied land parallel to the coastline (Rowley 1997:29).

The late Saxon period had seen the continued development of urban communities in England. Town life that had disintegrated in the post-Roman period gradually re-emerged in the mid Saxon era in the form of trading centres or *wics* (e.g. Norwich). Craftsmen and servants were attracted to the palaces and the religious communities (Sawyer 1998:221). Major religious festivals attracted crowds, which used these centres for local exchange. Viking activity had posed a great threat to this and prompted a phase of building defences and fortified towns, especially in the south (e.g. Ipswich), and defended important river crossings (e.g. Norwich, Shrewsbury) (Rowley 1997:24). Inland travel was possible but it was safer and easier to do business with coastal markets (Sawyer 1998: 222).

The erection of town defences and the creation of burhs provided security for trade and commerce that encouraged the development of a considerable number of thriving towns in late Anglo-Saxon England. Merchants were attracted by the potential and security towns could offer them and long-distance merchants contributed substantially to the capital assets

of some of the cities (Nicholas 1997:115). By the 11th century, economic activity stimulated by trade, saw flourishing markets and craftsmen (Sawyer 1998:233; Nicholas 1997:100-6). The cities were principally centres for consumption, and to a lesser extent trade and manufacturing. The trade that centred on the growing towns in the 11th century was primarily in food and basic industrial products of the surrounding area, and the larger cities also saw overseas trade, such as with the Low Countries (Nicholas 1997:105). The towns maintained strong links with the countryside through markets. Within the walls there was also arable land and agricultural workers (Rowley 1997). Of course, trade and commerce was hugely beneficial to the kings and towns from income drawn from tolls and taxes, generating much wealth.

England was, on the eve of the Norman Conquest, one of the most highly urbanised parts of northern Europe (Nicholas 1997; Sawyer 1998). At least 10% of its population lived in towns. London and York had estimated populations of at least 5000 (Sawyer 1998:204) and 112 places were defined as boroughs by the late 11th century (Rowley 1997:83). The extent and importance of those towns were probably underestimated as towns were used as a mean of centralising political and economic control (Rowley 1983:123). The impetus for urban development was to mark the centuries following the Conquest. Some of the newer towns, however, were not able to maintain their development and either disappeared or shrunk to become larger villages (Rowley 1997:83).

Events during the second half of the 12th and early 13th century, however, had far reaching implications. Flanders and Normandy were lost to the French kings, marking the end of the Norman period in England. There were trade repercussions as the focus was shifted from the north-west of Europe towards mainland France and the south (Sawyer 1998). The growth of urban industry in the 12th century reflected a shift in fashion and industrial technology, with long-distance trade based on manufactured goods such as woollen cloth. The agrarian success of the post-Conquest period, evident in the form of the expanding interregional grain trading in the 12th century, had brought rapid population expansion and increased population density, which had potentially promoted the establishment of infectious diseases such as leprosy (Cox and Roberts 2003:218, Nicholas 1997). As the

growing cities relied on food, often imported from a considerable distance, securing reliable food sources forced agriculture to breaking point (Nicholas 1997:176).

Eventually, crisis point was reached in the 13th and 14th centuries with famines, exacerbated by wars between England, France and Scotland in the 14th century. These intensified the impact of the Back Death, with a subsequent reduction of the population size by 35-50% (Roberts and Cox 2003:225). The evidence for the size of the English population before the 11th century is unfortunately scarce, but an estimate using Domesday records has been placed at 1.5 million individuals (Sawyer 1998:149).

2.2. Presentation of the English sites

The table below provides a summary list of all the sites used in this research project. Eight English sites are investigated, but three of them are only used in specific parts: Abingdon is only used for some of the non-specific stress indicators, and Ketton and Empingham are solely used for the isotope analysis. Three French and two Swedish sites complete the materials.

Site names	Date	Total Size	Total adults	Type of cemetery	Portion excavated (estimates)
English sites					
Wing (Bucks)	11-12th c.	76	63	Rural	*ca.* 25%
Raunds Furnells	10-12th c.	363	191	Rural	95-100%
Abingdon (Abbey)	11-12th c.	74	67	Rural	Unknown
Ipswich (School St)	10-11th c.	95	79	Urban	*ca.* 50%
Fishergate 4	11-12th c.	128	84	Urban	*ca.*50-75%
St Nicholas Shambles	11-12th c.	234	182	Urban	*ca.* 50%
French sites					
Rouen (N-Dame)	10-12th c.	661	375	Urban	*ca.* 95-100%
Cherbourg (N-Dame)	10-11th c.	164	81	Urban	*ca.* 50%
Arras (Préfecture)	11-12th c	67	51	Urban	Unknown
Swedish Sites					
Löddeköpinge	11-12th c.	1176	694	Rural	*ca.* 60%
Lund (T1-3, K3,D3)	10-12th c.	1461	851	Urban	50-100%

Sites used for isotope analysis	Date	Size	Analysed (oxygen)	Type of cemetery	Portion excavated
Ketton	10-12th c	72	23	Rural	*ca.* 90%
Empingham II	5-7th c	153	18	Rural	*ca.* 70-80%

Table 2.1. Sites investigated in this project.

Wing, Buckinghamshire (see site plan h p. 261), is a rural cemetery of late Anglo-Saxon/early Norman date (11th-12th century) attached to the present parish church (All Saints). Northamptonshire Archaeology excavated Wing in 1999 under the supervision of Iain Soden (forthcoming). The rescue excavation preceded land re-development, where two new houses were to be built in place of an old Victorian school, under which part of the cemetery was located, immediately south-east of All Saint's Church. The presence of a cemetery had first been recorded when the school was originally built. The excavation was

limited to the area affected by the footprints of the two proposed dwellings, i.e. approximately 30 m x 20 m. The excavation showed that the original graveyard extended further south and east of the current cemetery, beyond its present confines. The excavated portion is believed to represent *ca.* 25% of the total cemetery (Mark Holmes, pers. com.) and probably formed its southern limit. It is unclear, however, whether the rest of the cemetery is contemporary in date to the excavated portion, or if it extends to later periods. No associated buildings were discovered during excavation.

Dating was established to the 11th and the 12th centuries by an Ethelred II coin and a late thirteenth century cutting through graves provided a *terminus ante quem*. This was later confirmed by radiocarbon dating. The excavated cemetery consists of 76 individuals as well as several disarticulated skeletons. The bone preservation is good, despite some crushing from machinery incurred during the early stages of construction work. The skeletons were analysed by myself under Jenny Wakely's supervision at the University of Leicester. As requested, a report was sent to Northampton Archaeology, which will soon be published alongside the archaeological data.

The Wing settlement dates back from the 7th century and was a farming community. The clay and loam soils still produce high quality grassland for dairy cattle grazing and hay cropping for the feeding of livestock in the winter. Wheat and barley were the main arable crops (Aylesbury Vale District Council 2000). A medium-sized settlement, it was not isolated though its proximity to the river Thames must have provided much contact and exchange. The construction of the manor, castle, a substantial church (extensively modified in the 10th and 13th centuries) and priory demonstrates some local importance (Aylesbury Vale District Council 2000).

The ownership of the manor, which had belonged to the kings of Wessex, passed to the Norman kings after the Conquest. A motte and bailey castle (Castle Hill) was built around that time. Many features of All-Saints church date back to the 9th-10th century and predate the Benedictine priory (Wing or Ascott Priory). The latter was, until the dissolution of the monasteries, the biggest estate in the area and All-Saints church became the priory church.

The considerable size of the church suggests that its patron was someone of note or that the village was of importance (Aylesbury Vale District Council 2000). Maud, daughter of Henry I, gave the manor, church and priory (probably part of her dowry) to the monastery of St Nicholas Andavagensis at Angier in 1130, where it remained for three centuries (Aylesbury Vale District Council 2000). This would suggest some contact with the continent.

Wing, a medium-sized rural settlement, provides an interesting comparison with the other towns of this project, and where possible will be compared with Raunds, a large rural settlement of similar date.

Raunds Furnells, Northamptonshire (see site plan e p. 259), lies north-west of the present village, which is situated on the south side of the Nene Valley in East Northamptonshire. The cemetery was fully excavated in 1977 under the direction of Andy Boddington. In 1979 it became the responsibility of Graham Cadman who directed it until its completion in 1984. Initially the project was to investigate the development of the Raunds landscape, primarily though response to rescue threats but additionally with field, archival and analytical research programmes (Foard and Pearson 1995). With minimum soil erosion, the 363 recovered burials are believed to form the totality of the graveyard. The bone preservation is very good. The skeletons were analysed by Faye Powell and the report published in Boddington 1996.

The settlement of Raunds was established during the 6th century and continuously occupied until the late 15th century. The buildings present in the 11th century may have formed the manor of Burgred, mentioned in Domesday Book. A small church set outside the manor complex in an unused area was built in the late 9th or early 10th century (Boddington 1996). Land was eventually cleared for the churchyard once burial rights were granted, possibly in the early 10th century. The main period of usage of the cemetery seems to have been between the early 10th century and the early 12th century when the church was made redundant and the burial rights were removed (Boddington 1996:14-5).

200 years of building additions and rebuilding of the church ensued and the churchyard was remodelled to accommodate the new designs (Boddington 1996:5-6). At first burials were close (2.5 m) to the church walls. Subsequent overspill to the west and east was followed by the infilling of the north-east and the south-east corners of the graveyard plot (Boddington 1996:11). In the 11th century, adults started being buried closed to the church walls and infants right up to them ('eaves-drip' position) (Boddington 1996:13). The cemetery layout shows clear zonation. The south part of the churchyard and, to a lesser extent, the eastern part, seem to have been more popular areas, particularly for male individuals. Less favour was shown to the female adults, which were more numerous to the west and north of the church (Boddington 1996:55). After 200 years, the cemetery was effectively full and few graves could be added without disturbing earlier burials. Around the time of the Conquest, space was ruthlessly made for new burials, along with plans to build a bigger church. For some reason the new church was never built and the old one was made redundant, and the first generation of inhumations were left largely undisturbed (Boddington 1996). During the late 12th or early 13th century the church was converted into a manorial building and eventually incorporated into the late medieval manor house and, with time, the very existence of the churchyard was forgotten.

It is probable that the cemetery served a population of about 40 people (Boddington 1996:70). The people buried at Raunds were mainly from the manor house, its dependencies and neighbours. A small group of males exhibit signs of external tumble (where the bones, mostly of the torso, are not in anatomical alignment due to decay before burial and disturbances by soil movement and animals), probably because they had been buried in an advanced state of putrefaction. It is possible that they had died while away from the settlement and were subsequently brought back to be buried. Such treatment would suggest that they might have been of some status in the community (Boddington 1996:36).

Abingdon Abbey, Oxon. (no site plan). Abingdon was first excavated in 1922-3 with the expressed intention of recovering the site of the Norman abbey church and conventual buildings as well as the Saxon church (Biddle *et al.* 1968). Stenton's (1913) documentary

searches had confirmed the importance and multi-phase nature of the site. The first monastery had been founded in *c.* 675, but it would appear that a Viking raid had left it derelict. Ethelwold of Glastonbury, on behalf of King Eldred, re-founded the monastery in 959. The Norman church was built between 1091 and 1120, and at the time of the Norman Conquest, the abbey was the largest landholder in Berkshire after the king (Baker 1949). Abingdon was the first of the large monasteries to be closed down after the Dissolution and the abbey quickly became ruinous and buildings disappeared within 50 years (Baker 1949).

The excavation was sponsored by the Society of Antiquaries and Berkshire Archaeological Society. Sir Charles Peers and Sir Alfred Clapham directed it, but most of the work was in fact supervised by Mr A E Preston and his secretary Miss A C Baker, with the digging carried out by four labourers. Biddle *et al.* (1968:61) called the excavation inadequate, even in comparison to amateur excavations of the time. The labourers were left largely unsupervised, Preston had no excavation experience and between them, Peers and Clapham only visited the site eight times (Biddle *et al.* 1968:61). There was no excavation report apart from some site notebooks, and the original compass survey was so poor that the site plan was of limited use. In addition, it was unclear how the trenches interconnected and there were many disagreements between written and visual records. It is only the thorough notes that Miss Baker kept in the form of a diary, trench notes and draft report that enabled any subsequent publication, even though she had no previous experience in excavation (Biddle *et al.* 1968). The skulls were examined by Jenny Wakely at the University of Leicester and the teeth in particular were comprehensively analysed by Nigel James, also at the University of Leicester. They both kindly gave me full access to their archives as no reports have been published. Biddle *et al.* 1968 provides the only published archaeological background to the site.

The presence of a cemetery merely proved to be a hindrance to the progress of the excavation, and most of the skeletal material was pushed aside, bar 75 skulls, three skeletons and a variety of other bones presented to Miss Blackwood (of the Department of human Anatomy, University Museum, Oxford) for the museum collection. They form what is called Abingdon 1, or Abingdon Abbey. The excavation records do not allow us to locate

the position of the graves in relation to each other and the abbey, thus providing dating evidence, but a large quantity of the burials had 'pillow graves'. In other sites where pillow graves were found, they have been attributed to an early Norman date (11th-12th century) (see, for example, St Nicholas Shambles). It is not possible to place the burials exclusively with the monastic or lay cemeteries, but the presence of females and children suggests lay burial for at least some of the graves (Biddle *et al.* 1968:67). The monks were most likely to have been buried in the south-eastern part of the church (Biddle *et al.* 1968:67). Many of the graves had been extensively disturbed, suggesting use over a long period of time (Biddle *et al.* 1968:67). To the north-west of the abbey was the abbey vineyard. In 1989 a lay cemetery of late medieval date was excavated there, revealing over 700 skeletons.

(NB. The nature of the skeletal remains at Abingdon meant that they were only included in the cribra orbitalia and enamel hypoplasia studies)

Ipswich (School Street), Suffolk (see site plan d p. 259). Ipswich is a coastal town dating from the 7th century onwards. Suffolk Archaeology Unit, under the supervision of Tom Loader, excavated the late Anglo-Saxon cemetery from 1983 to 1985. The excavation was both rescue in nature and part of a community programme. It included a group of seven areas and a total size of 2600m^2 (Loader, pers.com.). The cemetery was situated just along the inner side of the south-eastern town defences (which are 10th century in date) at School Street. No church or evidence of buildings was located in the excavation area (Loader, pers.com.). The earliest structure on site is of the 7th and 8th century, the latest near the dissolution of the friary (established in the 13th century) in the 16th century. Most of the structural remains are of the 10-11th centuries. It is possible that there was a church originally, but no evidence has been uncovered so far, although it could possibly have lain further north of the cemetery (Loader, pers com; Wade, pers. com.).

The urban cemetery is believed to be late Anglo-Saxon, and of a domestic nature (Loader, pers.com). Despite the excavation only potentially covering the southern half of the cemetery, the burials are believed to be representative of the period (Loader, pers.com.). The cemetery was dated to *ca* AD 950-1050 using stratigraphy, coins and pottery. No

radiocarbon analysis has been carried out. In 1985, an excavation across the street to the west revealed five isolated late Saxon burials. Such instances are common in Ipswich where possible family groups were buried in land behind properties and a number of isolated bodies have been recovered in the past, all roughly contemporary (Loader, pers.com.). This suggests that cemetery inhumation was not the only accepted form of burial at that time in Ipswich. The site consists of 95 individuals, of moderate bone preservation. The skeletons were analysed by Simon Mays at English Heritage's Ancient Monuments Laboratory and the results presented in a comprehensive, but unpublished, report.

There is evidence of important early industry in early medieval Ipswich (e.g. Ipswich ware) (Alsford 1998). By Domesday, Suffolk was one of the most populated and prosperous counties of England and Ipswich an economic centre for the region (Alsford 1998). Ipswich's location on the coast and its prosperity attracted Viking raiders who plundered the town in 919, which prompted the construction of the town defences. Further raids occurred in 991, 1010 and in 1069, one of the last assaults of the Danes on East Anglia. It also suffered at the hands of the Normans when the Earl of East Anglia Ralph de Guader appropriated one-third of the borough's revenues, greatly impoverishing the town (Alsford 1998, Sawyer 1998:209). The town struggled in the 10th century and the evidence of trade would seem to have been of a local nature (Wade pers. com.)

Ipswich did recover eventually in the 11th century, taking advantage of its location for international trade across the North Sea with access into the Baltic, the Rhineland, Scandinavia and the Low Countries. Ipswich exported primarily medium quality wool and cloth and enjoyed a wide-ranging trade with Flanders and the Low Countries (Wade pers. com.). The town centre saw the development of the various markets i.e. corn, cloth, fish etc. and the quayside was another focus for occupation and commerce (probably wholesale) (Alsford 1998:2). Local trade remained of importance, as there were few market centres in the area (Alsford 1998:3). In Ipswich there were separate street markets for corn and bread, dairy products, apples and wines, meat and poultry, fish and pies, timber and cloth (Rowley 1983:124). Ipswich had access to the river systems, which also meant access into the

agricultural lands of inner East Anglia. Thanks to its commerce and industry, Ipswich soon re-emerged as a prosperous town, with a growing population that had been substantially increased by Danish settlers (Alsford 1998:2). The Ipswich guilds, as in Arras (see below), regulated local trade and commerce and grew in significance from the 12th century onwards (Alsford 1998:14). The period covered by the cemetery coincides with the period where raiders and the advent of new authority constantly challenged prosperity. Despite the politically and economically difficult times, however, Ipswich had managed to keep its commerce and industry active, and was on the way to prosperity.

St Nicholas Shambles (City of London) (see site plan a p. 257), is an urban parish cemetery dating to the 11-12th century (White 1988). The parish church and cemetery of St Nicholas Shambles is situated at the west end beneath King Edward Street and the south side close to and beneath the pavement of Newgate Street. St Nicholas was excavated by the Department of Urban Archaeology of the Museum of London in 1975-77 and 1979, under the direction of Alan Thompson, as a rescue excavation. The land was being redeveloped with a new British Telecom Centre replacing the GPO Headquarters Building. The investigation concerned the small parish church of St Nicholas Shambles and its cemetery, mostly to the north side of the church (area approximately 21 x 17 m) and in the south-western corner of the site adjacent to Newgate and King Edward Street (Schofield 1988:7). The area of excavation was dictated by modern boundaries, but documentary evidence suggests that the excavation comprised the majority of the cemetery on the northern and eastern side of the church. There is no evidence to suggest that there were more burials south and west of the church (Dyson 1988:8). The site was dated 11-12th century using pottery and stratigraphy from the various stages of the expansion of the church and the burial styles.

The cemetery consisted of 234 individuals. The bone preservation is fair but most of the skeletons are incomplete and broken. The skeletons were analysed by William White at MoLAS (Museum of London Archaeology Services) and the results were published in White 1988.

The area of St Nicholas Shambles is believed to have been a sector where butchers resided and exercised their trade (White 1988:49). Excavations close by have revealed early goods from France and Germany, proof of an already expanding international trade (Ford 2001a: 1). Attacks from Viking raiders did not spare London and there were attacks throughout the 9th century but they did not interrupt trade for long. By the 920s the city had become the most important commercial centre in England, with exotic international trade, markets and industry (metalwork and weaving) (Ford 2001a:2). As the port developed, trade flourished in medieval London and the city's population increased steadily, and it was fast becoming far greater than in any other city in England (Ford 2001a:3). London became a major centre for the importing as well as the distributing of goods to other parts of the country. Both William I's Charter and the relative stability that followed the Conquest served to increase both trade and inhabitants as livelihoods were secure once more. By 1100, London had emerged as the most important urban centre of England (Rowley 1983:105-6), an outstanding commercial centre of substantial political importance.

London citizenry might not have then been recognised as a corporate entity, as in the likes of merchant cities of France and Flanders, but it certainly had power. In order to control their industry and trade, merchants and craftsmen of the city organised themselves into a complex system of guilds (Ford 2001b). These were a major influence in the Middle Ages as for instance the money raised by commerce and guilds were eventually able to finance the King's attempts to conquer France (Ford 2001b).

Fishergate 4, York (see site plan b p. 257), is an urban cemetery of the presumed St Andrew's church. The site of the cemeteries of St Andrew's, 46-54 Fishergate, York, lies directly to the east of the confluence of the Rivers Ouse and Foss, west of the medieval street Fishergate (now Fawcett Street and George Street). The site was excavated in 1985-86 by the York Archaeological Trust under the direction of R.L. Kemp. It comprised two adjacent open areas and a series of trenches totalling 2,500 m². There were 412 burials that spread over the 500 years of occupation of the site, which were split into periods, 4b to 6c which were determined chronologically and with the construction of the church. There are

131 individuals attributed to period 4, with good bone preservation. The skeletons were analysed by Gillian Stroud and the results published in Stroud and Kemp 1993.

It is believed that the burial grounds stretch further south and west beyond the limits of the excavation (Stroud and Kemp 1993:121). It is difficult to calculate how much further they spread. Some are likely to be beneath an adjacent hotel car park. It is believed, however, that the excavated skeletons provide a representative sample (Stroud and Kemp 1993:121-2).

The first sign of occupation begins in the 8th century (phase 3). Period 4 and its 131 skeletons are of specific interest here and date from the second half of the 11th century until the end of the 12th century. Ceramic evidence (Stamford ware, splashed and gritty-type wares and small amounts of York glazed wares) was used to date the graves (Kemp 1993:134). Other features include foundations of a wooden church and settlement evidence such as rubbish pits and structural evidence. These features were part of a settlement that may have belonged to a continuous ribbon suburb represented by a number of early churches on either side of the medieval Fishergate (Stroud and Kemp 1993:127). This route, south from Foss Bridge and possibly of Roman origins declined in importance when the city defences were erected in the 12th century. St Andrew's church, later (late 12th to late 16th century) became a Gilbertine priory with monastic inhabitants and well-to-do members of York society buried in the cemetery (period 6) (Stroud and Kemp 1993:121). Evidence of inter-personal violence is clear in period 4: a large number of males bear evidence of blade injuries. A group of them are part of the same grave, which could suggest death in battle (Stroud 1993:232).

The history of York had its share of violence and political upheaval when the Vikings captured York in 866. Under a Scandinavian regime, however, Jorvik became a major river port, part of the extensive Viking trading routes throughout northern Europe including Ireland, the continent and Scandinavia, and reaching beyond Byzantium (City of York Council 2000). This greatly contributed to its development and by the 10th century, York was second only to London in wealth and population (Rowley 1983:120).

In 965 its last Danish ruler was driven out and the Kings of Wessex ruled Jorvik jointly with their southern kingdom. William I came to York in 1069 to subdue rebellion in the North, causing great destruction and bloodshed. In time, however, York was allowed to prosper again, becoming a profitable port and centre of trade, particularly in wool (City of York Council 2000). Craft and industry, always substantial in York, were particularly skilled (City of York Council 2000). York also acted as the main administrative and judicial centre for the north of England, and had a royal charter by the 12th century, confirming its trading rights both in England and in Europe (City of York Council 2000).

York has been fortunate in that some of its rich heritage has been preserved and considered a priority by the town, particularly its Anglo-Scandinavian past. Many excavations have been carried out and the results extensively published (e.g. Addyman 1989). Environmental archaeology has always been of interest to the York archaeologists, and the information it has provided has greatly increased our understanding of past environments (Addyman 1989:244).

2.3. Presentation of the French sites

Rouen, Seine-Maritime (formerly part of the Duchy of Normandy) (see site plan c p. 258), is a large urban cemetery from the cathedral of Notre-Dame (Our Lady) dating from the 10th-12th century. The site is composed of the two sides of the cemetery flanking Notre-Dame cathedral in the town of Rouen. Although the site is split into two zones, Cour d'Albane et Cour des Maçons, they are both part of the same cemetery. Cour d'Albane was excavated in 1985 and the Cour des Maçons in 1997, both under the supervision of Jacques Le Maho. More than 1500 m^2 were excavated, revealing archaeology from the 3rd century AD onwards.

Of the 1,000+ skeletons excavated, only those dating from the 10-12th century were analysed for this project (although four inhumations dating end of 9th - early 10th century were also included in the samples) and consisted of 661 individuals. The skeletons were

well preserved and fairly complete. The skeletons had been previously analysed by Cécile Niel at the University of Caen (France) as part of her master's dissertation and PhD thesis. Full access to the skeletons and archive was granted, and all skeletons were re-analysed by myself, especially with reference to the paleopathology.

Rouen, standing at a strategic place between sea and rivers, was firmly established by Roman times as a port, trade and cloth-making centre and had developed its trade routes, especially with Britain (Le Maho 1994a). Two churches, Our Lady (*ecclesia major*) and Saint Etienne (baptismal church), were part of substantial episcopal complex, common in Gaul at the time in large urban settlements (Niel, pers. com.). Only one cemetery was used for the two churches, although they had zoned areas (for example Saint Etienne, the baptismal church, has a large number of infants).

Fire, raids and invasions contributed to the changing landscape of the town and the churches with destruction and abandonment. The Viking ransacking of 841 brought the most devastation (Le Maho 1994b:65). The first inhumations appear under the eaves of the St Etienne, marking the end of *extra muros* burials (Le Maho 1994b:65). Relics, such as those of the 7th century bishop Romain, protector of the city, were also brought back and housed in the purpose-built St Romain tower at the cathedral. AD 911 marks the official installation of the Viking chef Rollo in Rouen. Christianisation of the Vikings was probably slow and focused on large urban centres such as Rouen (Le Maho 1994a:35-36). From then on, the elite sought burial in the cathedral itself.

Under the Viking dukes major building redevelopments took place and there was a shift from the religious and aristocratic power of the 9th century, to a mercantile one in the 10th century, as Rouen became an important trading centre. Rouen's prosperity was based on handling the Seine's trade with England and transferring river-borne goods to the land route. Rouen was the chief city of Normandy and grew more rapidly than Paris (Nicholas 1997:66). These changes were similar to those occurring in York and Dublin at the time (Le Maho 1994a). Rollo oversaw land redistribution, enabling the installation of refugees from ports and monastic boroughs of the Lower Seine who had fled their communities

since the departure of monastic communities in 885. Many foreigners were noted in Rouen, mostly merchants but also pilgrims. Rouen merchants were also recorded passing the port of London with wine. Although the Normandy rulers were Scandinavian, the population remained generally Frankish (Nicholas 1997:66).

In the 10th century, Notre-Dame saw huge building activity that only ceased in the 14th century (Le Maho 1994a:36-44). Land surrounding the cathedral was also used for housing and workshops. The Cour d'Albane became the cemetery from the end of the 10th century until the end of the 11th century, when it was abandoned because it became too full (Le Maho 1994a:41). The Cour des Maçons, to the south of the cathedral, took over burial duties. Graves multiplied from the end of the 11th until the beginning of the 12th century. As the cemetery filled up, land previously leased by the church was reclaimed to increase its burial capacity. Part of Saint-Etienne church had been destroyed by fire and was also used for burial space, which enabled the Cour des Macons cemetery to expand to the west until the end of the 12th century, when it was declared full (Le Maho 1994a:42). The few burials between the 13th and 16th century are mostly related to the church and not included in my sample. A layer of flint covered the cemetery, now redundant, and some through roads were created. Later it was paved over so as to produce a more impressive vista surrounding the cathedral and the cemetery was relocated (Niel, pers. com.).

The individuals inhumed in the cemeteries of Notre-Dame are of the parochial population, however, its location – the cathedral and its proximity to the bishop's palace - makes it without doubt the place of inhumation of choice of the richer population (Niel pers. com.), as well as that of the parish population. The Cour d'Albane probably combined a bigger proportion of the craftsmen, while the Cour des Maçons had more master builders (e.g. stone masons and cutters) that were involved in the development of the cathedral (Niel pers. com.). It is their workshops, located on the edge of the Cour des Maçons that gave the area its name. The graveyard population, though, was mostly parishioners.

The cemeteries were excavated as completely as possible. Three areas, however, could not be investigated: 1) under the floor of the present cathedral (which has never been

excavated), would include potential burials around the smaller church and under the porch (probably a specially favoured spot for burials); 2) a border of a metre around the walls of the present day cathedral was not excavated for security reasons. Le Maho, however, believes that few skeletons located there would have survived the Second World War bombs and the pits created by the blasts (1994c); 3) burials located just outside the excavation area (urban works undertaken in the proximity of the cathedral, however, have not located any other burials. It is therefore supposed that the majority of the burial ground were within the bounds of the excavation). In spite of the limitations, the archaeologists believe that at least 90% of the cemetery was excavated, a near fully excavated site cemetery representing a comprehensive cross-section of the people of Rouen at the time.

Cherbourg, Manche (formerly part of the Duchy of Normandy) (see site plan g p. 260), is a small 9th-11th century coastal urban cemetery attached to the church of Notre-Dame (Our Lady). The cemetery is located on the site of the old castle, in close proximity to the port of Cherbourg. The rescue excavation was conducted in two sessions: the Notre-Dame car park excavations of 1978 and 1981, under the supervision of Jaqueline Pilet-Lemière, and the Place Foch excavation of 1995, under the supervision of F. Delahaye. About half of the total cemetery is believed to have been excavated (Pilet-Lemière, pers.com.). These excavations are the only ones to have been conducted in Cherbourg. The town's archaeology is relatively unknown. J. Pilet-Lemière has excavated many trenches throughout the town, but these have unfortunately revealed little about its past (Pilet-Lemière, pers.com.).

In total 164 skeletons were excavated. The skeletons were reasonably well preserved, but those from the earlier excavations have suffered extensively from the poor surplus storage facilities at the University of Caen. They are stored in dark and damp surroundings where fungi has contributed to the decay of the material and the cardboard boxes that contained them. The skeletons had already been damaged in the 17th century during the destruction of both civilian and military quarters of the castle, of which little remains today (Alduc-Le Bagousse, pers.com.). An incomplete osteological archive was available, but as it was

particularly focused on metric analysis, I completely re-analysed the material for the purpose of this project.

Until the second half of the 11th century, the church and its cemetery were the only ones identified in the small town, whose origins date back from the 4th century AD. There are three phases in the burial site (Pilet-Lemière, pers.com.). The first one is between the 7th and 8th centuries, when the church and its cemetery were first built. The second phase is the main period of use between the 9th-11th centuries. This coincides with the attachment of Cherbourg to the Duchy of Normandy in 911. As a port it was of importance to Normandy, as much of its 10th century commercial development was linked to the North Sea. The receipts of a customs post near Cherbourg increased fourteenfold between 1049 and 1093 (Rowley 1997:11). However, Cherbourg never developed to the scale of ports such as Rouen and remained a regional centre of minor importance (Pilet-Lemière, pers.com.).

The third phase of the cemetery starts in 1063, when the parish church became a canons' chapel ordered by William the Conqueror, and thereafter only monks and canons were buried in its grounds. A new church (church of the Trinity) was built further south and took over parish duties including burials (Pilet-Lemière, pers.com.). The cemetery population was mixed and as well as the normal inhabitants it includes better off citizens, sailors, soldiers and inhabitants of the castle (Pilet-Lemière, pers.com.). Cherbourg appears to have been archaeologically and historically unremarkable, a small town of minor military or ecclesiastical importance. It developed strong trading links though, especially with England, links that had been established since the Romans. It was also the main market town for the region as the thick forests further south created a natural frontier with the rest of the duchy of Normandy (Pilet-Lemière, pers.com).

Arras (-préfecture), Pas-de-Calais (formerly County of Flanders) (no site plan), was an urban parish cemetery for the cathedral. The site is located at the centre of the town of Arras on the county hall main square. The east-end was excavated in 1991 and the choir in 1992 under the supervision of Alain Jacques on behalf of the town of Arras. The cemetery was used from the Merovingian period and replaced a Roman building. The inhumations

analysed here were from the chancel and *choeur* of the later cathedral. The burials were dated 11-12th century as they were cut by the foundations of the Gothic cathedral built in the 13th century, providing an *ante quem* date. At the time the main cemetery was *extra-muros* from the cathedral.

67 individuals were excavated. The skeletons were analysed by Joel Blondiaux at the Centre d'Etudes Paléopathologique du Nord and the Institut de Médecine Légale de Lille (Blondiaux, unpublished). There were great difficulties in obtaining archaeological information on this site, as so little is known about it, particularly regarding the conditions of the excavation and of the community that once lived there. The fact that it is a cathedral cemetery allows us to expect that the inhumed population must be similar to that of Rouen.

The history of Arras and Flanders is a particularly complex one in the Middle Ages. Its prosperity from the production of cloth and wool meant that it attracted interest from the neighbouring rulers of the time, keen to acquire part of its wealth and as a result the frontiers of Flanders were constantly being changed as land was conquered or lost, much to the detriment of the people living there. Arras was part of Artois and constantly changed hands between Flanders and France, but between the 9th and the late 12th century, Arras was under the authority of the Count of Flanders (Brown 1997).

By the end of the Roman times Arras had a well-established trade which already included cloth production. The town was destroyed by Germanic forces but was rebuilt in the 8th century surrounding a large monastery dedicated to St Vaast. The monastic activity is thought to have been the leading factor in the establishment of Arras as a textile area (as was often the case in Flanders) (Nicholas 1997:32). The land was otherwise poor and only trade and craftsmanship could bring prosperity. It was ideally situated for trade, with extensive sea and land routes around it. England, its main producer of raw wool, was within easy reach and the finished product could then be sent all over Europe via Arras or Bruges.

The Counts of Flanders, as the Dukes of Normandy and Burgundy, were vassals of the French king, but were in actual fact much more powerful and were able to rule their

territory much as a separate kingdom. In the 11th century Flanders developed its maritime power to counteract Britain, but Flanders' land expansion stopped and from then on, as its economic growth developed, all the efforts of the Counts were spent in preserving their land and wealth from the French and the English. Artois was soon lost, however, when it was given to the French as part of a dowry (Nicholas 1992).

This would only be the beginning five centuries of almost constant battle. However, in the period investigated, Arras was an established and prosperous cloth-making town. Craftsmanship developed and fine raw wool produced by Britain was sent to Flanders to transform it into fine quality cloth. Coastal towns such as Calais received the wool which was then distributed by boats up rivers into inland towns like Arras. The development of guilds, which controlled much of Arras' economic wealth, made the town powerful in its own right as well as the charter that Arras received in 1180 (Nicholas 1997:133).

2.4. Presentation of the Swedish sites (formerly part of the Danish kingdom)

Lund, Scania (no site plan), was part of the Danish kingdom from the end of the 10th century until 1658, when it came under Swedish rule. Lund was created as an administrative and religious centre as part of Danish King Sweyn Forkbeard's attempt to unify the kingdom by urbanising it and building up the administration in its eastern limits (Arcini 1999:13, 28). He ordered the construction of the first church (which is very likely to be *Trinitatis*, i.e. Trinity), as a means of gaining the support of the powerful Church, which he needed in order to model his kingdom into a continental one. Lund soon became one of Denmark's most important towns of the medieval period with the country's largest mint and a flourishing trade and commerce.

The period observed therefore coincides with the urbanisation of medieval Lund and the settlement of its socially and ethnically mixed population. In AD 990, Lund only had one church and churchyard, but went on to have 27 churches and monasteries and an archiepiscopal seat in the medieval period (Arcini 1999:19). By 1536, however, the Reformation caused the destruction of the city's churches and the closure of the cemeteries.

The material for this study derived from three adjacent cemeteries, some of which were used throughout various time periods. Altogether 3,305 skeletons were excavated. The material represents ordinary parishioners (Arcini 1999:17), although the earliest phase of the period observed reflects the new town's diversity with immigrant priests, administrators, artisans and slaves. The existence and approximate location of the Sancte Trinitas (Holy Trinity) church and parish had always been known. During construction works for urban utilities shafts in the neighbourhood of one of the oldest streets Kattesund, the exact location of the church and its cemetery was discovered, together with three other churches and their cemeteries. Years of rescue excavations ensued, with programmes in 1944, 1961, 1974-5 and 1982-4 and conducted by the town's archaeologists Torvald Nielsson, Claes Wahlöö, Anders W Mårtensson and Stefan Kriig (Arcini 1999:20). The bone preservation was good. The skeletons were analysed by Caroline Arcini at the University of Lund in the Department of Community Health Sciences for a PhD. Her work was then translated and published in Arcini 1999.

When Arcini analysed the skeletal material, she coded and split the three neighbouring, but distinct, cemeteries into phases (Arcini 1999:20):

- T for Trinitatis, the first church, which was first made of wood then rebuilt in stone and was in use from *ca.* 990 to 1536 and was, between 990 and 1050, the only church and churchyard of the city, therefore representing the first inhabitants. It was split into T1: *ca.* 990-1020/30, T2-3: *ca.* 1020/30-1100, with T, T4 and T5 spanning between 1100-1536. From T1 to T3 the churchyard was at its largest, spanning over 7,000 square meters, of which 3,170 have been excavated (*ca.* 45%). T1 contained 283 individuals and T2-3 826.
- K3 is for Kattesund, a timber church east of Trinitatis, used between *ca.* 1050-1100. K3 was fully excavated and contained 257 individuals.
- D3 stands for Drotten ('drott' in Norse means ruler), also a timber church situated south of Trinitatis and dating *ca.* 1050-1100. At least half of the cemetery has been excavated and contained 95 individuals.

Kattesund and Drotten refer to the areas of the town in which they are situated. The actual names of the churches and their dedication are unknown. Along with many other churches in Lund, they were demolished in 1100, but unlike Trinitatis, Drotten and Kattesund were never rebuilt in stone, and their existence was therefore forgotten until recently (Arcini 1999:26-7). They represent the very first parishes, which might have catered for specific congregations.

Burial customs of the churchyards seem to have been very specific according to the areas. Log and trough coffins were found in the outer area of T1-3, while in the inner area charcoal or lime grave linings were common. Many graves were found with wooden stick in, on or under the coffin. Arcini (1999:33) interpreted these customs as being evidence of different population groups. According to Biddle (1986), charcoal lining was favoured in graves of high-status individuals and seems to be specifically an English custom. Another English custom, according to Rodwell (1989) is the plastering of lime of the grave to give the illusion of stone lining. According to Rieth (1937), log and trough coffins with sticks are a German and Slav tradition. Burial customs in the southern part of D3 would seem to suggest the presence of a foreign elite, which possibly included some Englishmen, who had an important role in the city as minters, officials and priests (Arcini 1999:36). In K3, there seemed to have been a socio-economic distinction between burials in the south and north of the churchyard.

Lund, as a city, had a varied population. Artisans, labourers and builders must have been required for the construction of the stone and timber churches, as well as the construction of the king's and bishop's courts. Soldiers were also present. Houses belonging to craftsmen, rich merchants and artisans' stalls have been identified and there is abounding evidence of animal husbandry and barns in the city, and pasture land outside the town borders. A large market place and evidence of fishing would have provided the inhabitants with their food requirements (Arcini 1999:29-31).

Löddeköpinge, Scania (see site plan f p.260). The village of Löddeköpinge is situated on elevated ground on the northern bank of the river Lödde in western Scania. Archaeological

remains from the prehistoric period to the early Middle Ages were revealed in the 1960s and 70s when the village was undergoing large expansion (Ohlsson 1980:68). As arable and grazing land was being redeveloped for housing, a comprehensive programme of excavations dictated by the pace and extent of the redevelopment was carried out over a total period of 24 months under the direction of Tom Ohlsson from 1974, joined by Hampus Cinthio in 1977. Finds and structures dating principally around the period 800-1100 were revealed, corresponding to the end of the Viking Age. They included the remains of a settlement (some 60 structures, including 28 pit-houses, hearths, ovens and wells) with a harbour and a market place in the northern part, and an early Christian cemetery and its church in the southern part (Ohlsson 1980). Churchyards only start appearing in Scandinavia after the 10th century when the country is christianised, and large cemeteries only become prominent from the 11th century when urbanisation began in earnest.

It has been established that Scanian villages in the Viking Age with names ending in *-köpinge* were trading places with a chiefly local trade (Ohlsson 1980:74). This seemed particularly true in Löddeköpinge as the area was principally sandy and marshy, and could not have provided suitable arable land close to the settlement. The topsoil only had a depth of 50-90 cm down to the sterile sand (Ohlsson 1980:72). The finds supported the theory that trading activities had been of great importance for the settlement, and the finds would suggest that it was of more than local importance. The pottery was not evocative of typical south Scandinavian Viking Age settlements, but more akin to that found in known large trading centres such as Birka and Kaupang, and indicated intensive relations with the southern Baltic region, western Europe and southern Norway (Ohlsson 1980:74). The settlement was continuously used between *ca.* 800-1100, although some dwellings suggest only seasonal use. Continuity of Viking Age settlements into the Middle Ages is difficult to establish in Scandinavian material. The majority of Scanian Viking Age settlements, however, cease to exist by the 11th century, with no real continuity. Evidence of great changes in the settlement partterns of the 11th-12th centuries have been attributed to agricultural-technical innovations (Ohlsson 1980:111). The period observed here is

therefore a transitory phase between the Viking Age and the Christian Middle Ages, typified by a change in settlement pattern.

In 1974 a churchyard and traces of a timber church were discovered 300m from the current village church, outside and east of the defined settlement area (Cinthio 1980:113). Excavation and analysis of the material was conducted over a decade. The cemetery boundaries were clearly defined in the south, east and north by a rampart and ditches. The western side was not evident due to the area not being available for investigation, but the estimated total area of the cemetery was calculated at *ca.* 5,000 square metres, of which 2,600 were excavated and the total number of graves was estimated at 2,500 (Cinthio 1980:114). 1,412 skeletons were excavated and dated from the first half of the 11th century to the middle of the 12th century by using coins (Persson and Persson 1984:84). The bone preservation was good. The skeletons were analysed by Ove and Evy Persson at the Institute of Archaeology at the University of Lund and the data specifically pertaining to the human remains were published in Persson and Persson 1984, Cintio and Boldsen 1984, Boldsen 1984 and Cinthio 1980.

Infants between the ages of 0 and 2 years of age were concentrated in the central portion of the eastern area, suggesting that a church might once have stood there (Cinthio and Boldsen 1984:116). The church would have been demolished and another one built further to the west. Position of the arms in interred bodies in southern Scandinavian material are taken as indicators of relative chronology and once plotted, it became apparent that the burials in the western part of the cemetery were on average later than those in the eastern part (Cinthio and Boldsen 1984:118). The Charon coins were found in the eastern part of the cemetery and indicated a burial date of AD 1050-1100 (Cinthio and Boldsen 1984:120). Once the cemetery was extended westwards, few graves were dug in the eastern part of the cemetery, suggesting that the cemetery was extended and that the new church was built around or a little before 1100.

By plotting male and female locations in the cemetery, there was clear evidence of males favouring southern burials and females the northern part of the cemetery (Cinthio and

Boldsen 1984:123). The burials were then plotted according to total femoral length (femoral length is closely related to living stature), with the taller femora taken to represent higher social standing (especially in sub-optimal nutritional conditions). By doing this, it emerged that the shorter males were buried in the northern part of the churchyard and the taller females in the southern part or close to the church (Cinthio and Boldsen 1984:124-5). Assuming that sex ratios were 1:1 and the sample excavated representative of the whole buried population, the lower echelons of society formed *ca.* 33% of the population, the middle echelon 43% and the upper echelon 24% (Cinthio and Boldsen 1984:126-7) (therefore representing a cross-section of the population).

2.5. Brief presentation of the isotope analysis material (further information about the sites can be found in the isotope analysis chapter).

Ketton, Rutland (formally Northamptonshire) (see site plan j p. 262), is a rural settlement and cemetery dating from the 11-12th century close to Stamford and Rutland Water (large man-made reservoir). The site is situated on Ketton quarry and was excavated 1998 by Northamptonshire Archaeology under the supervision of Iain Meadows on behalf of Castle Cement, the owners of the land.

The settlement consists of a single-cell church, a cemetery and four timber halls. The settlement is small, probably only composed of a few farmsteads. Although it has a church, it is not believed to have been an independent parish. The settlement was in all probability linked to the village of Ketton, about a mile and half away from the site. The erection of the church had probably been a show of social status (Parry, pers. com.). Further north of the site an Iron Age/ Romano British farmstead (2nd-3rd century AD) with a small cemetery has been recently excavated. The site was provisionally dated AD 900 to 1100 using Stamford Ware pottery and later confirmed with radiocarbon dating to *ca.* 1075.

The totality of the cemetery was excavated. However, the cemetery was close to the surface and it is possible that upper layers might have been eroded by ploughing. The Anglo-Saxon cemetery consists of 72 individuals. The bone preservation was poor; bones are fragmented

and eroded. The skeletons were analysed by students under the supervision of Jenny Wakely at the University of Leicester. Jenny Wakely submitted a report to Northamptonshire Archaeology and I re-examined most of the skeletons for the purpose of this project.

Empingham II, Rutland (formally Leicestershire) (see site plan I p. 261), is an early Anglo-Saxon (5th-6th century) cemetery near Stamford. Anglian Water Authority discovered the cemetery by chance in 1974 during the construction of Rutland Water (Timby 1996). The field it was located in was being landscaped into a car park. The site, in a rescue operation, was excavated in 1974 by members of a local archaeology group under the supervision of Sam Gorin, and in 1975 by the Department of the Environment's Inspectorate of Ancient Monuments, under the supervision of Nicholas Reynolds.

The cemetery was probably part of a medium-sized settlement but no buildings were associated with the cemetery. It is possible that the settlement might have been Site 3, which is further east (Cooper 2000:2-3). Grave goods were used to date the cemetery from the late 5th to early 7th century (Timby 1996). 153 individuals (and one cremation) were excavated in total. The bone preservation is extremely poor and little osteological analysis was conducted. The teeth were the only useable material and extensive analysis was undertaken by Justine Bayley and Simon Mays at English Heritage's Ancient Monuments Laboratories between 1974 and 1989, and eventually published in Timby 1996.

2.6. Discussion

The sites selected for investigation in this project were chosen for their availability and their correspondence to specific demographic parameters and population profiles (see chapter 4 section 4.2 for a description of the requirements). They were also chosen because they had been excavated and analysed to high standards. The published reports were for the part most comprehensive and provided substantial archaeological background.

This was, however, unfortunately not the case for all the sites here. An incomplete archive existed for Cherbourg, but there were no reports on the excavation or the analysis of the skeletons, so they had to be completely re-analysed. The archaeologist who had led the excavations was still working at the University of Caen and was therefore able to pass on information about the excavations. Although the human remains from Arras and Abingdon had been comprehensively analysed, they lacked accompanying archaeological information for various reasons. Being unpublished sites, however, it was deemed important to include them in this study so that others could then access their data. Ipswich was in a similar position as the human bones report was unpublished and there were no excavation reports available. Fortunately, I was able to contact the archaeologist in charge of the site who was very helpful in providing information verbally, as well as some site plans. Since Wing and Ketton had been very recently excavated, no reports were yet available, but continuous contact with the archaeologists involved in the excavation also meant that information was available.

In this project, I was particularly interested in using a mixture of sites, some which are better known because they have been published, others that are less known because they have not been published and the reports are in short supply or not easily available. Others, such as the French and Swedish sites, might not have been previously known to British archaeologists and biological anthropologists and would therefore be of interest as they bring a new dimension to the study. This of course meant that large amounts of time were spent contacting the foreign laboratories and institutions, and attempting to locate suitable collections to include in this project. It is hoped, however, that the selected sites provide an appealing combination.

Chapter 3. Isotope Analysis

Strontium and oxygen isotopes as indicators of migration: a pilot study of two Anglo-Saxon settlements in Rutland.

3.1. Introduction to the study of migration in archaeology

Population movement and migration (the movement of people through geographic space) is an essential part of population studies, past or present. Today, relationships are explored between migration and urbanisation, industrialisation, agriculture, development, family structure, gender roles and ideology (Kearney 1986). The study of historical patterns of migration have also contributed to explain its impact on demography and pathology in the past (e.g. McNeill 1979). Previously, scholars had to rely on written text, archaeological landscapes and artefacts, linguistics and place-name studies. The advent of modern population genetics and other scientific tools has provided unique insights in the past and have contributed to a revived interest in the study of ancient migration.

The study of past migration and population movement in history and archaeology has, however, always been fraught with difficulty. One factor is the limited availability of reliable textual resources, especially contemporary ones, which means that heavy emphasis is placed on the interpretation of these documents and archaeological evidence. Interpretation of resources and artefacts is, however, not as objective as it should be. Härke (1998) argued that although it had long been established that archaeologists' attitudes and outlook were shaped by their contemporary social and political context, this insight had failed to have " been applied in more than a cursory fashion to questions of academic views on [...] early historical migrations and the profound changes in outlook concerning this question over the past three or so decades" (Härke 1998:19). He also went on to add that regardless of the lack of fundamental change in the available data, there had been a recent complete turn around in majority opinion on the Anglo-Saxon migration, which now rejected the theory of mass immigration and subsequent ethnic cleansing to favour the current theory of virtually no immigration and complete continuity of the native population

(*ibid*:40). He attributed this to the changes in attitudes and expectations of the archaeologists who interpret the archaeological record (*ibid*:41).

Reynolds (1985) also drew attention to how the use of traditional but misleading terminology causes confusion. This arises because of the association of culture with genetics and language and with biological descent, and can only be addressed by using more accurate definitions. She also highlighted the danger in assuming that the people we call Anglo-Saxon automatically perceived themselves as such and as a cultural unit, simply because they corresponded to a period of time that we had defined. In addition, their perception of identity and difference might not correspond to our modern perceptions of national and ethnic division.

Despite these difficulties, it is still useful to attempt to identify an immigrant component in a site as it greatly contributes to the overall interpretation of the buried population. It is also vital for anthropological analysis. The demographic and pathological investigation of human remains from cemeteries give us insights in the structure of the population, its health and adaptation to the environment, and in some cases socio-economic status and occupation. Population movement will affect the demography, paleopathology and profile of the interred population in relation to the numbers involved, the distance that is covered by the immigrants and the timeframe of the movement. The newcomers would have different health status and exposure to stressors. As well as suffering from diseases they were previously protected from, they could bring with them diseases from their previous habitat to which the native population might have no immunity (Roberts *et al.* 1992). This would have a direct impact on the transmission of infectious disease and diseases associated with the poor and poor living conditions (Roberts and Cox 2003).

It is not always straightforward to recognise the subgroups in a population that gives the appearance of a fairly homogenous community (Brothwell 1981). By adaptating Brothwell's factors for population bias (1981:106) we can establish the following list of likely immigrants and their impact on an established community:

1) Outsiders are often brought in for their specialised skills: merchants, trades- and craftsmen, soldiers, labourers and slaves. Depending on their socio-economic status they might have different health and immunity status and different exposure to pathogens than the rest of the population. The immigration could be short-term, seasonal or long term.
2) The integration of an immigrant or group of immigrants can vary: high status single individuals or marriage partners might integrate into the existing community whereas a lower status or religiously distinct group of immigrants might be segregated from the community.
3) An isolated sub-population could form that might respond differently to stressors to the rest of the community as a whole. As a result, infectious diseases might affect one part of a community to a greater extent than another.
4) Immigrants can take over a part of a settlement and still be a minority when considering the overall population. Slaves or low-status immigrants that are integrated into the population and have adopted its ethnic identity might be still receive different burial rites because of class distinctions which could mark them out archaeologically.

Traditionally, distinction between locals and immigrants in an inhumed population relied on the examination of skeletal metric (such as craniometry) and non-metric traits, as well as the study of grave goods and burial customs, none of which have proved particularly satisfactory. Grave goods and burial customs are heavily dependent on social factors and particularly the notion of ethnic and cultural identity. It is also impossible to distinguish between foreign goods acquired through trade from those that accompanied the immigrant to its new settlement. Lucy (2000:15), in her analysis of Anglo-Saxon burials, rightfully concluded that people buried with 'Germanic' grave-goods were not necessarily migrants or even descendants of migrants. Indeed, grave-goods are more likely to indicate social and economic considerations (Arnold 1997).

The use of osteology to determine ethnic identity has also been beset with methodological and historical complications which have proved almost overwhelming to the discipline (Mays 2000a:277). Craniometrics and non-metric trait analysis have nevertheless been used

successfully to ascertain family groups and ethnic origin in cemeteries (e.g. Lalueza Fox *et al.* 1996; Dodo and Ishida 1990; Malim and Hines 1998:308, 311).

There is a strong genetic component in cranial variability (Kohn 1991) and craniometrics have been an established tool in population studies for some years now, but their use seems to have been limited in Britain when compared to, for example, Japanese or Far-Eastern studies on ancient migration. Mays (1998:101) believes that such disparity is caused by differences in theoretical thought and orientation between Japanese and British archaeology, whereby culture history remains a predominant theme in Japanese archaeology. He also believes that craniometrics have been perceived as 'old-fashioned and politically questionable', leading anthropologists to favour the study of pathological lesions rather than normal skeletal variation (Mays 2000a:277-8). There has been a revived interest in ancient migration since the rise of post-processual archaeology and the current interest in the archaeological study of ethnicity, of which biological relationships are an important component (Mays 2000a:278). So far, however, this has not translated into a revival in craniometrics studies (Mays 2000a:278, Mays 2000b), but rather a quest for new methods, such as ancient DNA and isotope analysis. A probable reason for this is that to conduct craniometric analysis, a representative portion of the skulls in a population need to be fairly complete and with no post-mortem alterations in their shape. This is unfortunately rarely the case.

There are over 400 described non-metric variants in the human skeleton (Saunders 1989), many of which have a significant genetic component in their causation (e.g. the studies of Sjøvold 1984 and 1987, Berry 1978). Skeletal morphology is, however, highly variable within population groups and many traits can be significantly influenced by nutrition and other factors operating during the growth period (Mays 1998:110). A mixture of traits from different groups can also be present in a skeletal assemblage (Mays 1998:103). Tyrell has argued that much confusion has arisen in the archaeological community from a lack of understanding and over-simplification of what non-metric traits can be used for (Tyrell 2000:289). This is reflected in the incomplete recording of the traits which, along with

many still unresolved methodological problems, has led to the unfortunate limited use of non-metric variants in population studies (Tyrell 2000:292).

3.2 The use of isotope analysis in population movement studies

A recent advance in biological anthropology is the ability to determine place of birth and subsequent migration through the analysis of strontium and oxygen isotopes present in animal and human bone and teeth. Once absorbed, the values, which vary according to the geography of an area, become part of the chemical composition of our body. They are then locked into the bones and teeth during growth, reflecting the environmentally available isotopes. They therefore become ecological markers of population movement and locational stability in ancient populations, providing us with a tool for distinguishing migrants from individuals local to an area. They can be used to trace ecological processes and assess fluxes in organisms, communities and ecosystems. They have allowed new ways of examining a variety of topics of fundamental importance to biologists, such as feeding ecology and food webs, nutrient flow and assimilation, habitat use, migration pattern, distribution and discrimination of subpopulations (Katzenberg 2000).

Isotopes are chemical elements that share the same number of protons and electrons, but differ in the number of neutrons. They are divided into stable (which do not decay) and unstable (which decay at a known rate) isotopes or radioisotopes (Urey 1947). A mixture of at least two isotopes, one isotope is usually predominant and the others present in traces. It is the ratio of the two most dominant isotopes that is analysed. Isotope ratio analysis of naturally occuring isotopes is used to define a characteristic chemical signature.

Traditionally, isotope analysis has been the domain of the physical sciences, primarily in geochemistry, sedimentology, climatology and oceanography. Advances in sample preparation and analysis have reduced the cost (currently *ca.* £500 per tooth) and time requirements for such analyses and isotopes are now more widely used in the biological sciences and related subjects such as archaeology and physical anthropology (Katzenberg 2000).

As scientists became increasingly aware of the potential of isotope analysis in archaeology, research into their applications developed rapidly. Stable carbon, discovered almost serendipitously whilst experimenting with ^{14}C on maize. It revolutionised the way paleodiets were investigated, focusing on the greatest human diet change, the transition from hunting and gathering to subsistence farming by using two isotopes: carbon (^{12}C and ^{13}C) and nitrogen (^{14}N and ^{15}N) (Mays 2000b). Carbon isotope analysis in North America has been mostly carried out for the study of the rise of maize agriculture (Schoeninger and Moore 1992), and in Europe to answer the marine vs. terrestrial diet components between the Mesolithic and the Neolithic, e.g. Tauber (1981 and 1986). The information gained on the type of nutrition preferred and/or available to individuals in the past provides information on their nutritional status and its effect on growth and development as well as stress and health (Larsen 1997). Cultural differences caused by access to foodstuffs according to gender or social position have also been examined using lead isotope analysis, such as in Carlson (1996).

Migration investigations have been the most recent application of isotope analysis in the field of archaeology and anthropology through the use of strontium and oxygen isotope analysis. Various studies have firmly established their use. The first attempt to use oxygen isotope ratios to an anthropological end was the analysis of soldiers from the war of 1812 who died at the Snake Hill site in southwestern Ontario, for the purpose of identifying their place of origin, and hence nationality (Schwarcz *et al.* 1991). Recently, two historical Mexican populations were successfully assessed for population movement and locational stability using oxygen isotope analysis (White *et al.* 1998). Strontium is slightly more established with thorough and larger scale analyses. Grupe and Price's work analysed the strontium ratios in the teeth and bones of the Bell-Beaker burials in Bavaria. The results suggested great mobility, with a fifth to a quarter of the population coming from regions with different geologies, up to 220 km (Gruppe 1996; Price *et al.* 1998). Price and colleagues assessed patterns of migration in the Grasshoper Pueblo in Arizona, using modern rodent remains to give an indication of local values, and it emerged that a third to

half the individuals were immigrants from at least two distinct geological areas, results that confirmed zonation observed in the cemetery (Price *et al.* 1994a,1994b; Ezzo *et al.* 1997).

Because the application of the technique to archaeological materials is still relatively recent, it has not been undertaken on many sites so far. We are therefore severely lacking comparative material. Ideally, a large proportion of samples from all the investigated sites would have had their isotopes analysed. It was, however, impossible financially or during the time frame of a PhD to conduct so many analyses. In addition, the method is destructive, and few curators would allow it on a large scale. It was therefore believed to be more suitable in the context of this project to conduct an pilot study that would not only contribute to our knowledge of migration patterns in England, but also increase our understanding of the uses of isotope analysis in migration research. Our aim here is to observe and define the natural variation in strontium and oxygen isotope in a local population. This should contribute towards providing future researchers with a controlled set of data against which to compare populations of unknown origin and diversity. In a first instance, we will simply attempt to determine whether the individuals come from the Rutland area.

For these purposes two neighbouring archaeological sites from Rutland were chosen. Ketton, a late Anglo-Saxon settlement, provided the opportunity to investigate a self-contained and potentially static small community, which was unlikely, on historical grounds, to have contained migrants. Despite poorly preserved skeletal material, a selection of non-metric traits could be observed denoting four possible family groups and supporting the hypothesis of family groups with no or little exotic components. Empingham, situated on the other side of the valley just a couple of miles away from Ketton, was an early Anglo-Saxon settlement larger than Ketton (Cooper 2000, Timby 1996). Grave goods provided some evidence of overseas trade or contact, and its setting near a time of great population movement caused by the Anglo-Saxon colonisation of England, would suggest an increased likelihood of the presence of an immigrant component. Unfortunately the skeletal material was too poor to conduct metric and non-metric analyses. The working hypothesis was that

it would be more likely to display a higher proportion of non-native settlers and that this diversity would be reflected in a greater isotope diversity.

It was decided to use cattle, sheep/goats, pigs and horses from the settlements in addition to the human remains to assess natural variability within a local population, to aid the distinction between immigrants and native individuals. The animals were used as a baseline against which human samples were compared. Price *et al.* (2000) investigated the relationship between animal skeletal tissue and human remains in terms of $^{87/86}Sr$ values. They concluded that small animal remains, such as rodents, provided a homogeneous signal of local Sr levels and a strong correspondence with the indigenous humans, providing a good proxy for measuring the Sr isotope ratios that are biologically available to the local human population. Species used largely depended on availability. Their research focused on small animals because they were easier to collect in large numbers, although small animals have smaller home ranges and may not incorporate all sources of Sr available in the area of a given site. They recommended use of archaeological animals, as modern animals might differ from local sources of Sr isotopes for various reasons: composition of feed, pollution, fertilisers etc. Archaeological settlement sites usually have skeletal remains of many domestic animals such as cattle and sheep, which can provide us with the acceptable range of values for a local community, as was attempted here.

The project was submitted to the NERC Isotope Geochemistry Laboratories Steering Committee who approved the oxygen isotope analysis for the thesis and strontium isotope analysis was undertaken under separate funding by Jane Evans. This is currently being written up as Evans and Tatham (2004), and Tatham, Evans, Chenery (forthcoming). The oxygen analyses were carried out by myself under the supervision and guidance of Carolyn Chenery.

As oxygen isotope analysis have been less frequently used to answer migration studies, this study focuses mainly on the oxygen isotope analysis of animal and human tooth enamel to address the following questions:

1) What is the external reproducibility (natural diversity) of oxygen isotopes in a static historical UK population?
2) Is the mean isotopic value of the population consistent with modern day estimates of drinking water in the area?

   If it is not the case, could it be due to:

   a) climatic differences between present times and Anglo-Saxon times?
   b) different sources of drinking water?
3) How do the children compare to adults – do we see a consistent trophic (relating to feeding) shift in the oxygen ratios? Is it comparable to modern shifts?
4) What is the reproducibility of oxygen in animal populations? Do the calculated drinking water values of the animals concur with that of the adult humans? If not is it due to:

   a) different drinking water supplies?
   b) calibration line (the correlation of values to a standard for comparative purposes) differences?
   c) different growth patterns on animal teeth?

3.3: Strontium isotopes (Sr)

Several studies have been carried out in the last ten years using strontium isotopes to investigate modern animal mobility and migration away from the place of origin through the natural uptake of geological strontium (Chamberlain *et al.* 1997, Hobson 1999, Koch *et al.* 1995, van der Meerwe *et al.* 1990). They have also investigated hominid and animal fossils for migration and feeding strategies (Horn *et al.* 1994, Koch *et al.* 1992, Sillen 1998). Ericson (1985) is widely credited with bringing the potential of strontium isotope analysis to answer questions of migration to the attention of the anthropological community.

Strontium is believed to be the most useful isotope to be used as an indicator of population movement (Price *et al.* 2002). The bedrock is the primary source of the strontium isotopes (Capo *et al.* 1998). Radiogenic ^{87}Sr is formed over time by the decay of rubidium and comprises approximately 7.0% of total strontium. The other naturally occuring isotopes of

strontium are non-radiogenic and include ^{84}Sr (~ 0.56%), ^{86}Sr (~ 9.87%) and ^{88}Sr (~82.5%). Variation in natural materials is conventionally expressed as a strontium isotope ratio ($^{87}Sr/^{86}Sr$) which varies among geological terrains as a function of the relative abundance of rubidium and strontium and the age and type of rocks. Ratios of $^{87}Sr/^{86}Sr$ generally vary between 0.700 and 0.750 for English values. Geological units that are very old (>100 mya) and had very high original Rb/Sr ratios will have very high $^{87}Sr/^{86}Sr$ ratios. In contrast, rocks that are geologically young (<1-10 mya) and that have low Rb/Sr ratios, such as late Cenozoic volcanic fields, generally have $^{87}Sr/^{86}Sr$ ratios less than 0.706. Rocks that had a very low initial Rb/Sr ratios, such as basalt, can have $^{87}Sr/^{86}Sr$ ratios less than 0.704. These variations may seem very small, but they are exceptionally large from an instrumental standpoint and far in excess of analytical error (Price *et al.* 2002:118). (see map of strontium values p. 266).

Strontium in the bedrock filters into soil and groundwater and eventually into the food chain (Sillen and Kavanagh 1982; Price 1989). Strontium does not fractionate, meaning that the isotope ratios recovered in rock, groundwater, soil, plants and animals should reflect those of the underlying bedrock (Price *et al.* 2002:118), although the absorption levels can vary due to many bio- and geochemical factors. The strontium concentration diminishes throughout the trophic levels (Faure 1986). Recent research (Sillen *et al.* 1998, Burton *et al.* 1999, Price *et al.* 2002) has demonstrated that high variability of soil and plant values can be caused by the high variability in the strontium ratios found in the bedrock itself, meaning that values can vary within a small geographical area.

If the biologically available Sr isotope ratios can differ substantially between bedrock and environmental values (such as soil and plants), it can make isotope analysis on human remains potentially less precise as their source of intake can be highly variable and not restricted to a defined geographical area. However, studies such as Vogel *et al.* (1990) on elephant bone and ivory have shown a surprising homogeneity in the strontium values in spite of heterogeneity in rock, soil and plant isotope ratios. Price *et al.* (2002) argued that bone and tooth formation act as a powerful averaging mechanism for local $^{87/86}Sr$ values,

and that as a result animal and human skeletal tissue can provide a good estimate of biologically available strontium.

The Sr isotope composition of bones and teeth acquired through diet will therefore reflect that of the local geology so that it can be used as a geographical tracer of where the individuals grew up (during the formation of the bones and teeth) and died. Recent research into the composition of skeletal tissues has amply demonstrated both the possibility and the practicality of using Sr isotopes to identify immigrants in archaeological sites (e.g. Price *et al.* 1994a and 1994b, Ezzo *et al.* 1997, Sillen *et al.* 1998). Price *et al.* (2002:119) identified two issues from such investigations, which require attention:

- Because the levels of Sr isotope ratios environmentally available vary considerably within a local area according to the bedrock, we cannot determine a specific ratio for that area. In addition, in an omnivorous human diet the food catchment area is potentially large and possibly derives from varied geological sources.
- Similarly, the unavoidable variability present in human bone and enamel isotope ratios can make it difficult to distinguish some migrants from locals. Extreme values that clearly demarcate an outsider are not a problem, but there is no objective criterion for distinguishing individuals with values close to the local range or average.

We attempted to rectify this by using the animals to provide us with the range of values acceptable for a local population. To create a confidence limit for separating migrants and indigenous individuals, the mean of biologically available strontium isotope ratios +/- two standard deviations is used. While this criterion is arbitrarily selected, used conventionally it becomes an objective means of identifying residential change in archaeological contexts.

3.4 Oxygen isotopes

Oxygen isotope analysis has been primarily used in paleoclimatic studies, particularly to elucidate shifts from ice ages to warmer climates. Cores from former lakes can reveal temperature and climate shifts over thousands of years (e.g. von Grafenstein *et al.* 1996). The $\delta^{18}O$ of meteoric (rain) water is a key proxy in many approaches to paleoclimatic reconstruction.

Oxygen has three stable isotopes with the following abundance: ^{18}O (99.763%), ^{17}O (0.0375%), ^{16}O (0.1995%) and the $^{18}O/^{16}O$ ratio is normally determined. Urey (1947) proposed that the oxygen isotope ratio in various minerals depended on two variables: the local environment temperature and the oxygen isotopic ratio in the environmental (i.e. surface and rainwater) water. The isotopic abundances are very small, so they are expressed as parts per thousands (‰, read as parts *per mil*) relative to an international standard. The common standard for oxygen is SMOW (Standard Mean Ocean Water) which has an arbitrary value of 0. When the ratio has been calculated and corrected using the standard, the δ notation is used, where $\delta x = [(R_{sample}/R_{standard}) - 1] \times 10^3$ (Ehleringer and Rundel 1989). R_{sample} and $R_{standard}$ are the high-mass to low-mass isotope ratios of the sample and the standard respectively. Positive δ values indicate an enrichment in the high-mass isotope relative to the standard, negative values indicate depletion, therefore a lower temperature (Koch 1998).

In general, the $^{18}O/^{16}O$ in surface waters (referred to as meteoric waters because they come from rain) and in precipitation vary predictably along latitudinal and temperature lines (Dansgaard 1954, 1964), and to a lesser extent altitude and distance from the sea (which are secondarily affected by temperature) (see oxygen cycle map p. 265). Worldwide studies of the oxygen isotope ratio distribution in rainfall have revealed that variability within the system is quite high (Dansgaard 1964), however, this variability is listed and fairly predictable and has a limited affect in a study over a small area of Britain (Darling *et al.* 2003; Darling and Talbot 2003). The drawing in the appendix explains how the isotopes contained in water will have varying ratios according to temperature and humidity, which affect evaporation and precipitation. In England, for example, since rain varies predictably along longitudinal lines, the oxygen isotope ratio of surface waters in Cornwall will be different from those in the east of Scotland. (see map of oxygen values p. 264)

The potential use of oxygen isotope measurements of mammal bone phosphate (which forms teeth and bones), including fossil bones and teeth, to elucidate palaeoclimates was recognised long ago (Longinelli 1973, Longinelli and Peretti Paladino 1980, Longinelli 1984, Luz *et al.*. 1984, Luz and Kolodny 1985). The oxygen isotopic ratio in body tissues

reflects the origin of the water imbibed as a liquid and, to a lesser extent, the oxygen obtained from food (Longinelli and Peretti Paladino 1980). For animals or humans living in a single watershed and drinking water of the same isotopic composition, we expect similar isotopic ratios in bone mineral (Longinelli 1984). Paleoclimatic investigations using human teeth have also enabled the explanation of historical events such as the decline of the Norse colonies in coastal Greenland (Friecke *et al.* 1995).

Because oxygen isotope ratio is altered according to temperature, and assuming that it is stable, it can also reveal locality through the absorption of local drinking water. This provides us with ecological markers of locational stability or movement. As a result, oxygen is now increasingly being used in migration studies in archaeological populations to identify foreigners in a population and the geographical origin of immigrants (e.g. White *et al.* 1998, Schwarcz *et al.* 1991), although many scholars believe this potential has been largely untapped (White *et al.* 1998:643).

3.5. Oxygen equilibration and fractionation in mammals

Between drinking water and showing the ratios in teeth and bones, a complex process of assimilation takes place. As the water is ingested, it becomes body water (δ_{bw}). The $\delta^{18}O$ of a mammal's body water is controlled by the balance of oxygen-containing compounds entering and leaving the body. The most significant oxygen inputs are principally the water drunk (δ_w) (Longinelli & Peretti Paladino 1980, Longinelli 1984), followed by the water contained in food and respiration of atmospheric oxygen (O_2) (Schoeninger *et al.* 2000). The outputs are milk, urine, faeces, saliva and sweat. It is the variation in the balance of these oxygen inputs and outputs that control the relationship between the body water and the $\delta^{18}O$ of the local drinking water, which therefore varies with ingested water and oxygen fluxes, rather than with environmental temperature (Bryant and Froelich 1995). As large mammals have lower metabolic rates, the relationship between body water and drinking water is increased (Bryant and Froelich 1995), so the calculation for extracting drinking water for mammal's teeth and bones will not be the same according to the animal's body size.

The body water oxygen pool then equilibrates with the phosphate in the body (that forms teeth and bones) at a relative temperature of ~ 37°C for all animals over one kilogram (Longinelli 1984, Luz, Kolodny & Horowitz 1984, Luz and Kolodny 1985). The isotope values that were present in the body water at the time are locked within the mineral components of the teeth and bones. The composition of the body water therefore controls the oxygen isotopic composition of teeth and bone and their phosphate oxygen (PO_4) isotope composition reflects the environmentally available ratios (Longinelli 1984).

The nature of the fractionation between $\delta^{18}O_w$ and $\delta^{18}O$ PO_4 or $\delta^{18}O$ of body water has been established empirically for several groups of mammals and appears to be linear, although the slope and intercept show interspecific variability (Longinelli 1984, Luz *et al.* 1984, Luz and Kolodny 1985, D'Angela and Longinelli 1990, Ayliffe 1991) (see the fractionation equation curves p. 265).

The $\delta^{18}O$ value of mammalian body water can also be affected by dietary behaviour as well as physiological processes (Friecke *et al.* 1998). It has usually been assumed that variation in $\delta^{18}O$ values of mammalian tooth enamel are due mainly to seasonal variations in the isotopic composition of ingested water, but seasonal changes in metabolic processes occuring within an animal itself may be the source of some or all of the intra-tooth variation. In their study, Friecke *et al.* (1998) compared the oxygen value of two sets of cows in the same climatic conditions but using different husbandry methods. The Wyoming cows were free ranging and they showed large intra-tooth variation. The Iowa cows were given dry food and tap water from the city. This lack of isotopic variation in the water resulted in a lack of isotopic intra-tooth variation and established the dominance of ingested water in determining $\delta^{18}O$ values. These data also demonstrated that in the absence of isotopically variable water, there is an insignificant amount of variation in $\delta^{18}O$ associated with seasonal changes in the metabolism of bovids that are not experiencing extreme dietary stress or environmental conditions.

There are many factors associated with variation, such as diet and seasonality. Sheep are selective grazers and are most likely to eat more leaves of grass than dry material but also enjoy tougher pasture such as moorland. Cattle are also grazers and eat grass leaves, but are less selective and are more likely to eat a higher percentage of dry plant material and hence drink more surface water relative to sheep. The difference in the summer might be greater between the sheep and the cattle. Other factors such as age and access to surface water and ground water are also important (D'Angella and Longinelli 1990; Longinelli 1984). Earlier papers by Kohn (1996) and Kohn *et al.* (1996 and 1998) assessed how physiology, diet and seasonality affected oxygen variability in animals. Balasse's studies (2002 and 2003) on intra-tooth variation and sampling have greatly expanded the picture by demonstrating the presence of seasonal cycles in large mammals' teeth. For the purpose of our study, we attempted to remove as much enamel down the tooth as possible to average out the variation in the ratios when using animal teeth for isotope analysis.

3.6. Tooth enamel formation and variability in the context of isotope analysis

Bone and teeth retain their oxygen isotope composition for long periods, sufficient to carry out detailed studies of archaeological samples (Iacumin *et al.* 1996), but as biochemists have extended their investigations to older material, preservation of original material and isotope compositions have become increasingly problematic.

It has become evident that the oxygen ratio in the PO_4 component of tooth enamel is extremely well preserved, even in ancient samples (e.g. Bryant *et al.* 1994 analysis of a 12 Ma fossil horse teeth). Traditionally, bone has always been used preferentially for isotope analysis, mainly because collagen is required for palaeodiet investigation (isotopes and trace elements), as well as needing large samples for the various analyses. There are some substantial difficulties, however, associated with using bone, predominantly the risk of diagenesis (the physical and chemical changes occuring post-mortem after burial) and contamination of the sample after burial. Biogenetic phosphates are compositionally complex, and their chemical components do not all withstand isotopic alteration after burial. Bone, being porous, is particularly susceptible to diagenesis.

Budd *et al.* (2000) measured strontium abundance and $^{87}Sr/^{86}Sr$ ratio of 14 prehistoric and medieval human teeth from different individuals from four sites in the UK. They compared values in available soil, dentine (which they believed to be similar to the taphonomic processes observable in bone) and enamel to examine the integrity of the original biogenic material. The study documented significant differences between enamel and dentine in most instances, and minor differences between dentine and the soil. The authors argued that strontium abundance in the majority of enamel samples was similar to modern, unburied values. They concluded that enamel is less susceptible to diagenesis than dentine and, by extension, bone. The poor dentine values were caused by re-equilibration of the dentine with the values of the soil. Analysis of the bioavailable soil isotope ratios is therefore vital to assess and interpret data and to assess possible re-equilibration if bone must be used. It is also imperative to take into account the variation in bone formation and turnover, dependent amongst other things on age, sex and health, which makes the timing of a migratory event difficult to pinpoint.

Tooth enamel thus seems to preserve its original isotopic values over much longer periods than does bone (Lee-Thorpe and Van der Merwe 1987) because of the good crystallinity of its apatite and extremely low porosity. Tooth enamel is almost entirely composed of hydroxyapatite (a biological apatite also referred to as bioapatite), a calcium phosphate mineral whose general formula is $Ca_{10}(PO_4)_6(HO)_2$. Biogenic and mineral apatites are unique in that the phosphorous-oxygen bond is very strong, making it resistant to degradation and diagenesis and isotopic re-equilibration except under extreme acid/alkaline soil conditions or by microbial mediation (Kohn 1999:335).

When compared to bone, tooth enamel is particularly resistant due to its high structural density. Mineral fibres cluster into bundles that are highly elongated perpendicular to the surface of the tooth and that form an extremely compact, intergrown network (Kohn 1999:336). Studies of the pattern and process of enamel formation (for both deciduous and permanent dentition) have revealed considerable complexity and demonstrated that the enamel mineralisation is a progressive and discontinuous process (Balasse 2002:156). This

process is accomplished in at least two stages in which the mode and gradient of mineralization differ: 1) matrix formation and secretion with initial mineralization, 2) the stage of maturation with completion of mineralization (Hillson 1996). Because enamel is not remodelled once formed, its isotopic composition is a chronological record that reflects dietary and climatic factors at the time of its formation (Kohn 1999:335; Balasse 2002:156).

Time resolution in measurement of intra-tooth isotopic formation depends on the precision of the sampling procedure but also in the pattern of enamel formation (Balasse 2002:156). The timing of tooth formation and eruption is an important concern for interpreting oxygen and strontium isotope trends. The range of eruption times reflects natural variability among individuals. Unfortunately, the timing of initial enamel mineralization is not well known for most animals, nor is the duration of the mineralization period. It is well known, however, for the deciduous and permanent teeth of humans (Hillson 1986).This means that taking a sample of the same length in two different species will not cover the same time period. White *et al.* (1998) suggest that sampling of 10-30% of the length of a cattle tooth probably corresponds to 1-6 weeks of enamel production. For many animals, relating specific tooth compositions to specific seasons is complicated by the potentially long duration of tooth enamel production and the difficulties of sampling exactly the same location on each tooth (Kohn *et al.* 1998). Balasse (2003:8) suggests that little can be done about the duration of enamel mineralization, but that the sampling procedure can be improved. For our analysis, we have endeavoured to take as much crown enamel as possible vertically to ensure an averaged value for each tooth.

Formation of enamel is a two-stage process. First, an organic matrix is laid down which is then mineralised to become hard. This process occurs 'top down', i.e. from the apex of a tooth crown to the cervical junction, so that the enamel at the apex of the crown is older than at the base. In humans and other omnivores the teeth have relatively shallow crowns and long roots and the whole of the crown is apparent in the jaw, with occlusion and wear only commencing only once the crown is fully erupted (Hillson 1986, Berkowitz *et al.* 1992). The crowns of permanent premolars are formed between the ages of 2 and 7 years.

In ruminants, such as sheep and cattle, the teeth have tall (hypsodont) crowns and short roots. This structure is an adaptation to the high levels of attrition experienced by animals subsisting on a herbivorous diet. Tooth growth and eruption are prolonged so that the teeth are in use while still developing, and much more of the crown is still inside the socket. In young animals, wear at the apex is compensated by continued eruption of the crown, and root development is a late event (Young 1975, Hillson 1986). Bovine molar crown development is complete within 6 months for the first permanent molar, 12 months for the second permanent molar and 2 years for the third permanent molar (Grigson 1982, Hillson 1986).

Oxygen isotope composition is apparently unrelated to tooth type, reflecting the available environmental water. For deciduous teeth, however, $\delta^{18}O$ is also received in a relatively unaltered state through the mother (the first molar and partially the second molar, as they are formed in-utero) (Gadbury *et al.* 2000). Enrichment of ^{18}O in premolars could be caused by breastfeeding (human breast milk is formed from the body water pool and, thus, has an enriched in $\delta^{18}O$ compared with the water imbibed by a lactating mother as milk is an oxygen output (see fractionation section above). Because teeth are formed and erupt according to a known time frame, there are only minute isotopic differences in a given molar on either side of the mandible in the same individual (Balasse 2002 and 2003). Seasonal isotopic patterns are clearly expressed 'down tooth' (i.e. from occlusal surface to cervical junction) (Balasse 2003:7) in a given molar, although our understanding of the possible range in the timing of enamel formation among individuals makes the assignment of isotopes to season somewhat circular at the present time. However, these difficulties are more relevant to the study of diet and seasonal effects than migration.

The enamel isotopic values thus can vary in the following ways:

1) between teeth in the same individuals, caused by seasonal water intake and type of diet. Differences in water conservation capabilities in different animals, their body size etc are also factors (e.g. Koch *et al.* 1989, Bryant *et al.* 1996a&b, Friecke and O'Neil 1996, Stuart-Williams and Schwarcz 1997);

2) within the same tooth. Pioneering studies by Sharp and Cerling (1996), Cerling and Sharp (1996) and Friecke and O'Neil (1996) revealed significant 'down-tooth' (i.e. from tip of crown to cervical margin) isotopic variability linked to the long time span, changing diet and physiology, etc; encompassed in the molars of many large herbivores.

Taking a sample from the whole length of the crown allows seasonal cycles to be assessed. Balasse (2003:5) suggests taking a series of horizontal bands across the length of the tooth, possibly using laser ablation (such as Laser Ablation Inductively Coupled Plasma –Mass Spectrometry [LA-ICP-MS]), but since our aim here was not to record dietary or climatic changes, it was thought that taking samples across the whole tooth would be sufficient. This was easily achievable with animals but proved somewhat more difficult with humans as the teeth are smaller and rounder, with a very thin layer of enamel at the cervix of the crown. As a result, we would be expecting some variability within the samples even if they are considered to be of native individuals.

For the purpose of our study, it is important to remember the following:

- Using tooth enamel for isotope analysis will only be indicative of a change in residence between the end of tooth formation and the death of that individual, providing no information of the age at the time of a residence change or its length.
- Only first generation migrants can be distinguished from a native population. Anyone brought up and buried in the same area is considered native, regardless of perceived ethnic identity.

3.7. Site descriptions: archaeological background of Ketton and Empingham

Empingham II (Emp)

It has been disputed that between the mid-fifth and early sixth century, waves of colonisers, mainly Saxons and Angles, settled in England. The writings of Bede's *Ecclesiastical History of England* suggested that the invading force overwhelmed and slaughtered the native British population that had been left defenceless since the withdrawal of the Roman

army. It was originally thought that by the end of the sixth century a distinctive Anglo-Saxon Britain had emerged occupying the south and east, whereas the native Britons were pushed back to the Celtic fringes to the north and west and remained racially distinct from the Anglo-Saxon (Campbell 1991).

Recent works have played down the size and significance of the migration and its impact on the native population. Even in the east the native British survived, but their presence was less visible (Arnold 1997:26). There might not have been an invasion as such, rather small-scale influxes of people (Roberts and Cox 2003:168). The new settlers would have quickly mixed with the native population so that very soon there was no racial distinction between the two groups, whose genetic makeup was then consequently added to by the Vikings and the Normans (Hills 2003, Reynolds 1985). Few people would have been of pure native or invading descent after a few generations, or would even have known details of their ancestry (Reynolds 1985:399-400).

Until the advent of ancient DNA and isotope analysis, the attempts to quantify the scale and the impact of the Anglo-Saxon colonisation were made using language, place names and artefacts analysis to locate groups of people (e.g. Copley 1986). Archaeology has been more successful at establishing whether it was a case of change or continuity after the Roman period. Excavations have shown that there was a generalised shift from urban living in favour of scattered farmsteads and villages (Vince 1994:108). There seems to be a pattern in burial practices, with cremations in pottery urns popular in the east (as in northern Germany) and inhumation with grave goods favoured in the south. These different practices could be the result of different ethnic groups. Jewellery also shows some regional variances, but the difficulty lies in the precise dating. Because these changes are not uniform, it is unclear whether they are proof of ethnicity or caused by a combination of factors, e.g. economic pressure (Hills 2003). During the sixth and seventh centuries new villages were created in England, increasing the population density. Animals grazed on common land, fields that had been rested for a year, or after harvest. Winters would have been a harsh time for animals (Wakely, pers.com.). Rivers were the main source of drinking water until the eighth century (Arnold 1997:61).

The valley of the River Gwash and the surrounding area of Rutland seem to have been the focus of much Anglo-Saxon activity and saw a concentration of settlements throughout the sixth century (Timby 1996, Cooper 2000:149). Empingham is one of many Anglo-Saxon cemeteries known in the Rutland area, most of which have been excavated earlier last century, often partially and with a lack of interest in the skeletons (Timby 1996). They were frequently only discovered during construction works and were extensively damaged by machinery and agriculture as a result. Further, few reports have been published, providing us with little comparative basis (Timby 1996).

Iron Age and Romano-British occupation is also very much in evidence around Empingham. Empingham I is a small cemetery (14 inhumations), about one kilometre to the south east of Empingham II, which was excavated between 1967 and 1970. It suggests a chronological overlap with the earliest phase of Empingham II, the second cemetery of Anglo-Saxon date in the locality (Cooper 2000:2-3).

The cemetery of Empingham II lies approximately 1.5 km from the present village of Empingham and is within the ecclesiastical parish of Empingham in Rutland. The existence and location of the Anglo-Saxon cemetery of Empingham II was unknown until it was discovered by chance in 1974 during construction works for the reservoir Rutland Water. The site of the cemetery had been in agricultural use and was being re-landscaped as a car park. Heavy machinery had already damaged the site irremediably, crushing and partially destroying most of the skeletons (Timby 1996:10). A full excavation was then undertaken to remove the 135 inhumations (and the one cremation) found in an area of 725 m^2. However the excavation was not systematic and some finds were stolen from the site, which might have an impact on the interpretation. There were no buildings associated with the cemetery, but it is believed that the settlement must have started and then extended from Site 3, a settlement that is located further south (Cooper 2000:2-3).

A total of 155 individuals were excavated: 98 adults (43 males, 38 females and 17 adults of indeterminate sex) and 57 juveniles. The skeletal preservation was very poor, the bone

being fragmented and eroded. Teeth, however, were well preserved and an extensive analysis was undertaken by Justine Bayley and Simon Mays of the Ancient Monuments Laboratories of English Heritage between 1974 and 1989 and published in Timby (1996). Most of the teeth were separated from the rest of the skeletons for storage and were subsequently loaned to University College London for further research where it would seem that they were then lost. The teeth used for the isotope project were those that for some reason had not been separated from the skeletons, either because they were forgotten, or because they were additional teeth (i.e. found in the same grave but not belonging to that individual).

Despite the analytical difficulties associated with the cemetery of Empingham II and the lack of comparative material, the site seems to present characteristics of cemeteries in the East Midlands and perhaps East Anglia at this time (Timby 1996). Timby (1996) used the grave goods as a basis for dating the cemetery, which was calculated to be from the late 5th to early 7th century. She suggested that their type and quantity seem to reflect a cross-section of the society. The grave goods also showed a high level of wear and repair which might be interpreted as a consequence of use by the persons buried, or heirlooms passed through the generations (in which case it might impact on the date). The metalwork includes fine examples of workmanship and is suggestive of local manufacture, but artefacts such as amber beads and ivory jewellery indicate more wide-ranging trade or social contact (Timby 1996).

Although it is hazardous to make sweeping assumptions about a site such as Empingham II, especially when the archaeology is not as conclusive as one might hope, it seems to be a typical Anglo-Saxon cemetery of the area and period. It is impossible at the moment to know whether the cemetery contains the remains of local residents of Romano-British ancestry who adopted contemporary Anglo-Saxon customs, or whether the inhabitants are Saxon settlers and their descendants, or even a mixed settlement, with indigenous people cohabiting with new settlers. The latter is unlikely as the lack of a former settlement or cemetery linking the end of the Romano-British period to the beginning of the Anglo-Saxon period cannot prove population continuity in the area.

Ketton (KCC)

The Domesday Book of 1086 mentions the manor of Ketton held by the king, which included a priest. The complex multiple estates of the Anglo-Saxon or early medieval period had, by the 11th century, been replaced by smaller, self-contained manors (Gilchrist 1999) and nucleated settlements. The open field creation in the late 9th – 10th century East Midlands is believed to have been a reflection of social segregation within the landscape with individuals who might have been minor thegns or important freemen establishing distinct settlements (Courtney, forthcoming). This high status settlement framework could have attracted cottagers or bordars as their workforce. The presence of Lincoln, Stamford and St Neots type-ware ceramics in many river valley villages in the East Midlands suggests that these villages were created in the late 9th –10th century. In addition to the nucleated village of Ketton, there is evidence of smaller settlement units in the parish, in the form of scattered farmsteads or hamlets (Courtney, forthcoming).

The site of Ketton is four miles south-east of Rutland Water and is situated in fields a mile and half away from the village of Ketton, itself only a couple of miles south east of Empingham. Located on land belonging to Castle Cement Quarry, its existence was only discovered when machines were digging that part of the quarry (Meadows, pers.com.). Human burials and evidence of buildings suggested a settlement, which was excavated in its entirety in 1998 by Northampton Archaeological Unit under the supervision of Iain Meadows. An Iron Age/Romano British farmstead and a Roman cemetery have also been excavated in the quarry closeby.

The settlement is of a single-cell church, a cemetery surrounding it and four timber halls, one of which is larger and aisled. The settlement is small, probably only composed of a few farmsteads. Although there is a church with its cemetery, it is not believed to have been an independent parish, and the church was more likely to have been a show of social status (Parry, pers. com.). The settlement was in all probability linked to the village of Ketton. Stamford Ware pottery suggested a 10th-12th century occupation, and archaeologists interpreted the site as a manorial complex, inhabited by an extended family with its

labourers and servants (Meadows, pers.com.). The settlement seems to have been of high social status and was presumably subsidiary to a chief hall in Ketton village (Courtney, forthcoming). The size of the church of Ketton village, a pre-Conquest Minster, must indicate some wealth and status. The church present on the site suggests that the owner was of thegnly status (Parry, pers.com.). It was possible for an existing daughter church to be removed from the minster's parochia and become a private church when an estate was booked or created by charter (Sawyer 1978:248). It seems less likely that the mother church would have willingly granted valuable burial rights to a chapel so close to its own location. The reason for its demise is uncertain but the death or exile of its lord as a result of the Norman Conquest must be considered a possibility.

The associated buildings revealed very little other evidence, but the cemetery layout suggested two separate burial groups: one to the north and the other to the south (Meadows, pers. com.). The northern group is very distinctive from the southern one and is clustered around a tree hole. A child who seemed to have been decapitated was uncovered in one of the graves. This suggested an earlier, possibly pagan burial zone. However, when radiocarbon dating was carried out on some of the skeletons, the range of dates - from the late ninth century to the mid-eleventh century - were similar for the two burial zones. This not only demonstrated that the separate burial zones were contemporary with each other, but also that the manorial complex not only pre-dated the Norman Conquest, but had also ceased to exist by then.

The northern side of a cemetery is usually the least popular, people preferring to be interred on the southern and eastern sides (as found in Raunds [Boddington 1996:57]). Baptised children are typically closest to the church walls, known as the 'eaves-drip' location (Boddington 1996:55). There can also be a male/female segregation, but this was not observed at Ketton. The cemetery consists of 72 individuals: 11 males, 19 females, 5 adults of indeterminate sex and 37 juveniles. Apart from the distinct north/south zonation, the cemetery layout was typical of a small Christian settlement. The entire cemetery is believed to have been excavated and its population available for osteological analysis. Unfortunately, soil composition and the fact that the cemetery was close to the surface

meant that the bones were very damaged, eroded and fragmented. It is also possible that upper layers may have been eroded away by ploughing, removing the upper graves, but the archaeologists thought this was unlikely. Jenny Wakely of the University of Leicester supervised the general osteological analysis. The skeletons were reanalysed for this study to provide information on possible family groupings.

Non-metric traits used in conjunction with metrical analyses can provide information on possible family relationships. To gather maximum information, skeletons need to be complete and well preserved. This was unfortunately not the case for both Ketton and Empingham, where the skeletons were severely eroded and fragmented. Some non-metric traits could only be recorded from the Ketton bones that were in better condition and no measurements were obtainable for either site. It is important to be cautious when interpreting results from this analysis, as many non-metric traits that could have been present might not have been recorded due to poor bone preservation.

Nevertheless, if some non-metric traits were observed, it is such a small population that it would be unlikely that two individuals bearing no genetic link would share them. We distinguished four possible family groups according to these non-metric variations and the spatial relation between individuals with the same trait:

Group 1: KCC 3, 52 and 63.
All three have congenital absence of the lower (i.e. those of the mandible) incisors: KCC 3 misses the lateral incisors, KCC 52 and KCC 63 both miss the right central incisor. Missing teeth are more common than extra teeth, but the fact that it is the same tooth in the same part of the jaw that is missing increases the likelihood that these three females were related.

Group 2: KCC 70, 71 and 65.
The two juveniles KCC 70 and 71 share the same two traits: an ectopic tooth and a sternal aperture. Again, the possibility of these two juveniles being related is very strong. An ectopic tooth grows in an unusual place in the jaw, as for example the canine growing in

the middle of the palate. A sternal aperture is a development defect caused when the three parts of the body of the sternum fuse during development and a gap is left at one of the lines of fusion. KCC 65 also has a sternal aperture and in view of the close proximity to those other individuals, I would also include this individual in the group (KCC 65 also has spina bifida occulta [see group 4]).

Group 3: KCC 8, 14, 27 and 47.

These four individuals all have acetabular creases. This looks like a fold in the acetabulum, a part of the hip joint. Originally the pelvis is in three portions that fuse at a certain age, and rather than leaving a gap like in the sternal aperture, there is a mark similar to a line or fold. Another individual on the north side of the cemetery, KCC 47, has an acetabular crease and could be included with this group.

Group 4: KCC 34, 35 and 65.

KCC 34, 35 and 65 all have spina bifida occulta. Spina bifida is the defective closure of the vertebral arch. In spina bifida cystica there is an open canal with protusions of the meninges and/or the spinal cord, which leads to severe disability. In spina bifida occulta, the sacral canal is open, but there is no protusion of the meninges or spinal cord. The sacrum is usually protected by a strong sheath of tissue as protective as bone and there are no dangers linked to the malformation. Unless diagnosed using X-ray, the individual would be ignorant of any defect. KCC 34 and 35 have neighbouring graves in the north side of the cemetery. On the other hand KCC 65 is in the south part, and part of group 2 because as well as having spina bifida occulta, he has a sternal aperture.

There are two individuals who show evidence of traits shared by no-one else on the site: KCC 17 has a septal aperture and a perforation in the elbow part of the humerus. KCC 55 has a fused os trigonum, a bone ossicle that can sometimes be loose and that has fused to the talus.

The osteological analysis would concur with the archaeologists' description of the site as having been used by an extended family probably of some status and local to the area,

living with its labourers and servants. The diseases and injuries found on the skeletons are typical of rural living with the hazards associated with working with livestock and agricultural equipment in a population-controlled small settlement. There is no sign of unusual activities or a reason for the abandonment of the site before the Norman Conquest.

3.8. Summary of data selected for isotope analysis.

Site	*Adult*		*Juveniles*		*Animals*		
	Premolars	*other*	*Permanent*	*deciduous*	*Cattle*	*sheep*	*Pig*
Empingham	12	2	1	3	4	1	2
Ketton	16	0	6	2	5	7	1

Table 3.1. Summary of teeth selected for isotope analysis.

One tooth per individual with the exception of Ketton where one child [68] had one deciduous tooth and one permanent tooth sampled. For Empingham, the other adult teeth are one incisor and one canine. The animal teeth were collected from Site 3, which is contemporary with the cemetery and probably the original settlement. The Ketton animal teeth were sampled from the animal remains found in post-holes around the site.

In view of the date and size of Empingham there was a possibility that it would contain some migrants, whereas Ketton, a small settlement spanning a short period of time and showing osteological signs of a genetically homogeneous population was expected to show the least variation.

3.9: Analytical procedures.

Tooth selection criteria.

- Primarily healthy teeth, with no cavities and little attrition or post-mortem damage, to avoid contamination, weakening of the enamel and provide a good enamel yield.
- One premolar per individual was selected from either side of maxillae or mandibulae. Premolars were chosen by an elimination process. Incisors and canines usually display the clearest enamel hypolasia and their removal for chemical analysis would pose an aesthetic problem if skulls were to be later exhibited. Molars have complex occlusal

relief and are difficult to remove. Pre-molars are a good compromise with acceptable enamel surface, simple occlusal surface and are easy to remove. However in the case of Empingham, the paucity of teeth meant that an incisor and a canine from two maxillae had to be used instead of premolars, representing slightly different age categories of tooth formation. The crown of the incisor is formed between 10 months and four years after birth and the canine between 18 months and 6 years after birth.

- Molars from the lower jaw were selected in animals, usually the one with the most enamel surface and the easiest to cut. The focus was primarily the teeth of adults, but we also included a few teeth, both deciduous and permanent, of sub-adult individuals for comparative purposes.

One must bear in mind that this analytical procedure is destructive. There are problems linked to anti-sampling policies and ethical issues. The main objection for such analysis is the risk that the tooth might be needed later for other analyses. All removed teeth were inventoried.

Sample preparation.

Teeth were extracted from the jaw and cut in half longitudinally using a flexible stainless steel saw with a diamond cutting edge. Larger and tougher animal teeth such as cattle and horse were sometimes pre-sliced using a rock microsaw. The outside enamel was buffed to remove depositional contamination and the dentine drilled out using a tungsten drill, until only the enamel shell remained. The dentine and roots were discarded. During drilling, enamel could be checked under a microscope to assess the quality of the drilling by examining the enamel structure.

The enamel fragments had successive baths of dichloromethane and hydrogen peroxide to remove traces of organic matter and were then dried. The enamel was ashed in a nickel case under vacuum at 600°C to remove residual organic component and any trace of water. The enamel becomes a grey-white powdery substance, and the whitest ash (free of any charred organic matter) was selected for analysis.

Sample analysis.

Two methods were used to extract the oxygen from the enamel. The LAF (Laser Assisted Fluorination) analysis was used on the animals at the beginning of the project. The lab then developed silver phosphate (Ag_3PO_4) analysis and all animals and humans were analysed using this other method. Both methods gave good results and consistent reproducibility. There are many other techniques used to extract oxygen from bioapatite and the silver phosphate technique is traditionally the preferred method, although laser assisted fluorination, maybe handicapped by its heavy machinery requirements, is also believed to provide precise and accurate measurements (Vennemann *et al.* 2002). The scope of this PhD, however, was not to assess methodology regarding the different analytical techniques, and so only a brief overview of the methods is given. Both methods are very time-consuming, requiring *ca.* 3 days of analysis per batch of 10-15 samples (including standards and repeats).

Method 1. Laser Assisted Fluorination (LAF) (based on Cerling and Sharp 1996; Kohn *et al.* 1996).

This method requires reduction in an all-metal vacuum line at high temperature (in externally-heated nickel reaction vessels) with the reagent bromine pentafluoride (BrF_5), a highly reactive gas. Ashed enamel material is placed in a chamber where the 10 watt CO_2 laser melts the enamel and, combined with the reagent BrF_5, releases the gases, including the oxygen (in the form of phosphate (PO_4) and carbonate (CO_2) form). The gases are then passed through a metal line where they are purified using traps (both hot and cold) until only pure oxygen is obtained. That oxygen is then converted into CO_2 so it can be analysed in the mass spectrometer, here a dual inlet V.G. Isotech (Micromass) Optima.

Method 2. Silver phosphate (Ag_3PO_4) (based on O'Neil *et al.* 1994).

The preparation involves extracting the phosphate from the enamel and reprecipitating it as silver phosphate (Wright and Hoering 1989) (it can also be reprecipitated as bismuth phosphate, see Tudge 1960). This method involves fewer steps and is not hygroscopic, which minimises the potential for contamination by atmospheric water. It also seems to

offer better reproducibility generally as it only isolates phosphate oxygen. The material is dissolved into HNO_3 and reacted with HF to eliminate the calcium, precipitated with silver triphosphate and a thermal decomposition of Ag_3PO_4 with graphite for a CO_2 conversion. The CO_2 is analysed by continuous flow TC/EA (high temperature reduction) isotope ratio mass-spectrometer.

3.10. Interpretation of measured values and recalculated values for oxygen (into drinking water values)

Both mass-spectrometers are fully automated and the data are printed out as they are analysed. The raw data are then converted into δ values using the laboratory's computer software packages and are presented as raw $\delta^{18}O$ values. To check machine precision, analysis of standards and repeats are constantly carried out. The two standards igneous apatite UMS-1 and NBS120c are most commonly used for this type of analysis. Pure oxygen was also analysed each day and the accuracy of the results was constantly monitored. To correct against machine bias, the samples were repeated at least three times and the results were checked against the values of the standards (UMS1 and NBS 120C) and given as corrected values at the 1σ level ($\pm$ 1 ‰). The values were then tested statistically using T and F-tests.

Raw $\delta^{18}O$ values or measured values allow comparisons within species of the range of values, but they do not provide geographical information. Darling *et al.* (2003) supply a modern isotopic 'baseline' for the British Isles as a background for various applications including archaeological studies. Their analysis of precipitation values (Darling and Talbot 2003) and surface waters and groundwater (Darling *et al.* 2003) has provided specific geographical information in the form of maps of modern $\delta^{18}O$ values in drinking water available in the UK.

Species	*Equation*	*Reference*
Human	$\delta^{18}O_{(p)} = 0.46\ \delta^{18}O_{(tw)} + 19.4$	Levinson *et al.* 1987
Cattle	$\delta^{18}O_{(p)} = 1.01\ \delta^{18}O_{(mw)} + 24.90$	D'Angela and Longinelli 1990
Sheep	$\delta^{18}O_{(p)} = 1.48\ \delta^{18}O_{(mw)} + 27.21$	
Pig	$\delta^{18}O_{(p)} = 0.86\ \delta^{18}O_{(mw)} + 22.71$	Longinelli 1984
Goat	$\delta^{18}O_{(p)} = 0.92\ \delta^{18}O_{(mw)} + 24.39$	Huertas *et al.* 1995
Horse	$\delta^{18}O_{(p)} = 0.71\ \delta^{18}O_{(mw)} + 22.60$	

Table 3.2. Equations used to calculate $\delta^{18}O$ drinking water from raw values (phosphate oxygen).

However, to use the maps we need to translate the measured values into drinking water values. The formulae listed in table 3.2 (above) were used. Because of the difficulty in differentiating goat from sheep jaws, the sheep formula was preferred.

3.11: Results and discussion

Sample	*Name*	*Sex*	*$\delta^{18}O$ SMOW (raw values)*	*Drinking water values Levinson (calculated values)*	*Sr Concentration*		*87/86 Sr*
					Sr Ppm	*1/Sr *1000*	
EMP	37	F	17.5	-6.41	-	-	-
EMP	39	F	16.3	-8.95	83	12.0	0.70959
EMP	50	F	17.3	-6.74	82	12.2	0.71003
EMP	81	F	16.9	-7.63	55	18.3	0.70947
EMP	95	F	17.0	-7.41	-	-	-
EMP	115	F	17.1	-7.18	51	19.5	0.71048
EMP	94	IND	16.9	-7.60	76	13.2	0.71046
EMP	201	J (dec)	18.4	-4.28	-	-	-
EMP	child	J (dec)	18.7	-3.75	-	-	-
EMP	99	J (dec)	17.9	-5.48	-	-	-
EMP	26	J	17.1	-7.11	35	28.8	0.70947
EMP	3	M	16.4	-8.69	-	-	-
EMP	31B	M	16.1	-9.40	-	-	-
EMP	31C	M	17.7	-5.81	-	-	-
EMP	46	M	17.0	-7.32	35	28.3	0.70967
EMP	110	M	16.8	-7.91	45	22.3	0.71011
EMP	49	M	17.2	-6.88	55	18.3	0.71048
EMP	119	M	17.1	-7.28	58	17.4	0.70956
KCC	56	F	18.3	-4.69	97	10.27	0.710997
KCC	17	F	16.8	-7.92	58	17.28	0.709505
KCC	52	F	16.8	-7.83	60	16.60	0.709535
KCC	55	F	16.9	-7.72	75	13.28	0.710566
KCC	63	F	17.2	-6.98	86	11.67	0.710267

KCC	66	F	17.3	-6.79	81	12.38	0.709375
KCC	7	IND	16.3	-8.99	66	15.09	0.708966
KCC	54	IND	16.1	-9.44	126	7.96	0.709835
KCC	6	J	16.8	-7.78	104	9.66	0.709275
KCC	13	J	17.2	-6.97	44	22.62	0.709460
KCC	68b	J	17.2	-7.01	58	17.37	0.709878
KCC	32	J	16.6	-8.26	51	19.47	0.709244
KCC	40	J	16.2	-9.16	79	12.66	0.709564
KCC	57	J	18.2	-4.74	44	22.94	0.709553
KCC	68a	J (dec)	17.4	-6.46	53	18.89	0.709588
KCC	71	J (dec)	17.5	-6.33	86	11.63	0.709358
KCC	9	M	16.1	-9.39	69	14.40	0.709349
KCC	14	M	17.2	-6.97	153	6.53	0.712663
KCC	34	M	16.7	-8.07	62	16.24	0.709213
KCC	43	M	-	-	67	14.92	0.708578
KCC	47	M	16.2	-9.17	72	13.91	0.709372
KCC	58	M	16.8	-7.82	67	15.01	0.709392
KCC	64	M	16.4	-8.62	105	9.49	0.711407
KCC	65	M	15.5	-10.61	60	16.76	0.710489
KCC	67	M	17.2	-7.01	123	8.13	0.710261

Table 3.3. Results of the oxygen and strontium isotope analysis for Ketton (KCC) and Empingham (EMP) humans.

For the oxygen: raw values ($\delta^{18}O$ SMOW) and calculated drinking values. For the strontium: concentration and isotope ratio. NB: not all individuals were analysed for both strontium and oxygen isotope ratios. Analysis strontium: Jane Evans.
F= female; M= male; IND= adult of indeterminate sex; J= juvenile, with permanent teeth sampled; J (dec)= juvenile, with deciduous teeth sampled.

3.11.1. Oxygen isotopes distribution and detection of outliers

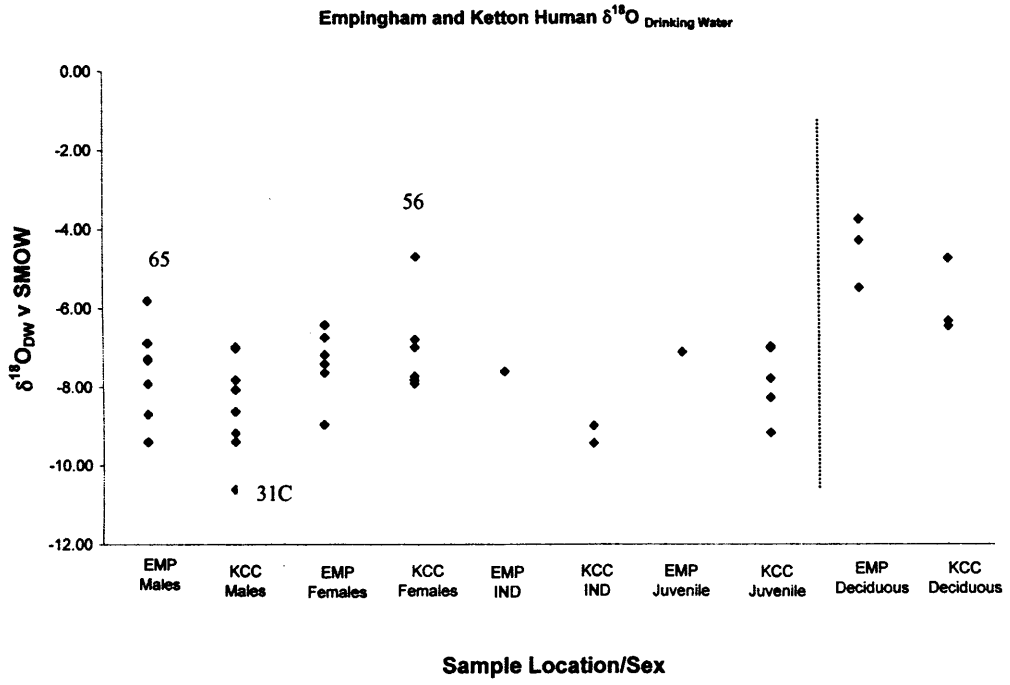


Chart 3.1. $\delta^{18}O_{drinking\ water}$ results for the humans organised by location and sex for the adults, and permanent teeth or deciduous teeth for the sub-adults (sex unknown).

This chart shows the distribution of the $\delta^{18}O_{drinking\ water}$ values for the humans calculated from the $\delta^{18}O_{oxygen\ phosphate}$ using Levinson *et al.* (1987) regressive formula. Two observations are immediately visible. Firstly, few individuals have $\delta^{18}O_{drinking\ water}$ values falling between the expected values of –7 to –8 ‰ for the region. The mean values, however, are of –6.99 ‰ (sd 1.47) for Empingham and –7.70 ‰ (sd 1.42) for Ketton, which fits with the expected values. No clearly identifiable outliers are visible, though a Ketton male (31C) shows depleted values compared to the other males, and a Ketton female (56) and Empingham male (65) show enriched values compared to others of their sex. Secondly, the individuals with deciduous teeth show enriched oxygen values compared to individuals with permanent teeth.

Two males (Emp 31C and KCC 65) stand out with extreme values compared to the other individuals. The Empingham male displays the highest value of both assemblages, but it is

still compatible with mainland British drinking water. The Ketton male, however, as the lowest value at –10.6 ‰, similar to one expected from Scandinavia or north part of central/eastern Europe (Chernery, pers. com.).

Dixon's Q-test was used here to test for outliers using Miller and Miller (1988). It is calculated as follows : Q= (suspect value – nearest value) / (largest value – smallest value) and checked against a table with critical values according to the sample size. Using the formula, it was determined that there were no outliers in the Ketton or Empingham adults. When outliers were checked per sex, none were found in Empingham males and females and Ketton males. The female KCC 56 was singled out as an outlier with a drinking water value of –4.7% ± 1 ‰. Such a value would suggest an origin from a warmer area of Britain, such as the southwest of England, south Wales and north-west Wales (Chenery, pers. com.).

The values of the children's deciduous teeth are more positive and can be seen in the upper part of the chart, beyond most of the adult values. Human breast milk is formed from the body water pool, and thus is heavier in the $\delta^{18}O$ than the water imbibed by a lactating mother (Wright and Schwarcz 1998). See Luz and Kolodny (1985) and Wright and Schwarcz (1998) for a full discussion on isotope ratios in breastmilk and the effect of weaning on body water isotope ratios. The results from our samples would suggest that the individuals with permanent teeth had been fully weaned by the time they developed their premolars.

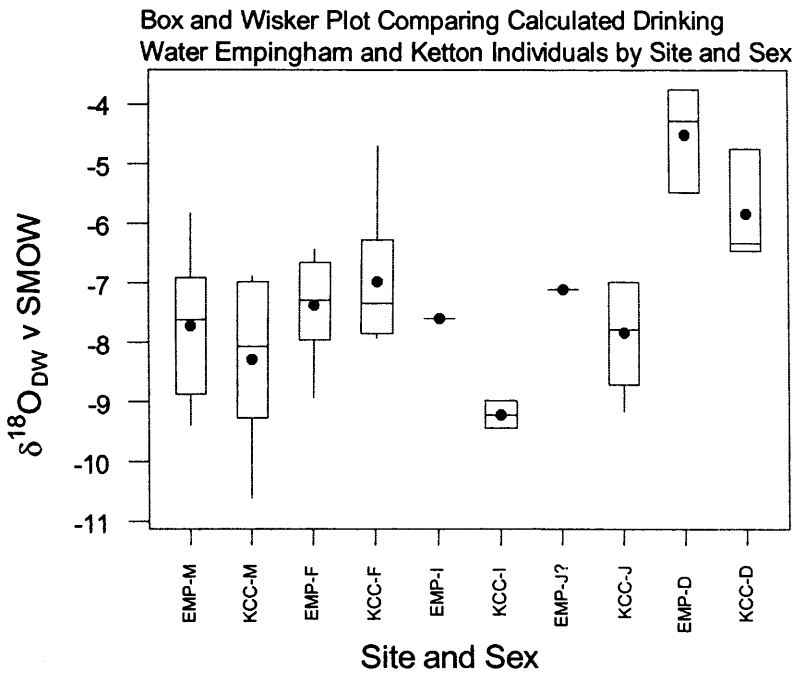


Chart 3.2. Box and whisker plot showing the $\delta^{18}O_{drinking\ water}$ human values separated by site and sex.

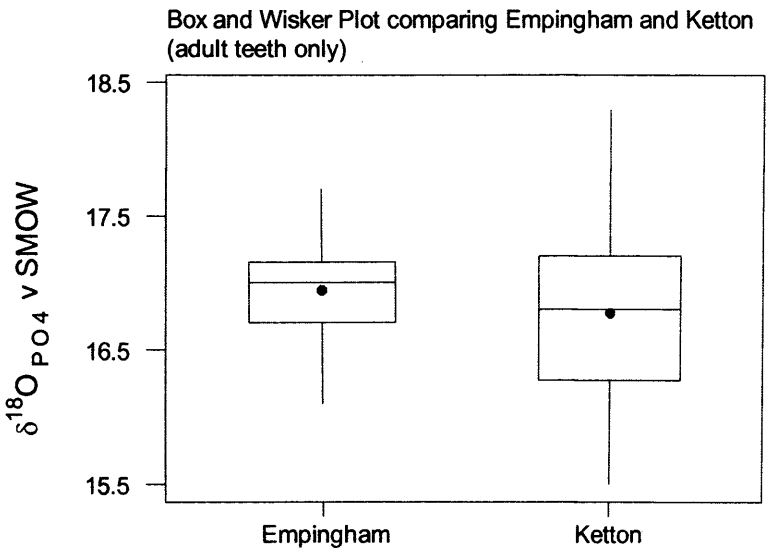


Chart 3.3. Box and whisker plot showing the $\delta^{18}O_{drinking\ water}$ human values by site (permanent dentition only).

Box plots allow us to visualise the distribution of the values with greater clarity and are useful for showing the distributional characteristics of the data. The dot represents the mean of the values. The middle line is the median, and the two outside lines of the box represent the superior and inferior quartiles. The whiskers show the extreme value within the upper/lower limit. The box and whisker plots enable us to visualise the distribution of the values between Ketton and Empingham. Most groups show means that are between –7 and –8 ‰. The spread of the values between the two sites is very different, with Ketton displaying a wider range of values than Empingham with an interquartile range approximately 1.15 times that of Empingham. This is especially true of the males in Ketton. The difference in range is even more pronounced when only permanent teeth are used, with a Ketton range nearly twice that of Empingham. There can be two reasons for this. Either the water available to the Ketton people shows more natural variability than the water drunk at Empingham did, or the water drunk by the Ketton people comes from a larger range of sources than for Empingham.

The males display a low overall median in both sites in oxygen phosphate values. The females display a very similar median value of +17‰, but Ketton females have a wider range. The Ketton males have a lower median value than the Empingham males (+16.7‰ vs. + 16.9‰) and a slightly larger interquartile range. The Ketton males also have a significantly lower median than the Ketton females (+16.7‰ vs. + 17.0‰). When the values of the males and females are added, it causes Ketton to have a larger range than Empingham. According to this reasoning, the low isotopic values of the adults of indeterminate sex in Ketton could therefore suggest that they are male (Chenery *pers.com.*). The same cannot be established of the adult individuals of indeterminate sex in Empingham or the majority of juveniles with permanent dentition, bar KCC 68A who falls within the male range and is therefore more likely to be male.

Statistical analysis was undertaken to assess if the distribution illustrated by the box plots were statistically significant. The F-test were carried out to show if the variances were equal between Ketton and Empingham as a whole. F= 0.648 p= 0.222 F critical= 0.393. F

being larger than the critical means that the variation is not the same at the 95% confidence level, therefore the variation at Ketton is statistically larger than at Empingham. The T-test was conducted assuming unequal variance. T= 1.015 p= 0.158 T critical= 1.692. T was less than the critical, meaning that the variances were not statistically significant. The drinking water is therefore the same for both areas. When the F and T tests were carried out between males and females from each site, they were also found not to be statistically significant. Although the range for Ketton was statistically larger than for Empingham, the statistical tests did not support the hypothesis of different drinking waters being the cause of it. It is therefore unlikely that there is an immigrant component in either population. Rather, the results would support a local origin, although for Ketton it is more likely that some of the individuals came from just outside the settlement. They would be drinking the same water, but not from the same spot.

3.11.2. Oxygen isotope analysis and animals

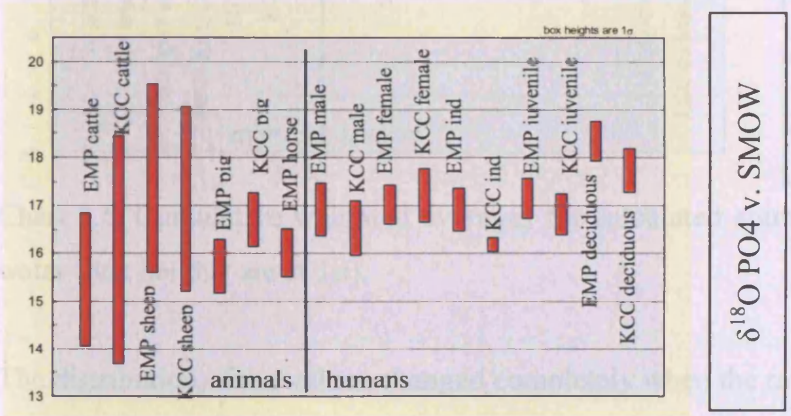


Chart 3.4. Cumulative weighted averages for animal and human $\delta^{18}O$ enamel phospate oxygen (box heights at 1σ).

This chart is compiled using the raw values (i.e. not calculated into drinking water values) for the phosphate oxygen in the enamel. The animal values should reflect the values of the isotopes environmentally available in the particular area of England that is investigated here. The chart shows that the animals provide a good estimate of natural variation in a population. The human values fit within the animal ones and no outsiders are visible. Using

this chart we can assume that Empingham and Ketton display values that fit within the natural variation of the population, suggesting a local origin.

Sheep and cattle present a wider range of values compared to the pig, horse and human values. More cattle and sheep teeth were analysed, and, having longer teeth, their values are more likely to be affected by seasonality factors. Balasse (2003) has extensively described and explained this intra-tooth variability. This can only be rectified by consistently taking samples from the same part of the tooth. Since our aim was to assess maximum population variability, this was not required in this study.

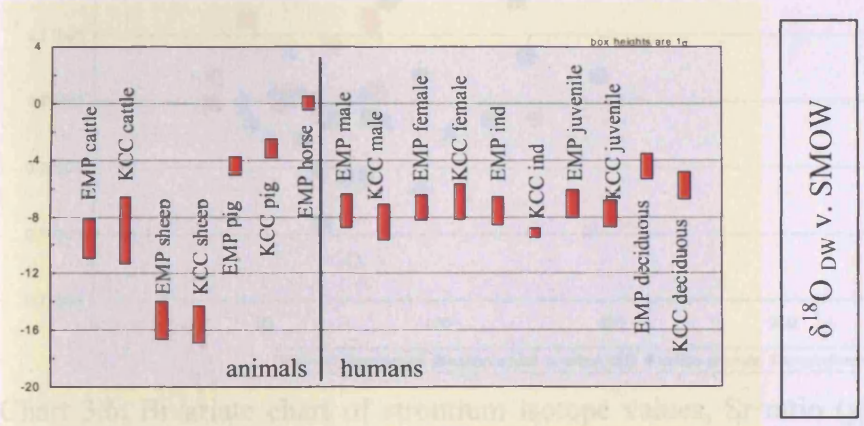


Chart 3.5. Cumulative weighted averages for calculated animal and human $\delta^{18}O$ drinking water (box heights are at 1σ).

The distribution of the values changed completely when the raw values were calculated into drinking water. Only cattle values remain comparable to the humans ones. The sheep, horse and pig values are no longer comparable. They do not even give values that are compatible with a UK origin. This illustrates well the difficulties in translating measured phosphate oxygen values into drinking water ones to provide comparative data. The formulas established for the sheep by D'Angela and Longinelli (1990), the pigs by Longinelli (1984) and the horses by Huertas *et al.* (1995) cannot be used on British material. At the moment, only cattle would seem to provide the best correlation between measured and calculated values. There is variability within the distribution of the human values, however, there is little difference in the overall average values and their variation at the population level.

3.11.3. Comparison of strontium ratios results with those of oxygen

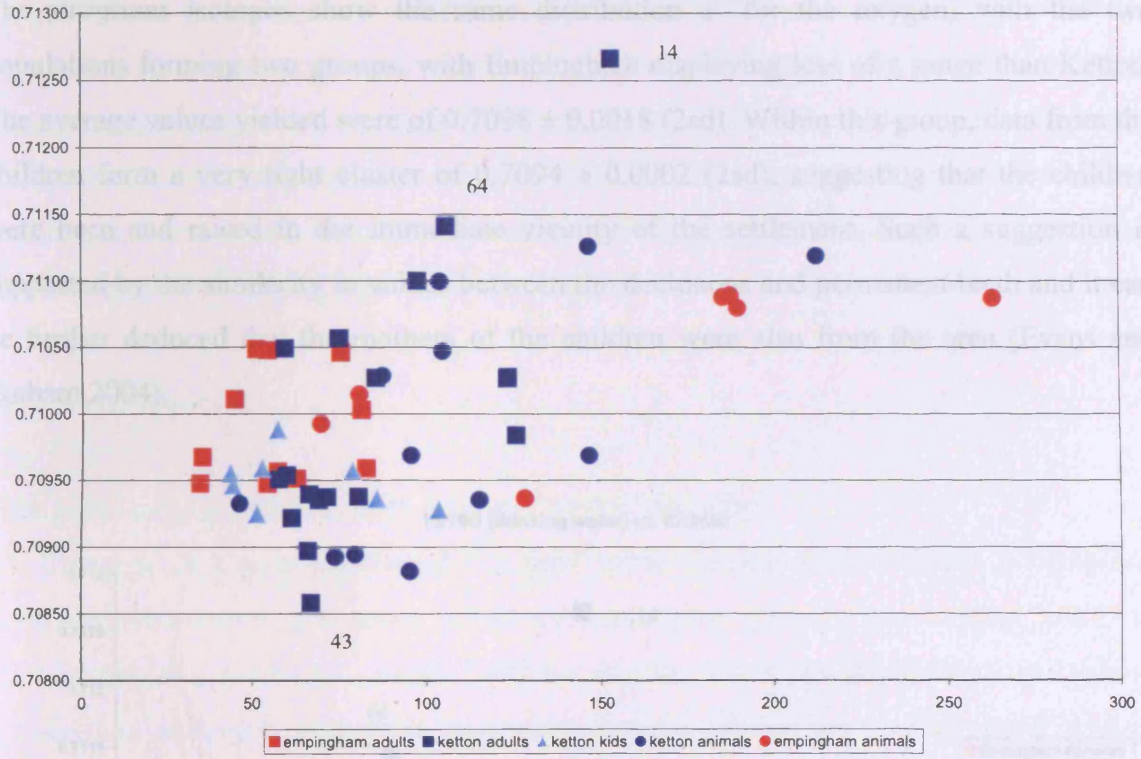


Chart 3.6. Bivariate chart of strontium isotope values, Sr ratio (y) over Sr concentration (ppm) (x). Animals (cattle, sheep, goats and pigs) are shown as dots and humans as squares.

The expected range of values for the geology of Rutland is between 0.7084 and 0.7100. Although the majority of individuals and animals fit in this range (including the children), a substantial amount of both Ketton and Empingham values show enrichment. Since this is observed for both humans and animals, it must be a natural variation.

Chart 3.6. shows that the animals tend to have higher concentrations of strontium, which is to be expected because of trophic shifts. Their ratios, however, are similar to those of the humans and prove that both animals and humans come from the same region. The animals have a comparable average and standard deviation of 0.7099 ± 0017 (2sd). Two individuals have values that are beyond those of the animals. The spread of values which reflect those of the animals prove that most of the humans are within the local values, and only three

individuals (KCC 64, 14 and 43) stand out, however they are not picked out as outliers using Dixon's Q test.

The strontium isotopes show the same distribution as for the oxygen, with the two populations forming two groups, with Empingham displaying less of a range than Ketton. The average values yielded were of 0.7098 ± 0.0018 (2sd). Within this group, data from the children form a very tight cluster of 0.7094 ± 0.0002 (2sd), suggesting that the children were born and raised in the immediate vicinity of the settlement. Such a suggestion is supported by the similarity in values between the deciduous and permanent teeth and it can be further deduced that the mothers of the children were also from the area (Evans and Tatham 2004).

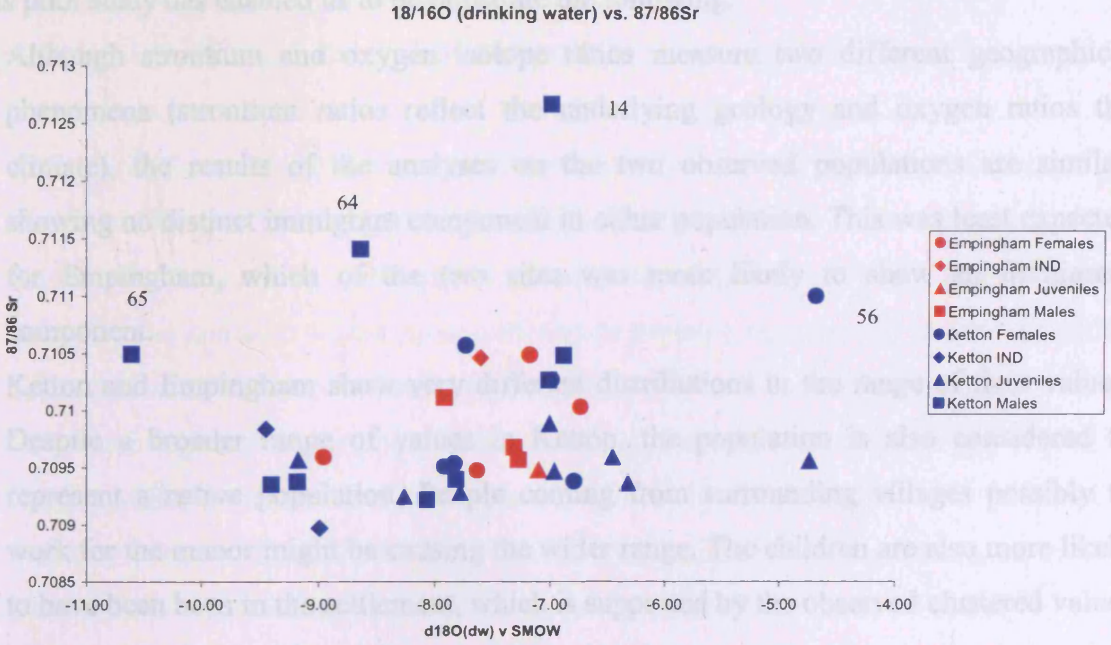


Chart 3.7. Bivariate chart showing strontium (y) and oxygen (x) isotope ratios (Humans only). NB: only individuals with both strontium and oxygen isotope ratios are included here.

Empingham, in red, is still heavily surrounded by the Ketton individuals, displaying a smaller range of values for both the oxygen and the strontium isotope ratios, confirming the earlier observations that the Empingham population is less diverse than the Ketton one.

KCC 56 and 65, the outliers for the oxygen values still stand out and also display some of the highest strontium ratios, but not the highest ones. The strontium outliers include KCC 14 and 64. They present, however, average oxygen ratio values close to the expected –7 to –8 ‰. These Ketton outliers (of which only KCC 56 was statistically significant for the oxygen) do not prove to be outliers for both strontium and oxygen isotope ratios, although they have borderline values. This illustrates the benefit from using both oxygen and strontium in population migration analysis. We cannot determine exactly where the outliers are from, but since their values are not vastly different, it could be suggested that they are still local, possibly coming from close by villages.

3.12. Conclusions

This pilot study has enabled us to demonstrate the following:

1. Although strontium and oxygen isotope ratios measure two different geographical phenomena (strontium ratios reflect the underlying geology and oxygen ratios the climate), the results of the analyses on the two observed populations are similar, showing no distinct immigrant component in either population. This was least expected for Empingham, which of the two sites was more likely to show an immigrant component.
2. Ketton and Empingham show very different distributions in the range of their values. Despite a broader range of values in Ketton, the population is also considered to represent a native population. People coming from surrounding villages possibly to work for the manor might be causing the wider range. The children are also more likely to have been born in the settlement, which is supported by the observed clustered values compared to those of the adults.
3. Though the results using the different isotopes were comparable, it is still useful to use both strontium and oxygen as they are independent measurements of the same phenomenon, and therefore reinforce the observed results. Individuals that might display extreme values for oxygen might have average values for strontium and vice-versa.

4. Animals have been successfully used to establish natural variability in a native population. There were, however, some limitations when attempting to translate raw $\delta^{18}O$ animal values into drinking water values for animals other than cattle. Different growth patterns of animal teeth and seasonality will also widen the range of values available in a single tooth (see appendix for down-tooth variability).
5. For both strontium and oxygen isotope ratios the range of values were slightly larger than expected, although the means were within the expected range. Since the animals showed a similar distribution, it was understood to indicate that modern-day estimates were not flexible enough to encompass the environmentally available isotopes at the time. Deciduous teeth have also successfully displayed consistent trophic shifts, meaning that our analytical methods are sound, and that observed differences are significant.

The observed differences in the distribution of values could be caused by various influences:

- There could have been a climatic shift between the early and late Anglo-Saxon period which would alter the oxygen ratio values. There is, however, no such evidence at present. If it had been the case, we would expect the sites to display different values (for example, one site with values more enriched or depleted compared to the other), rather than a different range in the distribution of the values.
- The water ingested might come from several sources. A well has been excavated at Ketton, which would be supplied by groundwater rather than surface/meteoric water as found in rivers. Wells have not been found in settlements predating the eighth century (Arnold 1997:61) (although Roman wells were used in towns), so it is unlikely that one was used in Empingham, where water must have been drawn principally from the river. In Ketton, however, the settlement might have been supplied in drinking water by both the well and the river.

Empingham displays a very homogeneous population with little variation, suggesting that it is local with few outsiders. This requires us to examine the question of identity. The individuals we analysed from Empingham have values which suggested they were

indigenous to the area. This does not preclude, however, that they might have been genetically and culturally outsiders from the native populations (and could have believed themselves to have been). It is also possible that the graves of immigrants were located elsewhere and were not included in what could also be a native cemetery that adopted Anglo-Saxon practices.

Ketton, on the other hand, is still a local population, but displays much more variability, possibly because the settlement needed to draw workforce from surrounding villages. This is a likely explanation as Ketton, being a manor complex, probably drew its workforce from surrounding areas who after working many years for the landowner was subsequently inhumed in the burial ground. Historical evidence supports this theory. Village nucleation took place between the late 9-12th centuries in the East Midlands, which also corresponded to a period when many river villages were also created in the late 9-12th centuries (Courtney, forthcoming), with several small settlement units appearing in the parish of Ketton (Courtney, forthcoming). The fact that Empingham suggests a strictly native settlement is more surprising as it is a much larger site and shows some evidence of contact with places beyond Rutland and England (see archaeological background to the sites, section 3.7 above).

Evans and Tatham (2004) tried to assess the probability that the values extracted from the observed populations would not be statistically distinct from other sites in England. The sites used included another Anglo-Saxon cemetery at West Heslerton in Yorkshire (Budd *et al.* 2002; Montgomery 2002); a Roman settlement from Mangotsfield near Bristol (Montgomery 2002), and another from Winchester (Montgomery 2002); a Dominican Black Friary in Gloucester (Budd *et al.* 2002; Montgomery 2002), and stone age individuals from Monkton upon Windborne in Wiltshire (Montgomery *et al.* 2000). The Mann Whitney and ANOVA assessments were used. The null hypothesis was rejected for the Monkton and Winchester sites, and despite an overlap in the dataset, was also rejected for the Gloucester site. The West Heslerton set fell within an ambiguous range with a 10% probability of not being distinct. The Roman individuals buried at Mangotsfield showed a strong probability of sampling the same isotope ratios as the Rutland sites. Both sites are

located on the Lias sedimentary rocks, despite being separated by a considerable distance. We suggest that with more data, it would be possible to create statistical fingerprints for the main geological subdivisions in the UK, against which populations of unknown origin could be tested (Evans and Tatham 2004:247). Oxygen isotope ratios, if used jointly with the strontium, would be able to distinguish between two populations with similar strontium isotope ratios caused by the same underlying geology.

Strontium and oxygen isotope analysis are definitely useful tools when assessing migration and population movement, but they are not without their limitations and difficulties relating to interpreting data. Much more work, especially comparative analysis is required. It holds the promise, however, of becoming the first tool of choice when looking at a population for a migrant component. A main obstacle to overcome is the time (for 3-5 teeth *ca.* 3 days prep and *ca.* 3 days analysis, to which repeats and the analysis of standards must be added) and costs (ca. £500 per tooth) involved in undertaking the analyses, which would prevent such tools from being used routinely. Also, unlike DNA analysis where just one analysis can be informative, analysis of only a few individuals from a population would reveal very little as a population profile needs to be ascertained first before any conclusions can be drawn about specific individuals. DNA, however, does not give information about events during a person's lifetime and may not distinguish well between individuals who were from the same racial type but came from different locales. Isotope analysis can also extract information from the teeth when the rest of the skeleton would be too damaged to enable DNA extraction.

[NB: this thesis was submitted in October 2004; subsequently the following paper appeared in print: Budd, P *et al.* (2004). Investigating population movement by stable isotopes: a report from Britain. *Antiquity* **78**:127-141. Some disturbing results had ensued from the strontium analysis of teeth from the Anglian cemetery of West Heslerton, Yorks. Specifically: "some lithologies give rise to highly varied ratio ^{87}Sr to ^{86}Sr so that it can be impossible to distinguish local from long-distance movement. The West Heslerton area is one such case and it seems highly likely that some areas of the UK will have a similarly complex and varied local Sr-isotope geochemistry. Our results sound a note of caution for

others working in similar geological settings and especially when Sr-isotope analysis is the only method employed." Despite this note of alarm, it is re-assuring that in the PhD thesis concerned the results from stable oxygen isotope analysis broadly corroborate the analytical results obtained for the strontium isotopes, so the approach taken is fully vindicated.]

Chapter 4. Comparative Palaeodemography

4.1. Introduction

Paleodemography investigates past populations where there are no or few written documents to enable us to assess their demographic patterns (Buchet and Séguy 2002). Considering the population as a singular object for quantitative analysis, it studies the structure and dynamics of populations, seeking to explain variations in population size, population density, age and sex structures, mortality, fertility and migration (Chamberlain 2000:101).

By determining and assessing variations in the age at death and the sex of skeletons, we are able to conduct paleodemographic observations on the archaeological populations. This in turn offers us information on the structure and dynamics of past populations, which is crucial in understanding the biocultural and epidemiological significance of disease (Cox 2000:61).

In demography, mortality rates are calculated by ratios of the number of deaths at certain ages and the population at risk at those ages over a defined period of time. We cannot calculate true mortality rates using skeletal assemblages, as we cannot define these periods. To overcome this problem, paleodemographers interested in modelling life expectancy in the past using skeletal assemblages have had to make assumptions, which are called 'false assumptions' by Angel (1969) and 'whopper assumptions' by McCaa (1998:1). According to McCaa (1998:1) and Chamberlain (2000:102), the assumptions are as follows:

- The observed population was stationary, i.e. static or closed, with no immigration or emigration of living individuals;
- The excavated data were representative of the living population, in spite of differential deposition, preservation and recovery;
- The age estimates are valid even though age estimates are acknowledged to be imprecise and inaccurate.

These assumptions are at the heart of the paleodemographical conundrum, where samples are usually incomplete and only assumptions can be made about their representativity, rendering the interpretation of population size and structure difficult and open to conflicting interpretation.

Carrier (1958) developed a method for calibrating age-ratios from empirical populations against those from models of stable populations experiencing various demographic growth rates. In 1982, however, Bocquet-Appel and Masset argued that "the information conveyed by the age indicators is so poor that the age distribution thus available can hardly reflect anything but random fluctuations and errors of method" (Bocquet-Appel and Masset 1982:329). Wood *et al.* (1992) further argued that attempts to defend paleodemography by means of paleopathology were doomed by the osteological paradoxes (see chapter 5 section 5.1 for a definition of the osteological paradox), demographic non-stationarity, selective mortality, and individual heterogeneity in the risks of disease and death.

The recent advances in paleodemographical methodology are still felt to have been a 'disappointment' (McCaa 1998:9) and the discipline has suffered from a pessimistic outlook. Whilst it is indeed hazardous to attempt to draw extensive conclusions from material that, due to its nature, is subject to so many limitations, yet demographical inferences can successfully be drawn from skeletal evidence.

The key issue central to this debate is how a 'population' is perceived by statisticians/demographers and archaeologists/anthropologists, and what is expected of the material. An archaeologically recovered population (i.e. that was buried then recovered) could not stand up to modern statistical tests because it will never conform to some of the most basic requirements needed for demographic modelling. Paleodemography, however, can provide a framework for comparative discussion and debate for establishing population profile.

It will be endeavoured here to assess and compare the age at death distribution of the sites investigated in this project and to use the data as a complementary tool to assess health.

This will be achieved by examining the sex and age at death distribution of each site using ratios and percentages, complemented by basic statistics in the form of chi-square analysis and T-test analysis. This will offer population profiles for each site. While we cannot infer longevity based on these profiles, we can nevertheless extract information on population dynamics.

4.2. Selection criteria of the sites for the project

The following sites were used in this chapter:

Sites investigated	*Data acquired by*	*Source*
Raunds	Published report	Boddington 1996
Ipswich	Unpublished report	Mays, unpublished
Fishergate 4	Published report	Stroud and Kemp 1993
	Additional data based on	Duncan 2000
St Nicholas	Published report	White 1988
Shambles	Additional data based on	Duncan 2000
Löddeköpinge	Published report	Persson *et al.* 1984
Lund	Published report	Arcini 1999
Arras	Primary analysis of skeletal material	Tatham
	and unpublished report	Blondiaux, unpublished
Rouen	Primary analysis of skeletal material	Tatham
Cherbourg	Primary analysis of skeletal material	Tatham
Wing	Primary analysis of skeletal material	Tatham

Table 4.1. Sites and sources used for the paleodemographic assessment.

The table above summarises which sites are investigated in this chapter and whether the information was extracted from reports (published or unpublished) or obtained by primary analysis of the skeletal material. NB: emphasis is placed on the adult population.

To remove as much bias from the analysis as possible and to provide a valid basis for comparison a few prerequisites had to be met when selecting the sites for analysis:

1. *Cemetery type.* Diversity in cemetery types was actively sought, with mixtures of urban and rural; inland and coastal sites. A certain level of homogeneity in the nature of the site was sought to make them comparable within the selection. As only a limited number of sites could be studied, they are therefore lay and domestic in nature, coming from parish cemeteries, thus observing the 'ordinary' adult population. They should have similar number of males and females, and not a particular type of population, such as the advantaged (e.g. monastic cemeteries) or the very ill (e.g. hospital cemeteries).
2. *Cemetery size.* It has often wrongly been assumed that the larger the site, the more representative the sample was of the parish or local population as a whole (Daniell 1997:124) and that smaller samples could only offer limited information. In view of the requirement for diverse populations and the availability of sites, there could be no initial selection based uniquely on the size of the samples. Bearing in mind the availability of skeletal assemblages, it was felt that a minimum number of 50 individuals in a site offered a reasonable size to work with. Roberts and Cox's (2003) work on health in Britain though the ages also elected this minimum number of individuals for their selection of sites.
3. *Cemetery completeness.* For a site to be representative of a given community, it has to be as complete as possible. Thus fully excavated cemeteries with bones in good condition were initially sought. The available skeletal assemblages though are rarely complete, particularly in the UK. It is frequently impossible to excavate entire cemeteries, either because subsequent land redevelopment and the establishment of modern boundaries have destroyed part of the cemetery, or because the nature of today's rescue archaeology means that only what is at risk of being lost is excavated. This is particularly true of urban contexts. In sites such as Wing and Ipswich, only a quarter and half (respectively) of the total cemeteries are believed to have been excavated. In the instance of Wing, the area of land being redeveloped dictated the size of the excavation. The effects of only having partial sites are discussed below in section 4.5. In addition, having good bone preservation is of equal, if not superior, importance.

Although Ketton was suitable for most of the criteria, the very fragmentary nature of its skeletal remains meant that they could only be used for isotope analysis.

4. *Reliability in ageing and sexing.* It is essential for this study that the individuals in each cemetery had been reliably aged and sexed. This was a problem for the skeletal material from Ketton and Abingdon: Ketton was analysed by multiple inexperienced observers, and in view of the fragmentary nature of the skeletons, it was felt that the resultant demography might be subject to errors and was therefore not included here. As the Abingdon sample was composed only of skulls it could not be sexed or aged as reliably as the other sites and might introduce a bias.
5. *Site date.* All the sites had to be dated between the 10th and 12th centuries AD for the purpose of this project, or have a phase of the cemetery dated to that period. This was the case for Fishergate 4, Lund and Rouen.
6. *Availability.* It was imperative that human bones reports, both published and unpublished, or the excavated skeletons, were available and accessible for consultation.

4.3. Sexing methods

Sex is the biological quality that distinguishes males and females. In the past, the terms sex and gender have been (wrongly) used interchangeably (see Walker and Cook 1998). Gender can be defined as the social significance placed on the biological differences between males and females. A cultural construct, it is linked to biological sex but is not exclusively defined by it (Mays and Cox 2000:117). Sex determination from dry bones relies on the existence and observation of regular and recordable differences in skeletal morphology between males and females, whereby the greater degree of dimorphism, the more accurate the sex determination (Mays and Cox 2000:117, Molleson 1994).

Weiss (1972:348) originally stated that there was a regular and systematic bias in the sexing of adult skeletons which was of 12% in favour of males. It has previously been observed that males often form the majority of sexed adult individuals in assemblages (e.g. Duncan 2000), but it is usually not usually statistically significant. Sexing an adult skeleton is now quite reliable and fairly straightforward, provided that the elements used to do so are

undamaged (Mays 1998:38). Meindl *et al.* (1985:84), when testing sexing methods in modern skeletons of known sex, found that sexing was 97% accurate if both the pelvis and skull were available, 96% with just the pelvis, 92% with just the skull and 80-90% when metrical criteria are used. Molleson and Cox (1993:206) also tested the methods on individuals of known sex of the crypt of Christchurch in Spitalfields, London, dating from the 18th -19th centuries, and found that identification of sex was 98% accurate. This means that the error zone is quite restrained if no more than 2% of the skeletons are assigned the wrong sex. The majority of errors in sexing individuals seem to be caused by ambiguous sex markers or incomplete skeletons.

The methods used to identify the sex of the individuals were essentially the same for all the cemetery samples as illustrated in table 4.2. The list is by no means exhaustive and currently represents the most recognised and widely used methods, since Buikstra and Ubelaker (1994) recommended them.

The sexual dimorphism of the pelvis indicates both functional modification and evolutionary adaptation (Mays and Cox 2000:118). In females, the pelvis is transversely oval with a relatively wider inlet, greater pelvic diameter and outlet, shaped to ensure obstetric success, whereas the male pelvis has a high and narrow structure (Mays and Cox 2000:118). Most of the observers analysing the sites used in this project relied on the shape of the pelvis using the following criteria, as described in Buikstra and Ubelaker (1994):

- the sciatic notch (more open in females and narrower in males)
- the pre-auricular sulcus (raised in females and flatter in males)
- the sub-pubic angle (more open in females and narrower in males)
- the ischiopubic ramus (wider in males and narrower in females)

Puberty in females occurs, on average, two years before males. Consequently, the extra years of growth and increase in muscle mass means that the shape of the bones will be affected by the sites of muscle attachments (Molleson 1994, Mays and Cox 2000:119). As a result, throughout the skeleton the females will commonly display more gracile markers

and the males more robust ones. Multifactorial influences in sexual dimorphism can also include genetics, diet and disease (Molleson 1994).

Sexual dimorphism in the skull also provides a number of diagnostic criteria.The main markers are the following, as described by Acsadi and Nemeskeri (1970) and Buikstra and Ubelaker (1994):

- the shape of the mandible (squarer and more accentuated in males)
- the mastoid process (enlarged and more pronounced in males, often absent or discrete in females)
- the supra-orbital ridge (enlarged and more pronounced in males, often absent or smaller in females)
- the nuchal crest (larger and heavier, often absent or smaller in females)

Measurements were also used in most cases, especially when individuals fell in the indeterminate category. The following, described in Bass (1995), are the most widely used:

- diameter of the femoral head (<42.5mm= female; 47.5mm= male)
- diameter of the humeral head (<43mm= female; >47mm= male)
- femoral midshaft circumference (<81mm= female; >81= male)

	Wing	*Ipswich*	*Fishergate*	*St Nicholas*	*Lund*	*Löddeköpinge*	*Raunds*	*Rouen*	*Cherbourg*	*Arras*
Sciatic notch	•	•	•	•	•	•	•	•	•	•
Pre-auricular sulcus	•	•	•	•		•	•	•	•	•
Sub-pubic angle	•	•	•	•	•	•	•	•	•	•
Ischipubic ramus		•	•	•			•	•	•	•
Mastoid process	•	•	•	•	•	•	•	•	•	•
Supraorbital ridges	•	•	•	•	•	•	•	•	•	•
Nuchal crest	•	•	•	•	•	•		•	•	•
Mandible	•	•	•	•		•	•	•	•	•
Metric standards	•		•	•	•	•		•	•	•

Table 4.2. General criteria used for adult sex determination.

These criteria were used to place adult individuals into five groups: male, probable male, female, probable female, and adult of indeterminate sex. For demographic purposes the 'probable' groups were then merged into the distinct male/female groups. Duncan (2000) demonstrated that there was no statistical advantage in keeping the individuals of established sex and those classified 'probable' distinct. All sites had a group of individuals that could not be sexed (indeterminate sex), either because of incomplete or damaged skeletons, or because the traits are ambiguous. These individuals, which represent an average of 6.8% of the populations studied, were not included in the analyses.

4.4. Ageing methods

The determination of age at death of adults in skeletal assemblages is unquestionably important not only for paleodemographic assessments but also to understand the epidemiological significance of disease (Cox 2000:61). Cox, however, also warns of the dangers of placing too much emphasis in the determination of age. Age might be very meaningful to us in our present society but to our ancestors, the majority of whom were probably "illiterate and [discalculate], consequently age was probably neither known, with

exactitude, nor relevant" (Cox 2000:62). Biological status and physical condition were much more likely to be of importance.

The ages that are important to us (e.g. 18 and 65) were probably irrelevant to past populations (Alduc-Le Bagousse 1994:31-2, Cox 2000:61-2). In addition, perceptions change, for example, the idea of childhood and when an individual becomes an adult (see Crawford 1991, Alduc-Le Bagousse 1994). Today, adulthood is socially considered to be an age of legal responsibility, which is placed at the age of 18, but only a few decades ago it was 21. In the 7th century laws of Hlothere and Eadric, the age of legal responsibility was placed at 10 years of age, which was also the age of criminal culpability (Crawford 1991:17). Under Aethelstan, this age of passage to adulthood seemed to have been raised to 12, from which age the death penalty could be exacted under King Canute (Crawford 1991:17). Alduc-Le Bagousse (1994) furthermore states that in the Middle Ages it was common for women of the aristocracy to be engaged at 12 and married at 15.

The individuals that we perceive today to be sub-adults, or children, could in fact have been treated as adults in both life and death, even if we do not today consider them to be so. This lack of clear adult/sub-adult division has led to a great confusion in human bones reports for age grouping (see Crawford 1991), least not because individuals aged 10-20 and specifically 15-20 are often under-represented in skeletal assemblages (Alduc-Le Bagousse 1994:37-38). Alduc-Le Bagousse (1994:38) calls the 15-20 year old group a 'no man's land' as it is wedged between the juveniles and the adults, not really belonging to either In reports the first age category for adult varies between 17 and 20. In our assemblages, individuals aged 17 and over were considered to be adult in Lund and Raunds, but in Fishergate, only individuals aged 20 and over were included in the adult population. All other sites considered the age of 18 to be the division between children and adults.

Choosing the age of 18 as cut-off point makes sense biologically, as it corresponds to the average age of skeletal maturity, when the last suture in the skull closes and epiphyseal fusion is complete (Alduc-Le Bagousse 1994:32). As individuals aged 18 and over are included in the adult population in most reports, the same was done here, to aid

comparative analysis, but also in the full knowledge that potentially individuals aged 12 and above could probably also be included in the adult group. Archives were used to rectify the adult population at Fishergate to include 18-20 year olds, but the Lund and Raunds results were not amended as the osteological difference between a 17 and an 18 year old is too minimal.

There has also been a trend in the past to under-report the older individuals (McCaa 1998, Cox 2000, Molleson and Cox 1993), in spite of abundant historical evidence that individuals in the past were quite capable of reaching old age. This partially reflects present misconceptions about longevity in past populations (Cox 2000:62).

A great obstacle associated with ageing methods is that they are mostly derived from analysis of modern material, and as a result they may not be accurately transferred to historic population. In addition, there is criticism that they may not even be consistent in modern assemblages (Molleson and Cox 1993:168). Bocquet-Appel and Masset (1982, 1996) have drawn attention to the fact that there are systematic errors in ageing skeletons using calibrations based on a limited and inappropriate reference population (see section 4.5).

There are a great variety of techniques available to the anthropologist to estimate the age at death of an adult skeletons, but there is still no primary or wholly satisfactory method, and it currently remains one of the major difficulties in human osteoarchaeology (Mays, 1998:50). Even when looking at just one area of the skeleton, for example the pelvis, different techniques can be used such as those used in Lovejoy *et al.* (1985) and Meindl *et al.* (1985). Some are relatively simple to use, like Brothwell's tooth attrition (1981), while others use more complex, such as dental microstructure (Charles *et al.* 1989).

Nevertheless, faced with the need to estimate age, anthropologists have to rely on these methods, even if they are not completely adequate. From the variety of methods available, the observer selects the techniques in two ways. Firstly, and most obviously perhaps, methods which are thought at the time to be reliable and that are well established in the

discipline. Secondly, methods which the observer will feel are best applied to the population studied. This can be as a result of the state of preservation of the material: for example, in St Nicholas Shambles, half the skeletons had fragmentary or missing skulls, so methods had to be used that also assessed the post-cranial skeleton (White 1988:29). In addition, all populations and individuals age at different rates. This can be due to environmental factors, life history or genes, and the compatibility of some techniques can vary according to the population studied. In Wing, for example, the age given by the pubic symphysis and the auricular surface coincided. In other populations studied, such as some Danish skeletal assemblages, the auricular surface often gave an estimate of a more advanced age (unpublished observations). Faye Powell, when analysing Raunds, felt that teeth gave an accurate age estimate, but that the cranial suture closure was too irregular to be used (Powell in Boddington 1996:114).

For the investigated assemblages, most observers seem to have used Brothwell's tooth attrition technique (1981), and at least one of the various methods using changes at the pubic symphysis. Some scholars have recommended the combining of several age indicators in a multi-factorial approach in order to improve the reliability of results (Mays 1998:55, Lovejoy *et al.*. 1985, Buikstra and Ubelaker 1994). It must be kept in mind that all ageing is a subjective approach and that the final age given to any individual has an element of intuitive interpretation of the results given by objective, systematic methods. Finally, it might also be noteworthy to mention that regardless of the techniques used, experienced observers often agree on an age. Thus, when tests on Coventry and Wing were carried out between myself, using McKern and Stewart (1957), and Dr Wakely, using the Suchey-Brooks set, we found that our calculated ages correlated well.

	*Wing**	*Ipswich*	*Fishergate*	*St Nicholas*	*Raunds*	*Lund*	*Löddeköpinge*	*Rouen**	*Cherbourg**	*Arras*
Molar attrition										
Brothwell 1981	•	•	•	•	•		•	•	•	
Miles 1962			•			•				
Pubic symphysis										
McKern & Stewart, 1957	•	•		•	•		•	•	•	
Meindl *et al.*. 1985			•							
Suchey *et al.*. (unpubl)	•		•	•						
Suchey *et al.*. 1988						•				
Auricular surface										
Lovejoy *et al.*. 1985	•		•					•	•	
Meindl and Lovejoy 1989	•							•	•	
Cranial sutures										
Meindl & Lovejoy 1985			•	•	•					
Perizonius 1984		•						•		
Masset 1982								•		•
Krogman and Iscan 1986						•				
Sternal rib										
Iscan *et al.*. 1984, 1985			•							

Table 4.3. Criteria used to assess adult age. * denotes primary data analysis presented in this study.

Table 4.3 (above) displays the criteria used for ageing individuals in the observed skeletal assemblages. Changes in the pelvis include the symphyseal face of the pubis and the auricular surface of the ilium, where age-related changes affect the appearance of the surface (texture, relief and margin definition) according to established age categories. The process is similar for the sternal rib end, which becomes increasingly irregular in morphology with advancing age. The difficulty in using this method lies in the accurate location of the fourth rib, which can be challenging to locate, as ribs are often broken and

fragmentary. Molar attrition assesses the gradual pattern of molar wear. Cranial sutures development looks at the sutures of the skull and their level of closure and obliteration.

4.5. Reliability of ageing methods and observers.

The work of Bocquet-Appel and Masset has forcefully influenced present views in paleodemographical modelling by exposing major flaws in the reference material used to establish ageing methods. In a reactionary paper entitled 'Farewell to paleodemography', Bocquet-Appel and Masset (1982) heavily criticised the reference populations by stating that:

1) the age at death distribution of studied populations reflected those of the reference sample too closely;
2) standards were developed from populations where age classes were not evenly represented and were therefore more likely to generate biased estimates for age at death;
3) the use of standards that left out older people, ignored sexual dimorphism and population specificity were likely to be biased;
4) currently available methods for estimating age-at-death were not sufficiently precise to afford accurate age classification groupings;
5) the variation observed was in fact caused by imperfect methodology and stochastic (i.e. with a random probability distribution) variation.

Buikstra and Konigsberg (1985) attempted to respond to the criticism. They acknowledged the issues surrounding the debate and defended the original choice of material used to establish current ageing methodology, but were not able to produce a real alternative. In 1996, in a paper called 'Paleodemography: Expectancy and False Hope', Bocquet-Appel and Masset reiterated the same concerns raised 14 years previously and bemoaned that the controversy had still not been resolved.

Another issue is that some methods were developed by extrapolation from analysis of archaeological material (Cox 2000:63). This material was also usually of unknown sex and age (e.g. Miles 1962).

Not only is it a concern that the techniques that we are using might not be transferable to historic populations, but also that they might not even be consistent with modern assemblages. By using archaeological material, we may be replicating fundamental conceptual errors; and if we use modern material, some socio-economic and genetic bias could affect perceived biological trends as well as introducing systematic errors in ageing skeletons using calibrations based on a limited and inappropriate reference population (Molleson and Cox 1993:168). The small size of the original sample could also skew age distribution and a disproportionate representation of sexes and ancestry (Cox 2000:63).

As a result, ageing methods are tried and tested on historical populations of known age and sex, when available, in an attempt to isolate problem areas and rectify possible errors. One of the best known studies is that that of Saunders *et al.* (1992), where methods which are the most widely used and believed to be the most reliable were tested. They included cranial suture closure (Meindl and Lovejoy 1985); changes in the pubic symphysis (Suchey *et al.* unpub.); the auricular surface (Lovejoy *et al.* 1985); and the sternal rib end (Iscan *et al.* 1984 and 1985). These were applied on a 19th century Canadian cemetery where the ages were known from parish records and coffin plates. The test showed increasing inaccuracy with increasing age and a bias consisting of the under-ageing of older skeletons.

The 'Complex Method', devised by Acsadi and Nemeskeri (1993), attempted to reduce bias by using a combination of at least two of the following four criteria to age individuals within a five-year bracket: morphology of the pubic symphysis, obliteration of the cranial sutures, structure of the trabecular bone of the femoral head and of the humeral head. Using multiple age markers has been recommended by the Workshop of European Anthropologists (1980) as the most reliable method for ageing skeletons. Molleson and Cox (1993), however, tested the technique on the skeletons from the crypt of Christ Chrurch in Spitalfields in London and found only a passable degree of agreement within fifteen years

of the known age (and less than 30% agreed within five years of the known age). There was a systematic error whereby individuals under forty were over-aged and those over seventy were under-aged.

There are many reasons to explain the inaccuracy of these 'reliable' methods, as discussed above. Three problems, which are intrinsically linked, are apparent: firstly, biological age does not necessarily correspond to (true) chronological age. Indeed, osteological age determination in adults is based on degenerative changes of the bones, which can happen at different rates as they are influenced by a number of factors, including an individual's genetic make-up, health and the environment. Secondly, our ageing material has been compiled from dissecting-room cadavers, who may have had a diet, health, lifestyle and environment inherently different to that of historic material. It is therefore questionable whether the same methodology can be applied to historic populations. Thirdly, doubts have been raised on how reliably the information on the age and medical history of cadavers was collected in the first place, potentially revealing a deep-rooted error in the reference collections themselves.

As well as the reliability of the methods, the reliability of the observers can come into question. Accurate osteological ageing is an arduous task as the morphological changes that we need to detect are subtle and the methodology are often complex. It requires experience and a sound knowledge of bone changes to age confidently and competently. This can prove to be difficult to the inexperienced observer, which can be further exacerbated by badly preserved skeletal remains.

Multiple observers can also be a problem. The level of inter-observer variability was assessed by Waldron and Rogers (1991) in the coding of osteoarthritis and found to be substantial. Because ageing is subjective, two observers may not assess the age of a skeleton similarly. Not only can errors be made due to varying degrees of experience, but the ageing techniques and the interpretation of the techniques could also differ. Inter-observer variability is a recognised problem in anthropology and measures must always taken to reduce it (see Mays *et al.* 2002b for guidelines on recording bones). A single-

observer analysis is preferred for the homogeneity of the ageing and the uniformity of interpretation of the methods.

There is another problem linked to inter-observer variation when a comparative study is conducted. Each human bones specialist uses techniques that suit his/her own experience, personal preference and skeletal material. Some age individuals within a five or ten year bracket, others, especially if the material is fragmented, prefer the more cautious distribution into three age groups: young, mature and older adult; and do not always make known the ages encompassed by the designations. In this project, they have been translated as: *adultus*: 18-30 years old; *maturus*: 30-45 years old; *senilis*: 45+ years old). It has been noted that anthropologists in general have a 'smooth digit preference', whereby it is preferred to assign even ages to odd, and ages ending in five and zero above all (McCaa 1998:3). No particular explanation can be provided for this, only that it is common practice and is not likely to have an impact in demographical investigation. It may be an attempt to bring into the calculations a recognition of the imprecise nature of the skeletal age estimates.

Ideally, for the ageing to be consistent and systematic, a single person would have to look at all the material. In reality, this is impossible because of both time and financial constraints and is rarely achieved today. The reports that were used here were written by human bones specialists of known proficiency and experienced guidance was available for primary skeletal analysis. It was also decided to follow the trends that seem to be currently favoured by anthropologists by placing individuals in four age categories: 18-25 years old, 25-35 years old, 35-45 years old and 45+ years old. The age categories are large enough to minimise errors but still remain informative and provide comparison points. Comparative age data between the sites will be presented in two age categories: 18-35 and 35+.

4.6. Possible effects of demographic analysis from partially excavated cemeteries

There is no doubt that fully excavated cemeteries provide the most reliable data when comparing demographic trends in the past. Partially excavated sites could project a

distorted image of the population, for example, if areas of the cemetery were reserved for certain individuals (known as zoning, e.g. clustering of males/females, social groups, age groups, etc.). Unfortunately, it is unusual for cemeteries to be completely excavated. Most excavations carried out currently are of an emergency rescue nature, where the size of the excavation will be largely dictated by the size of the land under threat and what is achievable within financial and time constraints. Even if fully excavated, cemeteries are rarely intact. Prior land redevelopment or reuse and changes in boundaries often cause some destruction. Skeletons can also be lost through soil erosion (natural or agricultural, e.g. through ploughing), soil type (especially acid soil) and grave cutting (Boddington *et al.* 1986).

Not using the material because it is imperfect is, however, pointless. Partially excavated sites and imperfect samples still provide invaluable information on the life and death of a population, we just need to be careful of the conclusions we draw about the whole population based on the sample analysed. All the partially excavated sites in this study were regarded to be representative of the total projected cemetery by the archaeologists who excavated them and these assumptions were not challenged by the human bones specialists who analysed them.

4.7. Hypotheses and methodology

In one of the first British textbooks on human bones analysis, Brothwell (1981:73) made statements that remain at the basis of paleodemographical analysis. They include the following assumptions:

1) Life expectancy is variable from group to group, but is generally far less in the past than in modern societies;
2) Trends can be seen through time and are related to diet, disease and other aspects of the culture and environment;
3) Differences occur between males and females;
4) Age-group composition can show variation from sample to sample and this could be related to cultural/environmental/biological factors;

5) Sex ratios between males and females should be approximately 1:1. However, there can be marked variation in archaeological samples, and this is likely to indicate the influence of cultural/environmental/biological factors that can produce bias.

In this analysis we will first observe the distribution of the age at death for each assemblage and we will assess if there are:

1) Male vs. female differences in the sex and age distribution of the adult population in each site;
2) Differences in longevity between the sites;
3) Regional differences in the age and sex distribution between English and continental (non-English) sites.
4) Differences between rural and urban population profiles;

Secondly, we will consider whether partially-excavated cemeteries can be supposed to be truly representative of past populations.

The statistics employed here are simple and do not require an advanced understanding of statistics. Percentages and ratios were used for basic age at death comparison between males and females. Chi-square tests, T-tests and probabilities were then used to find out if the results were statistically significant. Tables, charts and histograms present the results in section 4.7.

4.8. Results

The basic distribution of adults and sub-adults, followed by the distribution of the males and females in the adult population was first assessed. Table 4.4 summarises the findings.

Cemetery	$T_{sexed\ adults}$			$T_{ind.\ adults}$	$T_{sub\text{-}adults}$		T_{site}
		T_{males}	$T_{females}$		*(% child mortality)*		
Arras	48	27	21	3	16	(23.8%)	67
Wing	59	31	28	4	13	(17.1%)	76
Ipswich	63	35	28	16	16	(16.8%)	95
Cherbourg	61	29	32	20	83	(57.6%)	164
Fishergate	81	47	34	2	48	(36.6%)	131
St Nicholas	145	90	55	21	54	(24.5%)	220
Raunds	182	100	82	9	172	(47.3%)	363
Rouen	229	141	88	146	286	(43.2%)	661
Löddeköpinge	694	342	292	60	482	(40.9%)	1176
Lund	851	508	343	253	357	(24.4%)	1461
Total	2,413	1,350	1,003	534	1,527	(34.6%)	4,414

Table 4.4. Adult sex distribution of the investigated sites and division into adult and sub-adult (including individuals of known sex but indeterminate age).

$T_{sexed\ adults}$ is the total number of sexable individuals per site (including individuals of known sex but indeterminate age), T_{males} and $T_{females}$ are the total number of adult males and females, $T_{ind.\ adults}$ is the total number of indeterminate adults (some of them of known age), $T_{sub\text{-}adults}$ is the total number of sub-adults and the % relates to their total numbers in relation to the total population, and T_{site} is the total number of individuals in the site (including children).

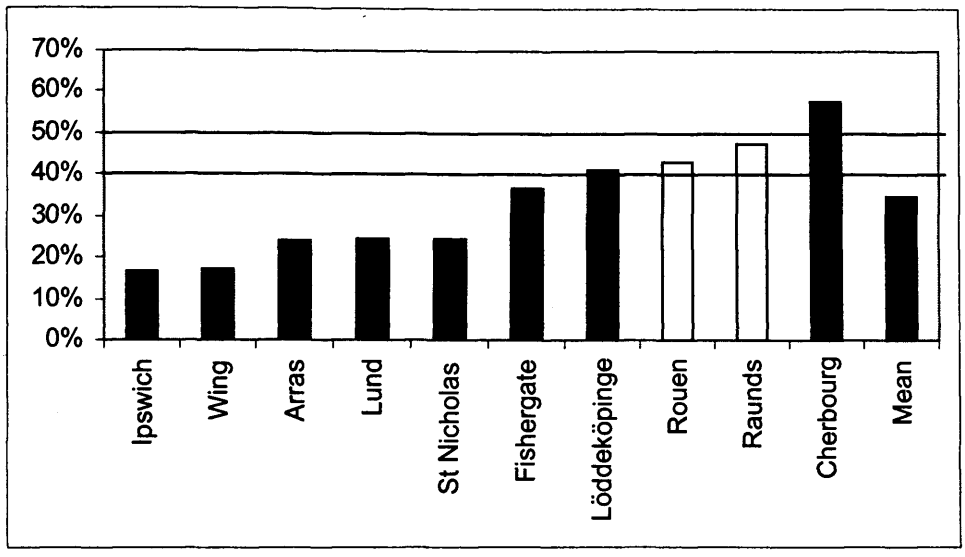


Chart 4.1. Percentage of sub-adults in the investigated skeletal assemblages (individuals aged up to 18 years old). Rouen and Raunds, in white, are the only sites where the cemetery was near-fully excavated. The two horizontal lines mark out the expected sub-adult sample.

We normally expect 40-50% of the archaeological assemblages to represent sub-adults (Coale and Demeny 1983). However, issues with bone survival and excavation, coupled with the frequent zonation of subadult burials means that in the context of partial excavations, the children are usually under-represented according to the areas excavated (Lewis 2000). A sample consisting of less than 30% of sub-adults is generally considered to have been affected by a preservational or recovery bias (Grauer 1991). The percentage of individuals under the age of 18 in our skeletal assemblages range from 16.8% at Ipswich and 57.6% at Cherbourg. Only Rouen and Raunds were almost fully excavated and they show some of the highest percentage of sub-adults. Despite the fact that Rouen is urban and Raunds is rural, they seem to display similar child mortality rates at 43.2% and 47.3%. Löddökopinge displays similar rates with 40.9%, suggesting that the excavated portion of the cemetery is likely to be representative of the population. Cherbourg, on the other hand, where an estimated half of the cemetery was excavated, had the highest proportion of sub-adults, suggesting an over-representation of the sub-adults in the excavated portion. Wing, where only 25% of the cemetery was excavated, presents one of the lowest percentage of subadult. Charts of the sub-adult age distribution for some of the sites are placed in the

appendix. It is therefore possible that sites with an under- or over-representation of sub-adults might not display a representative section of the cemetery.

4.8.1. Sex distribution in the skeletal assemblages

In the three tables below, the sexed adults are divided between males and females. Percentages and ratios are calculated and chi square is used to assess if the observed values are statistically significant from the expected ones. T-tests are used to assess the significance of the observed difference between the data sets. Sites are divided between English, French and Swedish sites (the French and Swedish material also form the continental, or non-English, sites).

All three tables (4.5, 4.6 and 4.7) use the following column heading: n_{males} and $n_{females}$ are the number of males and females of known age per site, $\%_{males}$ and $\%_{females}$ the percentage of males and females of known sex per site. The sex ratio is the number of males for every female. Chi-square is undertaken to assess whether the male-female differences in distribution are statistically significant. The null hypothesis expects that the observed values to match those expected, and that any difference should not be statistically significant. The null hypothesis is rejected if they are calculated to be. X_2 is the chi-square statistic and p is the probability (where the null hypothesis is rejected at $p<0.05$), displayed within three decimals. Chi-square results that are statistically significant are in bold characters.

Sites	n_{males}	$n_{females}$	$\%_{males}$	$\%_{females}$	*Sex ratio*	X_2	*P*
Wing	30	23	56.6	43.4	1.304:1	0.924	0.336
Ipswich	27	20	57.4	42.5	1.350:1	1.042	0.307
Fishergate	44	26	62.9	37.1	1.692:1	4.628	**0.031**
St Nicholas	68	46	59.6	40.4	1.478:1	4.245	**0.039**
Raunds	98	77	56.0	44.0	1.272:1	2.52	0.112
Total	267	192	58.2	41.8	1.390:1	12.254	**<0.001**

Table 4.5. Sex distribution of the English skeletal assemblages (excluding individuals of unknown sex and age).

All English sites display a higher number of males than females, with an average ratio of 1.390:1. Only Fishergate and St Nicholas Shambles, however, show sex differences that are statistically significant. As these two sites are partially excavated, we cannot be sure that the observed difference in the male female distribution is a true reflection of the past population rather than a consequence of incomplete excavation affected by zonation, although neither site seems particularly affected by zonation in the excavated portions. Raunds is the only fully excavated site and also displays a higher number of males, but the higher proportion is not statistically significant with a $p = 0.112$.

The paired (or two-sample) T-test was undertaken to determine if the difference between the male and female distribution in the English sites were statistically significant. The results supported those of the chi-square analysis, with $t = 4.5$ $p = 0.011$ (df = 4), making the result statistically significant at the 5% level and rejecting the null hypothesis.

The next table looks at the sex distribution of the Swedish skeletal assemblages.

Sites	n_{males}	$n_{females}$	$\%_{males}$	$\%_{females}$	*Sex ratio*	X_2	*P*
Löddeköpinge	342	292	53.9	46.1	1.171:1	3.943	**0.047**
Lund	387	285	57.6	42.4	1.357:1	15.482	**>0.001**
Total	729	577	55.8	44.2	1.263:1	17.690	**>0.001**

Table 4.6. Sex distribution of the Swedish skeletal assemblages (excluding individuals of unknown sex and age).

The two Swedish sites both display a significant over-representation of the males, with an average of 1.263:1. The higher proportion of males is statistically significant and the null hypothesis is rejected.

The next table looks at the sex distribution of the French skeletal assemblages.

Sites	n_{males}	$n_{females}$	$\%_{males}$	$\%_{females}$	*Sex ratio*	X_2	*P*
Rouen	141	88	61.6	38.4	1.604:1	12.266	**>0.001**
Cherbourg	29	32	47.5	52.5	0.904:1	0.147	0.701
Arras	24	20	54.5	45.5	1.197:1	0.363	0.547
Total	194	140	58.1	41.9	1.386:1	8.73	**0.003**

Table 4.7. Sex distribution of the French and Flemish skeletal assemblages (excluding individuals of unknown sex and age).

Arras and Rouen both display a higher proportion of males. Cherbourg is the only site of all the investigated material that shows a higher proportion of females. For Cherbourg and Arras, the male/female proportions are statistically comparable and the null hypothesis is accepted. Rouen is the only French site that has a statistically significant over-representation of males, and since the site was fully excavated, it is likely to be an accurate representation of the sex profile of the buried population.

Paired T-test analysis was undertaken to determine whether the male and female distribution in the French and Swedish (non-English) sites were different from the English material, with $t = 2.16$ $p = 0.096$ (n.s) (df = 4), accepting the null hypothesis.

It is worth noting that the Chi-square and the T-test do not measure the same thing. Chi-square assesses whether the data differ significantly from the expected values. T-test analysis assesses the level of difference between two data sets.

4.8.2. Discussion

Only Wing, Ipswich and Raunds in the English sites, and Cherbourg and Arras in the continental sites, show a distribution of males and females that is comparable and where the higher number of males (or of females for Cherbourg) are not statistically significant. The other sites all show a statistically significant over-representation of males. Cherbourg was the only site with a higher ratio of females than males, but the observation was not statistically significant. There are no immediate obvious explanations for the observed difference in male and female distributions in Rouen, Lund, Löddeköpinge, Fishergate and St Nicholas Shambles as none were military or monastic sites.

For the English sites, some possible explanations can be investigated for the male bias encountered in St Nicholas Shambles and Fishergate. The parish of St Nicholas Shambles was in an area of London specialised in butchery (Clout 1991:39-53), which has always been the preserve of men (Goldberg 1992:108) and could explain the preponderance of males in the assemblage. This would suggest, however, that they were largely unmarried. If it was the case, than it could explain the reduced numbers of sub-adults that would normally be expected from a parish cemetery.

Fishergate's male bias is most probably the result of the group of young men displaying weapon injuries who could be town outsiders (e.g. soldiers). A possible small monastic element must also be considered. After the lay phase 4, the phase 6 of the cemetery was

used by a Gilbertine Friary. Indeed, Kemp (1993b:130) acknowledges that there has been an element of uncertainty over the phase attribution in a minority of cases.

When searching the literature, it would seem that there is a systematic occurrence of a male predilection in most western skeletal assemblages that has been observed by many scholars (notably Weiss 1972, Waldron 1994, Mays 1995, Brothwell 1972 and Bennike 1985, Daniell 1997:128). This trend would seem to go against prevalence rates of modern populations, where there would appear to be a slight female predominance (Weiss 1972).

Three possible factors causing this uneven ratio in historic assemblages can be considered:

1. There could be an over-identification of males in skeletal assemblages through a systematic bias in the application of skeletal sexing methods towards the male classification.

Weiss (1972) estimated it to be situated at 12%. It could be the case that some human bones specialists might favour a male classification to a skeleton that might otherwise show ambiguous sex markers. Some anthropologists believe that bones of more gracile females, especially of more mature females who might have a lighter bone density, might be more prone to erosion and damage (Bennike 1985:34) and would consequently give rise to those incomplete skeletons which are harder to sex. Some skeletons which are ambiguous in the sexual traits could be those of females which seem too robust to be females, yet too feminine to be classified as men. We are conditioned to expect female skeletons to be substantially smaller, more gracile and with less pronounced muscle attachments (Iscan and Kennedy 1989:66-68). The sexing methods themselves rely on the varying degrees of 'feminine' and 'masculine' traits. However, some women must have been tall and robust, and many probably had a very physically stenuous lifestyle (Roberts and Manchester 1995:23). Weiss (1972:240) suggests that the potential for inaccuracy (which he estimates at 10-15%) lies in the use of sexually diagnostic traits which are graded as being 'larger' or 'smaller' rather than those which are absent or present such as the pre-auricular sulcus. Perhaps we are unwittingly classifying more feminine-looking males as 'probable male',

but masculine-looking females as indeterminate, especially when the pelvis is ambiguous. In the view of current sexing accuracy rates (see section 4.3), however, this is only likely to be an issue for individuals of indeterminate sex.

Thus a number of the formally classified 'probable' and 'indeterminate' individuals could be females. Duncan (2000:76) acknowledges the question of whether it was appropriate to combine individuals that had been sexed less securely (i.e. probable male/female) with those that had been sexed with greater confidence when the research objective was to compare the sexes as it might introduce a bias.

Duncan's research, however, proves this argument to be unfounded. When the 'probable sex' individuals were examined statistically it was shown that 'skeletons with doubtful sex characteristics were more often classified as females than males' (Duncan 2000:81) and that the data for of skeletal completeness did not reveal any consistent bias in long bone survival, especially as on some sites, elderly females were amongst the best preserved bones (p. 83-4).

2. As most sites are partially excavated (apart from Raunds and Rouen that are fairly complete), zonation could cause males to be buried elsewhere in the cemetery and result is a sex difference in the preservation and recovery of skeletal material.

This is somewhat unlikely though as of the 10 sites investigated only one site (Cherbourg) showed a slight over-representation of females compared to males, so it is unclear where the females would be buried. Raunds shows a comparable male/female distribution, but Rouen displays a female representation of the adult material at 38.4%, which is the second lowest distribution after Fishergate. Females could be at a higher risk of dying in childhood, either as a result of sex-specific diseases or differential health caused by a lower status than males, or even infanticide by negligence.

3. These sex imbalances must then be a true representation of the populations studied (if the partially excavated assemblages are deemed to be representative of the populations

interred), the distortion in sex ratios having arisen through various demographic or cultural factors.

Kirk (1996) suggested that rapid and permanent changes in mortality rates are associated with demographic transition, and that population movement could cause a male bias (Trupp 1965:6). Goldberg (1986, 1992), based on results of poll tax listings in the later Middle Ages, identified an inverse relationship between sex ratio and settlement size, where towns had a preponderance of females and villages of males. Goldberg suggested that a reduced demand in rural labour and an increased demand for manufactured goods and services in towns caused a female exodus to towns at the time. These females were usually young and unattached, many of whom probably subsequently found partners and settled permanently (Goldberg 1997). These young women would probably have found cheap accommodation in the poorer urban districts. Grauer (1991) suggests the over-representation of females, especially those under 35 years at death in St Helen-on-the-Walls may be a direct reflection of this pattern of female immigration and residence. The mortality rates would then have been increased upon the exposure of these young women to new urban bacteria to which they would have little resistance.

If this pattern of demography is particularly true of the later Middle Ages in England, are the explanations valid for the tenth to twelfth century? It would seem here to be the case with the immigration of young men to the larger urban centres one of the most likely explanations. The three sites with a statistically significant surplus of males were large urban population with a growing population and the sites that had a more comparable male/female ratios were rural settlements (Wing, Raunds) or urban settlements of more minor significance than the larger sites (Cherbourg, Ipswich, Arras). It is possible that young males emigrated away from smaller settlements to the larger centres with the hope of finding work, such as labourers, craftsmen or even as soldiers. These males, with a lower immunity and health status would be at an increased risk of contracting a disease that could be lethal (see chapter 5 section 5.1). In Fishergate, St Nicholas Shambles, Löddeköpinge, Lund and Rouen several cases of inter-personal violence resulting in serious injuries such as sword cuts were identified, supporting a potential soldier theory.

This influx of males would seem not to have corresponded to similar levels of female emigration. This could mean that these males might have struggled to find wives, creating a surplus of unmarried men and a high demand on females, both of which might have impacted of fertility rates. In such cases, we would expect to see an increased number of younger males in the assemblages, and if there was pressure on the females to be married, we might also expect to find a higher number of females of child bearing age dying from obstetric-related conditions. An excess of younger females compared to older females, however, could also suggest a female migration, but on a smaller scale to that of the males. Unfortunately, skeletal evidence cannot distinguish between the two hypotheses.

4.8.3. Age distribution (4 age groups) of the sexed individuals

By assessing the age distribution of the sexed adult skeletons, we can find out whether individuals were more likely to die in the younger or older age categories.

In a first instance, each site was looked at individually. Sexed individuals were placed into four age groups: 18-25, 25-35, 35-45 and 45+ (Ind. adults are adults on unknown age). The data for the two Swedish sites was not available in a format that allowed the presentation of the information is similar age categories to the French and English sites. Only three age categories could be created: 18-40, 40-60 and 50+.

In section 4.7.5, the data from the sites were collated into two age categories: 18-35 and 35+. This was done to ease comparisons between the regions by having two larger age groups, thereby reducing the error margin associated with ageing older individuals and reducing the error associated with having small numbers of individuals in age categories in some sites.

Wing

Age groups	*Males*	*%m distribution*		*Females*	*%f distribution*		*Total*
18-25	1	3.2	25.8	-	0	26.1	1
25-35	7	22.6		6	26.1		13
35-45	15	48.4	74.2	11	47.8	73.9	26
45+	8	25.8		6	26.1		14
Ind. adult	-			5			5
Total	31			28			59

Table 4.8. Wing: sex distribution per age groups (adapted from Tatham and Wakely, unpubl)

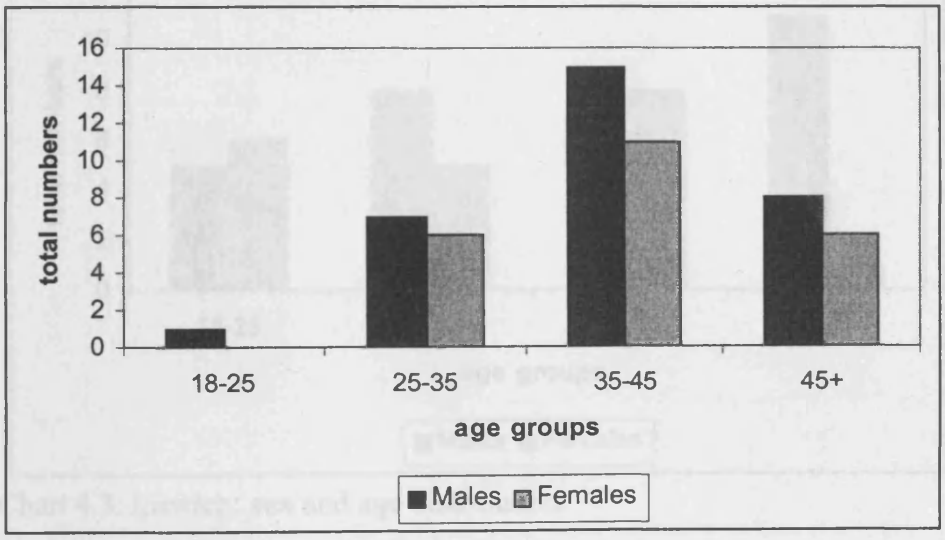


Chart 4.2. Wing: sex and age distribution.

48.4% of males and 47.8% of females in Wing are in the 35-45 year old age group. Only 1.8% of the adult population (one male) is in the first age group (18-25 year old), and no females are represented in this age group. The number of individuals in each age category increases with age, up to the 35-45 age group.

Ipswich

Age groups	*Males*	*%m distribution*		*Females*	*%f distribution*		*Total*
18-25	5	18.5	48.1	6	30	55	11
25-35	8	29.6		5	25		13
35-45	3	11.1	51.9	8	40	45	11
45+	11	40.7		1	5		12
Ind. adult	8			8			16
Total	35			28			63

Table 4.9. Ipswich: sex distribution per age groups (based on Mays, unpubl.)

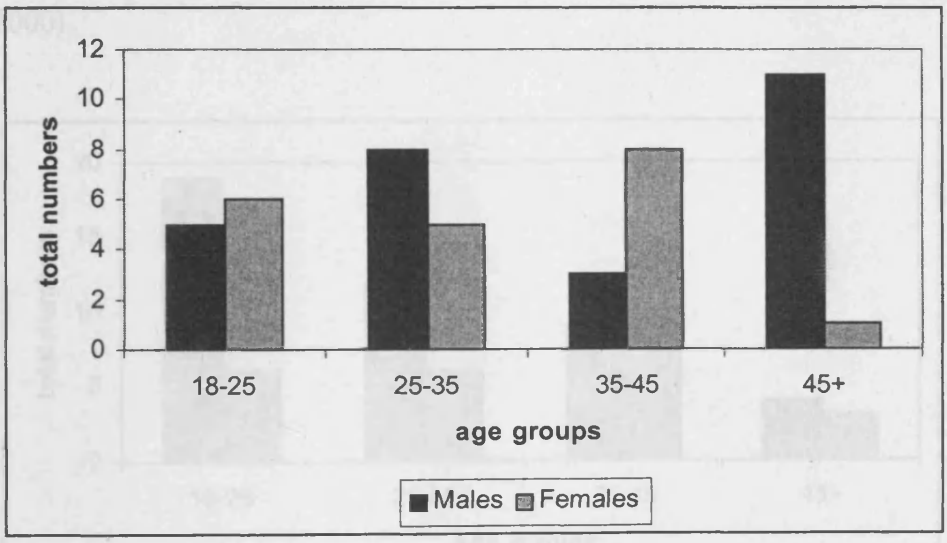


Chart 4.3. Ipswich: sex and age distribution.

In Ipswich 40.7% of the male population is in the older age group at 45+, but only 5% of the females. The majority of the females, 40%, were in the 35-45 year old group, the age category with the least males. For the females, however, when the first two age groups were combined, 55% of the females were in the 18-35 year old age category. The distribution of males and females in each age category is very different. Male numbers seem to increase with age, but there is a sharp decrease in numbers in the 35-45 year old age group with only 11.1% of the male population being represented there. The females display an even more irregular pattern, with a very sharp drop in the last age category.

Fishergate

Age group	*Males*	*%m distribution*		*Females*	*%f distribution*		*Total*
18-25	19	43.2	70.5	6	24	48	25
25-35	12	27.3		6	24		18
35-45	9	20.4	29.5	10	40	52	19
45+	4	9.1		3	12		7
Ind. adult	3			8			12
Total	47			33			79

Table 4.10. Fishergate: sex distribution per age groups (based on Stroud 1993 and Duncan 2000)

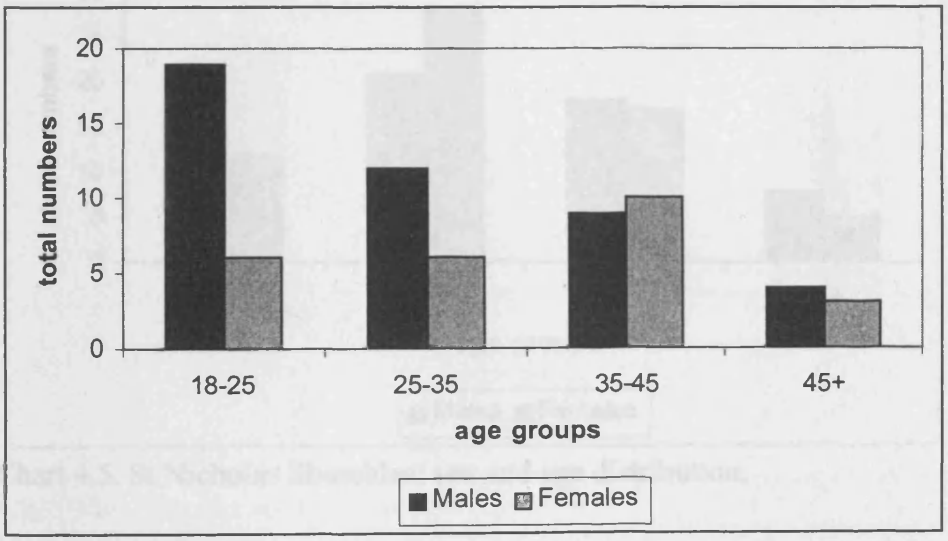


Chart 4.4. Fishergate: sex and age distribution.

Male distribution in the age categories decreases with age, 43.2% of the adult males in Fishergate are in the youngest age category (18-25 year old) and 9.1% in the oldest age group. Female distribution increases with age, with 40% of the females in the 35-45 year old category. The last age group, however, sees a sharp decrease including only 12% of all females.

St Nicholas Shambles

Age group	*Males*	*%m distribution*		*Females*	*%f distribution*		*Total*
18-25	21	30.9	61.8	12	19.3	64.5	33
25-35	21	30.9		28	45.2		49
35-45	18	26.5	38.2	17	27.4	35.5	35
45+	8	11.7		5	8.1		13
Ind. adult	23			12			35
Total	91			74			165

Table 4.11. St Nicholas Shambles: sex distribution per age group (based on Duncan 2000 and White 1988)

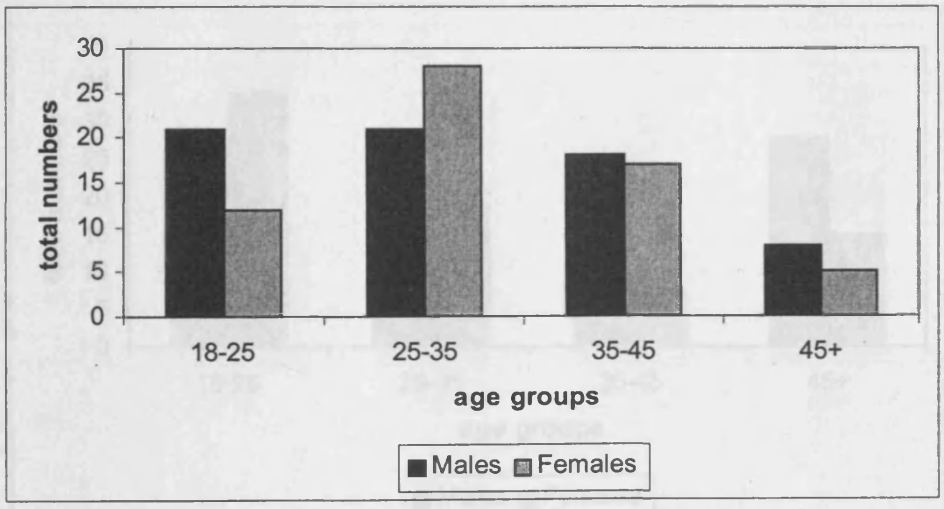


Chart 4.5. St Nicholas Shambles: sex and age distribution.

There is an equal distribution of males in the first two younger age category regrouping 61.8% of the adult males. The numbers then decrease steadily with age. Females show a similar pattern with decreasing numbers in the last three age categories. The first age category has few individuals, but the second one (25-35 year old) has the highest number of females, with 45.2% of the distribution.

Raunds Furnells

Age group	*Males*	*%m distribution*	*Females*	*%f distribution*	*Total*
17-25	22	22.4	34	44.1	56
		45.9		71.4	
25-35	23	23.5	21	27.3	44
35-45	25	25.5	7	9.1	32
		54.1		28.6	
45+	28	28.6	15	19.5	43
Adult	2		5		14
Total	100		82		189

Table 4.12. Raunds: sex distribution per age groups (based on Powell 1996).

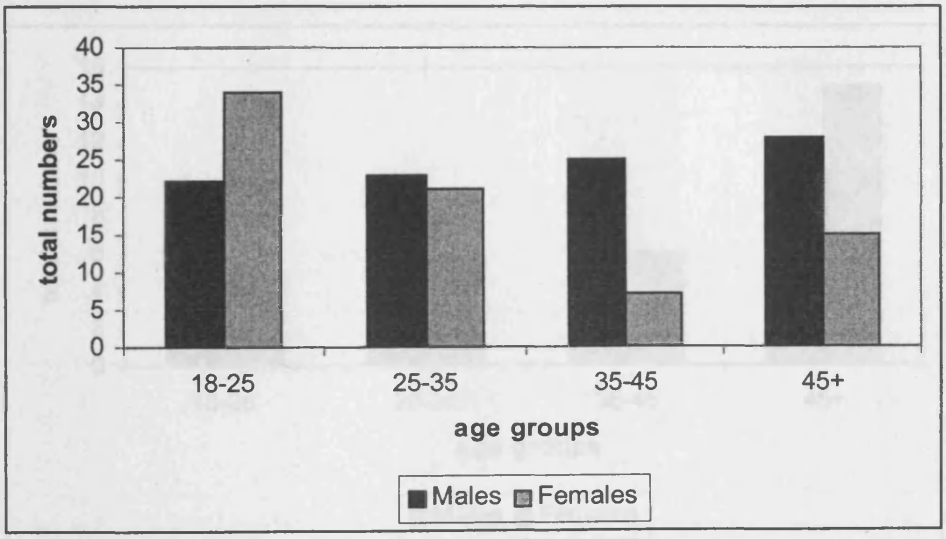


Chart 4.6. Raunds: sex and age distribution.

The age distribution of the males is fairly uniform with each age category well-represented, with numbers increasing with age. The older age category (45+) has the highest percentage of adult males at 28.6%. The females display a completely different pattern. 44.1% of all adult females in the youngest age category of 18-25. The numbers then decrease with age, but the oldest age group sees an increase in numbers.

Cherbourg

Age groups	*Males*	*%m distribution*		*Females*	*%f distribution*		*Total*
18-25	2	6.9	27.6	5	15.6	34.4	7
25-35	6	20.7		6	18.7		12
35-45	11	37.9	72.4	6	18.7	65.6	17
45+	10	34.5		15	46.9		25
Adult	4			3			7
Total	33			35			68

Table 4.13. Cherbourg: sex distribution per age groups.

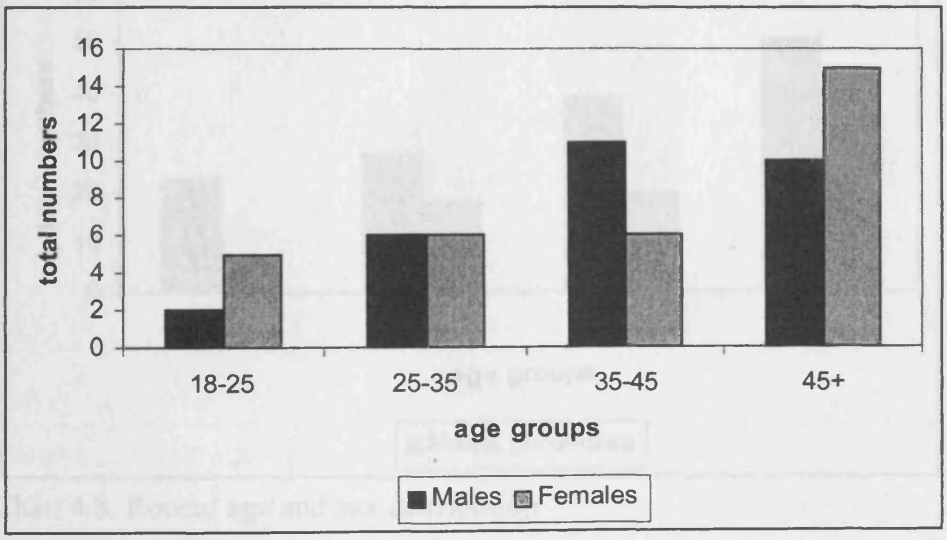


Chart 4.7. Cherbourg: age and sex distribution

The distribution of the males broadly increases with age, with a slight decrease in numbers in the last age group. The numbers peak in the 35-45 year old age category with 37.9% of the adult males. The female age distribution is fairly uniform throughout the age groups, with a sudden peak in the oldest age-group which contains 46.9% of all adult females.

Rouen

Age groups	*Males*	*$\%_m$ distribution*		*Females*	*$\%_f$ distribution*		*Total*
18-25	23	16.3	36.2	7	7.9	28.4	30
25-35	28	19.8		18	20.4		46
35-45	39	27.6	63.8	20	22.7	71.6	59
45+	51	36.2		43	48.9		94
Adult	10			17			27
Total	151			105			256

Table 4.14. Rouen: sex distribution per age group.

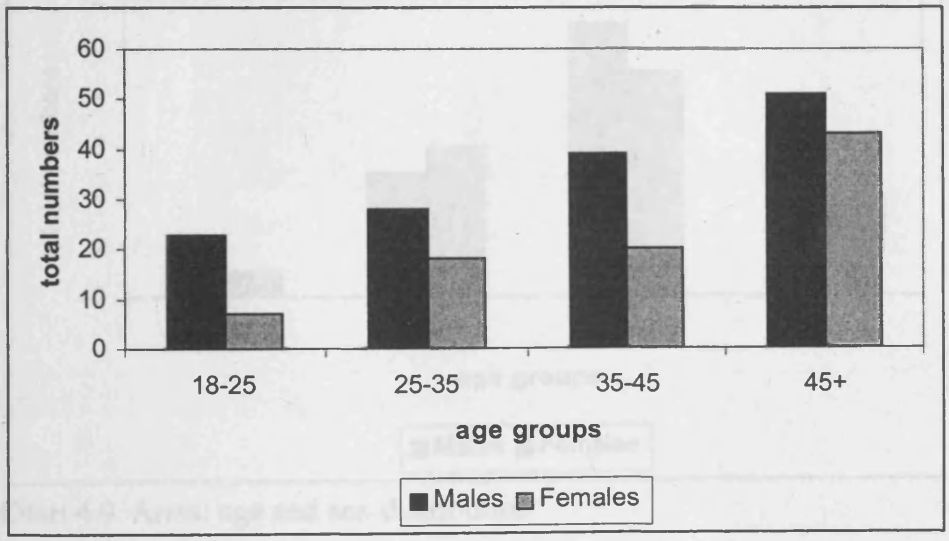


Chart 4.8. Rouen: age and sex distribution

Both adult males and females display increasing numbers with advancing age, and both show the highest percentage of individuals in the oldest age category with 36.2% and 48.9% for males and females respectively.

Arras

Age groups	*Males*	*%m distribution*	*Females*	*%f distribution*	*Total*
18-25	2	8.3	1	5	3
		29.2		35	
25-35	5	20.8	6	30	11
35-45	11	45.8	9	45	20
		70.8		65	
45+	6	25	4	20	10
Adult	3		1		4
Total	27		21		48

Table 4.15. Arras: sex distribution per age group (after Blondiaux unpubl.)

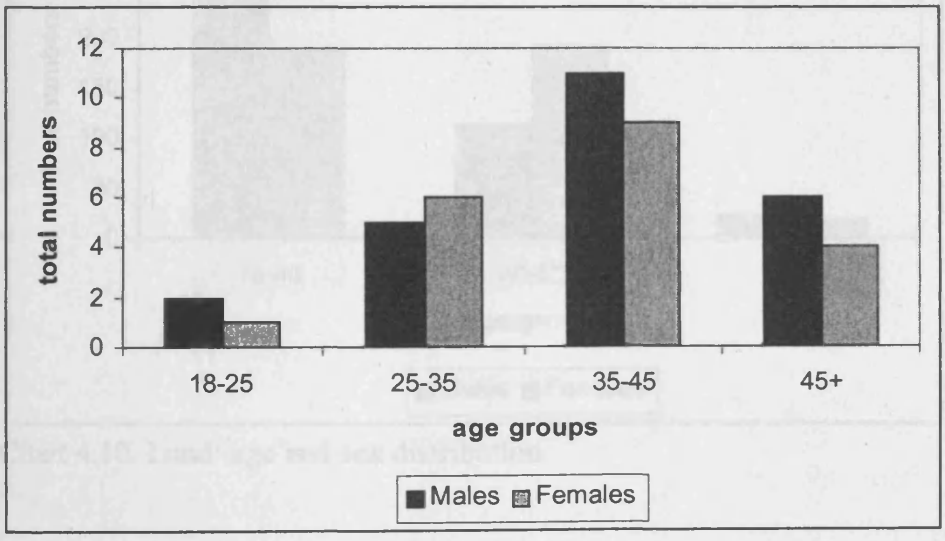


Chart 4.9. Arras: age and sex distribution

The male and female distribution follow exactly the same pattern, with numbers increasing with age with a sudden decrease in the oldest age category. Both adult males and females in Arras have the highest number of individuals in the 35-34 year old age groups with 45.8% and 45% respectively.

Lund

Age groups	*Males*	*%m*	*Females*	*%f*	*Total*
18-40	250	64.6	189	47.3	514
40-60	114	29.5	193	48.4	222
60+	23	5.9	17	4.3	43
Total	387		399		779

Table 4.6. Lund: sex distribution per age group (after Arcini 1999)

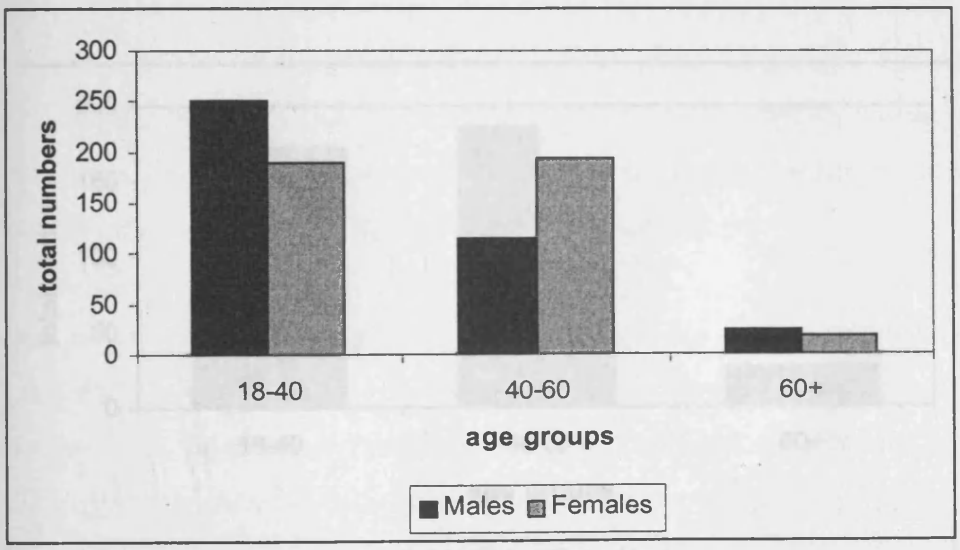


Chart 4.10. Lund: age and sex distribution

For the males in Lund, the number of individuals in each category decreases with age. For the females, the first two age categories show similar numbers, with 47.3% and 48.4% of the females in each age group. The older age category, however, is similar to the males and contains 4.3% of all sexed and aged females.

Löddeköpinge

Age groups	*Males*	*%m*	*Females*	*%f*	*Total*
18-40	131	38.3	173	27.3	364
40-60	185	54.1	92	14.5	321
60+	26	7.6	27	4.2	69
Total	342		634		754

Table 4.17. Löddeköpinge: sex distribution per age group (after Persson and Persson 1984).

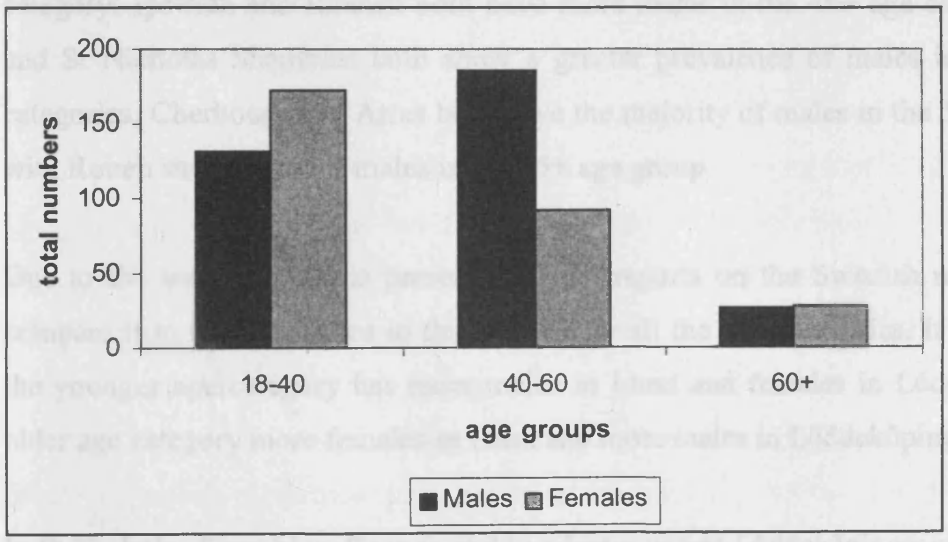


Chart 4.11. Löddeköpinge: age and sex distribution.

The female age distribution in Löddeköpinge resembles that of the male distribution in Lund, whereby the number of individuals in each age category decreases with age. The males here show the highest numbers in the second age category (40-60), with a sharp decrease in the last age group with numbers similar to those of the females.

4.8.4. Discussion

Most sites seem to have the highest percentage of their adult males and females in the 35-45 age category, especially the females in the English sample. Only Raunds differs, with more females in the youngest age category of 17-25. In Cherbourg and Rouen, the clear majority of females is in the oldest age category of 45+.

The adult males do not present such a clear picture. In the English sites, the various age categories are quite spread out. Wing has the majority of its males in the 35-45 age category. Ipswich and Raunds both have more males in the 45+ age category. Fishergate and St Nicholas Shambles both show a greater prevalence of males in the younger age categories. Cherbourg and Arras both have the majority of males in the 35-45 age category with Rouen showing more males in the 45+ age group.

Due to the way the data is presented in the reports on the Swedish material we cannot compare it to the other sites in this project for all the age categories. It would appear that the younger age category has more males in Lund and females in Löddeköpinge and the older age category more females in Lund and more males in Löddeköpinge.

In St Nicholas Shambles, Raunds and to a lesser extent Löddeköpinge, a greater number of females are under the age of 35. These results conform to the traditional expectation of a significant number of women dying as young adults (Wells 1975; Brothwell 1972). The popular assumption is that they died as a direct and indirect (e.g. haemorrhage and infections) result of multiple childbearing (Brothwell 1972:83). Such theories have been developed from finding females with full-term foetuses in the pelvic cavity, suggesting that they had died in childbirth. In St Nicholas Shambles, for example, there was such as case. The head of the foetus was too large to pass through the female's narrow pelvis and it is probable therefore that both mother and child had died during labour.

We cannot, however, rely on such findings to assess childbirth-related female mortality as the rarity of these cases would seem to suggest that it was in actual fact a rare occurrence.

After reviewing Brothwell's data, which ranged from the Neolithic to the Middle Ages, Manchester (1983:8-9) confirmed that the number of female deaths exceeded that of male deaths among those of childbearing age, with the reverse trend occurring among those surviving past the age of 35. Manchester (1983:9) further suggested that the lower social status of females might have had a direct effect on their health status, making them weaker and more susceptible to diseases. Wells (1961) and Grauer (1991) also share this view. Manchester also points out that the two are not inseparable, as inferior health could exacerbate the problems linked to childbearing. It will be useful to compare the sex distribution of general stress indicators in Chapter 5 (see sections 5.3.3, 5.4.2 and 5.5.1). The same could not be done for the infectious lesions in Chapter 6 as there were too few individuals displaying specific lesions.

Since the females in half of the investigated assemblages were more numerous in the 35-45 age group, it is unlikely that female mortality can be directly linked to the risks associated with childbearing. It is possible, however, to suggest that multiple pregnancies in females, if combined with poorer health due to low social and dietary status, could contribute to increased mortality in this age group.

Males were more numerous in the older age categories 35-45 and 45+. In Fishergate and St Nicholas Shambles, however, males were more numerous in the youngest age categories 18-25 and 25-35. This supports the suggestion that males are more likely to die young from inter-personal violence injuries (see Boylston *et al.* 2000:52) and/or as young migrants with a reduced immunity, as discussed in section 4.7.3. In the mass grave from Townton (AD 1461) which contains War of the Roses soldiers, the greatest proportion of males was in the 25-35 age range. 33% of individuals exhibited perimortem post-cranial trauma and 96% exhibited cranial trauma, the majority of which were sharp force weapon injuries (Novack 2000:91-95). Evidence of trauma was plentiful in Fishergate, supporting the evidence of violence-related deaths in young males. 22 individuals from the period 4 in Fishergate were called the 'Blade injury group' and were presumed to have died as a result either of their blade injuries or associated soft tissue trauma. They were young (mostly 20-30 years of age) and appeared to have been healthy at the time of death, probably more so then the rest

of the male population (Watson 1993:249). 19 of those individuals displayed injuries that were consistent with them having been made by a sharp implement and that showed no evidence of healing, with the skull and torso the most common site of weapon injury (Stroud 1993:232-4). There is no such clear evidence in St Nicholas Shambles, with three cases of cranial injury (one young adult male and two adult females).

Other sites also showed evidence of inter-personal violence. In Rouen, 14 individuals with cranial injuries suggestive of inter-personal violence were observed, of which four were likely to be sword cuts (all males). Three individuals in Loddekopinge showed evidence of sword cuts (two males, unhealed injuries, and one female, healed). Eleven cases of cranial injuries were recorded in Lund, with injuries resulting from blows and axes occurring in 30% of cases (all unhealed and almost exclusively young males). Head injuries were found in 1.8% of all males in the observed period (Arcini 1999:138). The majority of males with cranial injury were buried near the Trinitatis wooden church.

Other trauma than sword or axe injuries can be seen on the skull (an indeed other parts of the post-cranial skeleton), but they cannot be as readily differentiated between those occurring as a result of personal conflict and those of an accidental nature (Wakely 1997).

4.8.5. Age distribution (2 age groups) of the sexed individuals

Two age groups were selected: adults aged 18-35, and 35 years and over. The first age category, the younger adults, would include new immigrants (who tend to be young adults) and women dying from obstetrics-related conditions (Cox 2000b, Larsen 1997). The second age group encompasses all individuals over 35 years of age. There is no third group, e.g. 55+, enabling to remove some of the bias introduced in under-ageing older adults. Younger adults are much more accurately aged (Cox 2000), and the group 18-35 should encompass all the more accurately aged younger adults and the 35+ group the older adults.

	Sex	$n_{18\text{-}35}$	n_{35+}	$\%_{18\text{-}35}$	$\%_{35+}$	X_2	*P*
Wing	Males	8	23	25.8	74.2	7.258	**0.007**
	Females	6	17	26.1	73.9	5.260	**0.022**
	Total	14	40	25.9	74.1	12.518	**>0.001**
Ipswich	Males	13	14	48.1	51.9	0.037	0.847
	Females	11	9	55	45	0.2	0.655
	Total	24	23	51.1	48.9	0.021	0.885
Fishergate	Males	31	13	70.5	29.5	7.363	**0.007**
	Females	12	13	48	52	0.04	0.841
	Total	43	26	62.3	37.7	4.188	**0.041**
St Nicholas	Males	42	26	61.8	38.2	3.764	0.052
	Females	40	22	64.5	35.5	5.225	**0.022**
	Total	82	48	63.1	36.9	8.892	**0.003**
Raunds	Males	45	53	45.9	54.1	0.653	0.419
	Females	55	22	71.4	28.6	14.142	**>0.001**
	Total	100	75	57.1	42.9	3.574	0.059
Total 1	Males	139	129	51.9	48.1	0.373	0.541
	Females	124	83	59.9	40.1	8.120	**0.004**
	Total	263	212	55.4	44.6	5.475	**0.019**
Total 2	Males	131	106	55.3	44.7	2.637	0.104
	Females	118	66	64.1	35.9	14.695	**0.05**
	Total	249	172	59.1	40.9	14.083	**0.05**

Table 4.18 Sex distribution of the English sites by age group.

Total 1 includes all sites, total 2 excludes Wing.

Table 4.8 (above), shows the data placed into the two age groups. Ipswich is the only site where there is not a statistically significant age distribution of the sexed adults. Wing is the only site where both males and females have statistically greater numbers of older individuals.

St Nicholas Shambles and Raunds both have a comparable distribution of younger and older males, but statistically show a greater number of younger females. In total, St Nicholas Shambles displays a greater number of younger adults when Raunds shows comparable distribution for the total numbers, but with a $p = 0.059$ that is close to the significant level. Fishergate presents a greater number of younger males but shows a comparable number of females from both age categories. In total, there is a tendency towards more numerous younger individuals.

Paired T-test analysis was undertaken to determine whether the male and female distribution in the younger and older age categories in the English sites supports the null hypothesis of a comparable distribution. $t = 0.967$ $p = 0.388$ (n.s) (df = 4), where the null hypothesis is accepted. T-test was also undertaken to compare the age distribution of the English males, where $t = 0.307$ $p = 0.774$ (n.s.) (df = 4). The score for the females was $t = 1.06$ $p = 0.350$ (n.s.) (df = 4), where the null hypothesis was accepted for both sexes. These results indicate that the age distribution for the males and the females is similar.

In table 4.9 (below), Rouen shows a greater number of the older age category for both males and female. All the French sites show a greater number of older individuals for males and of all sexed individuals. Both Cherbourg and Arras display comparable numbers of younger and older females.

	Sex	n_{18-35}	n_{35+}	$\%_{18-35}$	$\%_{35+}$	X_2	*P*
Cherbourg	Males	8	21	27.6	72.4	5.827	**0.016**
	Females	11	21	34.4	65.6	3.125	0.077
	Total	19	42	31.1	68.9	8.672	**0.003**
Rouen	Males	51	90	36.2	63.8	10.787	**0.001**
	Females	25	63	28.4	71.6	16.4	**>0.001**
	Total	76	163	31.8	68.2	31.669	**>0.001**
Arras	Males	7	17	29.2	70.6	4.166	**0.041**
	Females	7	13	35	65	1.8	0.180
	Total	14	30	31.8	68.2	5.818	**0.016**
Total	Males	66	128	34	66	19.814	**>0.001**
	Females	43	97	30.7	69.3	20.828	**>0.001**
	Total	109	225	32.6	67.4	40.287	**>0.001**

Table 4.19 Sex distribution of the French sites by age group.

	Sex	n_{18-35}	n_{35+}	$\%_{18-35}$	$\%_{35+}$	X_2	*P*
Lund	Males	250	137	64.6	35.4	32.994	**>0.001**
	Females	189	96	66.3	33.7	30.347	**>0.001**
	Total	439	233	65.4	34.6	63.148	**>0.001**
Löddeköpinge	Males	131	211	38.3	61.7	18.713	**>0.001**
	Females	173	99	63.6	36.4	20.132	**>0.001**
	Total	304	310	49.5	50.5	0.058	0.810
Total	Males	381	348	52.3	47.7	1.493	0.222
	Females	362	195	65.0	35.0	50.070	**>0.001**
	Total	743	543	57.8	42.2	31.104	**>0.001**

Table 4.20. Sex distribution of the Swedish sites by age group

Lund shows greater number of younger individuals for both males and females and in total. Löddeköpinge, however, displays more older male but more younger females, which evens out the total numbers that show comparable age distribution.

Paired T-test analysis was undertaken to determine whether the male and female distribution in the younger and older age categories in the Continental (non-English) sites are significantly different. $t = 0.297$ $p = 0.781$ (n.s) (df = 4) meant that the null hypothesis was accepted. T-test was also undertaken to compare the age distribution of the non-English males, where $t = 0.180$ $p = 0.866$ (n.s.) (df = 4). The score for the females was $t = 0.881$ $p = 0.428$ (n.s.) (df = 4), where the null hypothesis for both sexes was accepted.

4.8.6. Discussion

The following observations can be made on the age distribution of sexed individuals:

- Ipswich is the only site where sexed individuals display comparable numbers in each of the age categories.
- Lund, Wing and Fishergate both present a higher number of younger males.
- Lund, Löddeköpinge, Wing, St Nicholas Shambles and Raunds display a higher number of females dying young.
- Löddeköpinge, Arras, Cherbourg and Rouen show greater number of males in the older age categories.
- Rouen is the only site where there is a greater number of both older females and older males.
- Apart from Lund where both males and females are more numerous in the younger age categories, the non-English sites display a higher number of older males. All the English sites show a greater number of sexed individuals dying in the younger age categories, and in Wing both males and females die in the younger age categories.

In section 4.7.2, it was suggested that the sites that showed a greater number of males (Lund, Löddeköpinge, Rouen, St Nicholas Shambles and Fishergate) were large and expanding urban centres that might have attracted young male immigrants from smaller

settlements in search of work. As young immigrants are usually younger males, sites with a greater number of males in the younger age categories might support this theory. Lund and Fishergate were found to be the examples of this, but in St Nicholas Shambles, where statistically there were comparative numbers of males in both age-categories, the chi-square score had a $p= 0.052$, which indicates almost significant differences. Löddeköpinge and Rouen both displayed a greater number of males in the older age category. It was also previously proposed that if an influx of males was not matched by a similar influx of females, there might have been a pressure on females to marry earlier, placing them at a higher risk of suffering from obstetrics-related conditions and dying at a younger age. Lund, Löddeköpinge and St Nicholas Shambles displayed a higher number of females in the younger age categories, suggesting that it was a possibility, although of course female migration is also a major consideration.

These findings do not contradict the possibility that male immigration might be responsible for the observed greater numbers of males in some of the larger and expanding urban sites. Young male immigration towards urban sites is therefore a likely factor in the observed increased distribution of males.

4.9. Conclusion

There is a marked over-representation of males in all the investigated populations apart from Cherbourg with male to female ratios ranging from 1.1:1 to 1.6:1. These superior numbers are particularly significant in the larger populations, which are both big cities and also have the biggest total number of individuals in the excavated sample. For the English region, these sites are Fishergate and St Nicholas Shambles. Only Rouen in the French sites has statistically more males than females, but both sites in Sweden show the same distribution. Arras and Ipswich were also major cities, and it is possible that their lack of male over-representation is a result of restricted excavation of the total cemetery. Löddeköpinge in Sweden is the only rural site with a statistically significant over-representation of males. The other two rural sites, Wing and Raunds, also display a higher of male to female ratio, but it is not statistically significant.

Not every rural site should be expected to yield comparable numbers of males and females. Wharram Percy is a substantially excavated rural cemetery from north Yorkshire dated 10th-16th centuries where 687 skeletons were recovered. In his analysis of the skeletal material, Mays (1997:124) identified 215 males and 136 females, giving a sex ratio of 1.58:1. Mays attributed this sex imbalance to a possible female-led migration from rural settlements to urban areas, where migrant female labour was absorbed into domestic service and craft industries such as weaving (Goldberg 1986). This imbalance is reflected in the cemetery from St Helen-on-the-Walls in Aldwark (also 10-16th century), a poor district of York with cheap housing, where there was a statistically significant sex imbalance in favour of the females, with a male to female ratio of 0.857:1 (Dawes 1980:11). This pattern is probably more typical of post 13th century settlements since none of our large urban sites, apart from Cherbourg, show more females.

The sex imbalance recorded in male numbers is therefore more likely to be the result of male-led migration, although we are not observing the over-representation of females in rural sites to make up for the difference. According to Nicholas (1997:181), pre-industrial populations show high death rates, reaching 6% even in 'normal' years. If cities were to expand, they needed immigrants to compensate natural losses. He estimated that by the 12th century, recent immigrants made up one-quarter to half the population of growing cities and were mostly drawn from surrounding areas, although the larger cities attracted newcomers from a larger catchment area. The bigger the city, the wider its attraction and, accordingly, the more diverse its population was likely to be. Distance also determined population density (Nicholas 1997:182).

Fishergate shows evidence of violence on a select group of young male individuals who also potentially enjoyed a better health status than the other males of the cemetery. They could have been soldiers from outside garrisoned there or locally recruited men. In St Nicholas Shambles, there is evidence that many butchers worked in the parish, and it is possible that as a result the cemetery shows a higher number of working men. In the observed period, both Rouen and Lund were experiencing huge expansion. Rouen was

being rebuilt as the headquarters of the new Viking dynasty (Le Maho 1994) with a shift of focus towards mercantile and political power, and Lund was founded by the king Sweyn Forkbeard as part of the strengthening of the administration of Denmark's eastern regions (Arcini 1999:28). Such times were reflected by the extensive church-building and expanding projects, and must have required specialised craftsmen such as stone cutters, masons, carpenters and joiners to work on the sites. As a major religious, political, administrative and trade centres, they must have attracted numerous immigrants working as merchants, labourers and craftsmen in the town, building sites and port. It would therefore seem that urban development and expansion through trade and industry centres will largely dictate population profiles.

Age distribution patterns appear highly variable from site to site and do not seem to follow a set pattern, and it is possible that it is a direct effect of partially excavated cemeteries. In the French sites, numbers seem to increase with age. In all other sites, numbers either generally increase or decrease with age, with differences more marked in the first and last age group. Ipswich, however, does not seem to follow any pattern. Rather than being an accurate representation of the population at the time, it seems likely the population profile we observe is a direct result of partial excavation. The same is probably true of Cherbourg and Arras. Rouen and Raunds, being the only sites that were fully excavated, it is interesting to see whether their population profiles are similar or very different from each other and others. Of course, the problem is that one is urban and the other rural. In Rouen both male and female numbers increase with age. In Raunds, the males show a similar pattern, but it is not so obvious for the females.

In the large urban sites, total numbers in each age category seem to decrease with age, with Lund, St Nicholas Shambles and Fishergate exhibiting a higher number of males in the youngest age categories, possibly caused by male-led migration. The same pattern is not so evident for females. Rouen, surprisingly, shows total numbers in each age group increasing with age, which is a pattern also found in Cherbourg. In rural sites, male distribution in the age categories seem to broadly increase with age and the reverse seems to be true for females, with more females in the younger age categories. Interestingly, a similar pattern is

observable for males in Cherbourg and Ipswich, which are towns of lesser importance when compared to London, York and Rouen. This could suggest that there was limited male migration to these towns, therefore no over-representation of young males.

When the data were split into only two age groups using 35 as the cut-off point between younger and older individuals, the overall picture was clearer: males and females in Wing, Cherbourg, Rouen and Arras; males in Ipswich, Raunds and Loddekopinge and females in Fishergate showed higher numbers of individuals in the oldest age category.

It would therefore seem that young males form the largest group in urban cemeteries because they have the most rapidly expanding age-group, inflated by immigration, and as a result have an increased likelihood of dying because of relative lack of immunity to infections in their new environment and low socio-economic status. Young females are more numerous in rural cemeteries, possibly because the population of young males young males is reduced by male-led migration towards the towns. The increased risks linked to childbearing add further to the numbers of females dying young. This pattern may change after the period under study emphasising the need for a contextualised historic approach.

Chapter 5: Non-Specific Stress Indicators.

The next two chapters relate to the paleopathological assessment of the human remains from the investigated sites, specifically looking at infectious diseases. The present chapter examines skeletal lesions that are classified under "non-specific stress indicators", i.e. that are not specific to any particular disease but that arise from exposure to pathogens (Larsen 1997:6). The non-specific lesions examined, which include cribra orbitalia, enamel hypoplasia and periostitis are all linked to infectious diseases. The next chapter (chapter 6) observes skeletal lesions that can be specifically attributed to a disease, here chronic chest infections, tuberculosis and leprosy.

5.1. Introduction: concepts of health and epidemiology, biological stress and the osteological paradox

The attainment of health, described as a "state of physical, mental and social well-being" by the World Health Organisation (1985), and the occurrence of disease, are essential parts of life and death (Roberts and Cox 2003:1). Diseases not only affect the lives of individuals, but also societies as a whole, and impact on the condition of human existence. Human behaviour and cultural and social institutions create the human environment, and if the level of mortality and morbidity in a population is altered, it can cause social disruption as a result (McGrath 1991).

Every episode of ill health will affect individuals to some level, impairing their normal life. People suffering from an illness make social demands, such as needing assistance with basic care such as washing and feeding. Those with more chronic and/or disabling conditions might require constant attention and help. So diseases do not only tell us about the medical history of a population, but also about the social aspect of disease and care of the ill, the cultural experience of disease (see Farmer 1998:345-372). Malformations, disabling or chronic conditions must have affected the individual beyond the physical level, influencing a person's standing in society, social and financial prospects, the ability to provide for themselves and their family, etc. (Farmer 1998). Some diseases also had a

stigma attached to them, such as leprosy, where sufferers were positively shunned from a community (Aufderheide and Rodriguez-Martin 1998:149).

Diseases not only affect the body in a purely physical/medical sense, but can also ultimately influence many aspects of a person's life, as well as potentially disturbing social, political and economic systems. Cartwright and Biddiss (2000) have recently re-appraised how diseases affected the course of economic and social history. The second chapter of their book examines how the Black Death, specifically the bubonic plague, one of the more lethal European diseases for the next three centuries, caused the death of one third of the population of Britain as an estimated two million people died. The epidemic swept the country, at its worst in 1348-49 but lasting nearly 13 years, and brought on extensive social changes as a result.

Agricultural practices probably saw the greatest transformation. The survivors reaped the harvest and prospered, as there was more of everything per head. As a buyer's market emerged, the price of goods became more affordable. The sudden shortage of labour meant that wages rose rapidly and peasants were able to move to better-paid work and improved work conditions. Legislation had to be introduced forbidding peasants from transferring employers and wages were frozen to bring back some stability. These measures succeeded to some extent, but the feudal system was ultimately replaced with a tenant-farmer system, creating a new class of independent farmers (Cartwright and Biddiss 2000:33). Because of the cost of labour, economic measures dictated the decrease of arable and increase of pasture, sheep fast becoming the main farm staple and wool the key to prosperity.

The Church was not spared by the epidemic. Monasteries experienced high mortality (some of them were completely wiped out due to the highly infectious nature of the disease) and parishes lost their priests. Extensive loss of wealth ensued as land, the Church's main source of revenue, was not cultivated through loss of manpower. Of more consequence was the Church's loss of power and influence, made worse by internal strife. Open opposition to the Church and rise in religious intolerance led to persecution and the displacement of minority groups within Europe, such as the Jews (Cartwright and Biddiss 2000:35).

It can be argued that archaeology reveals both the life experiences of entire populations at specific times in the past as well as those of individuals. Epidemiology, the study of the incidence and distribution of diseases, is concerned with the population rather than the individual and seeks to assess the frequency of specific diseases and influencing factors at particular times and locations. Paleoepidemiology refers to the prevalence and distribution of diseases in the past (Roberts and Cox 2003:3). Modern epidemiology establishes disease incidence by assessing the numbers of new cases of a disease in a population at a particular time (Waldron 2001:47). In cemetery populations, however, we cannot distinguish new cases from old when we cannot usually define specific time phases and we do not even know whether we have the 'real' population, as opposed to a biased sample. We can only ascertain the prevalence of a disease defined as the proportion of a population affected by a disease over a period of time (Waldron 2001:47). This information is still useful when comparing sites (e.g. urban vs. rural, male vs. female, etc).

Before analysing disease prevalence, we first have to understand how disease transmission affects the impact of the disease on an individual (diseases referred to in this study are of pathogenic origin). Disease is the result of the presence of the pathogen in the environment and a complex interaction of host, pathogen, and environment (McGrath 1991:407). There are many factors predisposing an individual to a disease once the pathogen is in the environment, the main determinant being immunity. There are two types of immunity: that genetically inherited or acquired from the mother via the placenta (innate or natural immune system), and that acquired through exposure to diseases (adaptive or acquired immune system) (Sompayrac 1999). The lack of immune response in a population to a new and unknown disease can cause an epidemic (Larsen 1997). The quality of an individual's immunity will also determine the body's capacity to successfully fight off a disease. A low immunity can be caused, for example, by an inadequate or deficient diet (Roberts and Cox 2003:6). This means that poor populations subject to environmental stress are at a higher risk of developing a disease. Roberts and Cox (2003:3-10) summarise the factors influencing transmission and predisposition to disease, which are shown in the following table.

Intrinsic factors
Immunity
Diet
Age, sex (e.g. osteoporosis; preferential treatment)
Ethnicity/geography (e.g. genetic predisposition)

Extrinsic factors
Environment and lifestyle (e.g. occupation)
Social status (e.g. access to food and medical aid)
Rural/urban (e.g. pollution)
Population density
Levels of hygiene (also access to clean water)
Climate and weather (affects survival of pathogens; seasonality)
Migration/population movement

Table 5.1. Factors influencing predisposition and transmission of disease (after Roberts and Cox 2003)

By improving their immunity, humans show a capacity to adapt to their environment. Humans use cultural mechanisms to adjust (such as keeping waste away from drinking water), but adaptation to environmental stress also takes place on many biological levels (Roberts and Cox 2003:11). Physiological adaptation, such as increasing red marrow space to produce more red blood cells, occurs over a person's lifetime (Roberts and Cox 2003:10). Natural selection over long periods of time causes genetic change at the population level (McElroy and Townsend 1996).

A population's size and density and its contact with the outer world are also of prime importance to the spread of infectious disease (Arcini 1999:110). Infectious diseases such as measles require annually 5,000 – 40,000 new hosts in order to maintain a continuous life cycle. The population has to be sufficiently large so that an infection of high virulence can

continue to exist, at least 300,000 to 500,000 for the case of measles (Black 1996, Cockburn 1967). Other diseases requiring dense populations are smallpox, plague, typhoid fever, chickenpox, mumps, influenza, diphtheria and cholera. Only those that will affect the individual for more than just a few days can leave a mark on the skeleton.

Once a person has been infected and has survived the onslaught of the disease he/she will develop an immunity against the disease and gain protection for a certain time after the infection or even for life with some diseases (Arcini 1999:111). In smaller populations that are isolated, the infection will destroy the preconditions that are necessary for its own existence. The potential new hosts will be children and immigrants who lack the required immunity, and older individuals who might have lost their previous immunity. However, infection of low virulence such as tuberculosis and leprosy can exist in smaller populations (Arcini 1999:111).

Human remains are the primary evidence for study of diseases and health in the past. There are, however, limitations to their use, and these must be taken into consideration when attempting to reconstruct health from archaeological populations (Waldron 2001:140-1). Firstly, our access to information is dependent on the recovery of human remains (McKinley and Roberts 1993:1). Survival of human remains will dictate our access and potential for analysis. Bone survival is influenced by many extrinsic factors, such as time and type of inhumation, clothing and body fat, soil composition and acidity, drainage, disturbance by animals or plants and so forth (Haglund and Sorg 1997). Excavation and handling can also damage bones, as well as lose evidence such as kidney stones, calcified fibroids, etc. (McKinley and Roberts 1993:5). Taphonomic processes and diagenetic alterations can also affect the appearance of bones and lead to misdiagnosis (Haglund and Sorg 1997).

Secondly, there are limitations imposed by the representativity of excavated populations, and whether the inhumed population reflects the living population of the time (recently discussed by Buchet and Seguy 2002). We may wrongly assume that a cemetery will include an entire population, but this is often not the case, as some individuals might be

buried somewhere else for religious reasons, funerary practices, segregation etc. Migration and population movement will further complicate the picture. Also, cemeteries are used over a period of time, so do not represent a single population as such. Only plague pits or battle sites, such as Towton, might be able to offer us a true insight of a whole population at a specific time (e.g Fiorati *et al.* 2000), although the survivors of the epidemic or battle will obviously be absent from the assemblage. In addition, archaeologists are usually unable to excavate the whole cemetery, especially in urban settings, so if burial zonation is practised, we might not have a representative portion of the buried population.

On the biological level, interpreting evidence of disease from bones can only offer a limited understanding. Medical textbooks are full of the difficulties in diagnosing a disease even when all the biological elements of a body are present and the patient is able to contribute (Waldron 2001:241). Human bones specialists, however, only have dry bones for diagnosis, a task made more complex as only a handful of diseases actually leave a mark on the skeleton. Ortner and Putschar (1985) suggest four possible effects of infectious diseases on individuals:

1) individuals are infected and die quickly. Influenza, the plague and smallpox are good examples of fast developing, often lethal, diseases;
2) they are infected but recover before the infection becomes chronic;
3) they are infected, survive but develop the chronic condition;
4) they never become infected.

Only those that develop the chronic condition can be observed skeletally, and in relation to the total number of infected individuals, these people are relatively few (Ortner and Putschar 1985, Kelley 1989).

There are diseases that affect the bone directly, such as osteomyelitis, and diseases that affect the skeleton secondarily, as is the case for most infectious diseases such as tuberculosis and leprosy, which primarily affect the overlying soft tissue and nerve endings. Bone has a limited response to disease. It will either form new bone (by osteoblastic activity, e.g. periostitis) or destroy bone (by osteoclastic activity e.g. osteoporosis, leprosy), or a combination of the two (e.g. arthritis, osteomyelitis, Paget's disease) (Roberts and

Manchester 1995:4-5). Given the limitations of bone responses to disease and trauma, it is not surprising that diagnosing diseases on dry bone material is difficult at best. Often, as in the case of periostitis, it is impossible to know the cause of the lesions, and these pathological changes are termed 'non-specific' because they are not due to a single known cause or to a particular pathogen. The fact that analysis is mostly made using macroscopic methods and not combined with microscopic tools such as histology, which are expensive and time-consuming, means that we might be missing important evidence (Schultz 2001).

The concept of 'stress' is central when assessing health and attempting to reconstruct adaptation and behaviour in past population (Goodman *et al.* 1988). Stress is defined as any environmental stimulus that invokes a reaction in a living organism. Larsen (1997:6) also describes stress as being 'a product of three key factors: 1) environmental constraints, 2) cultural systems, and 3) host resistance'. Goodman and co-workers (mainly Goodman and Armelagos 1989) developed a model for interpreting stress in archaeological populations (adapted in Larsen 1997:7). The model emphasises the environment in providing both the resources necessary for survival and the stressors that may affect the health of the population. The stressors that cannot be buffered by cultural systems or by host resistance factors will cause the individual to experience physiological disruption and a biological stress response observable at the tissue level (the 'stress indicators'). The individual may then die or survive the episode of ill health. In the case of survival, the impact of stress on the population is variable but can include decreased health, work capacity and fertility, as well as cause socio-cultural disruption. This will then bring the culturally induced stressors into the model (Larsen 1997:6-8, Goodman and Armelagos 1989). A population's ability to mitigate stress will have far-reaching implications medically, as well as socio-economically (Larsen 1997:6).

In 1992, Wood *et al.* suggested that inferring health from archaeological sites was fundamentally flawed because our methods in demography and pathology could only reveal the health of the non-survivors of a population (Wood et al. 1992:344). The notion of 'survivor' is important as we attempt to derive information from the dead about the health of the living at the time. Of course, everyone dies eventually, but it is the age at which

death occurs that is important here. Those interred will reveal the level of health at the time of death, and not necessarily the health of a lifetime. Information about age at death can also contribute to the investigation of health as satisfactorily, perhaps, as lesions. Some insight can be gained from health in childhood through 'stress indicators', such as Harris lines and enamel hypoplasia, but the information can still be limited (Wood *et al.* 1992:345, 353-5).

The 'osteological paradox' further complicates the picture. In the past, a skeleton with no evidence of disease was considered to be indicative of an individual in good health until the time of death, whereas a skeleton showing evidence of stress was unhealthy and possibly coming from a disadvantaged background. This was too simplistic. Wood *et al.* (1992:345) described two types of skeletons that would be indistinguishable from each other and yet would be of individuals that had a very different health status: those who had never experienced stress until their time of death, and those who immediately succumbed from acute stress before any stress marker could develop. In the skeletons with stress markers, each lesion is evidence that the individual had overcome the initial acute period of a disease and adapted to their environment. For example, in dental enamel, the presence of hypoplastic lines is proof that the individual survived the episode of ill health and died at a later date. Ortner (1991:10) states that skeletal lesions imply good immune response and a healthy individual, who is able to overcome illness (and become a survivor of that event). Larsen (1997:6-7) and Goodman and Armelagos (1989:242) recommend using multiple indicators to give a comprehensive understanding of stress and adaptation. Goodman (1993:287) also proposes that dividing stress markers into age categories would avoid the pitfalls of the osteological paradox by separating individuals who had many episodes of ill health and who had died young, from those who repeatedly survived such episodes throughout their life.

Presented with all these limitations, it might come as a surprise that any valid information can be extracted from skeletons, and any information gleaned can be used to make useful assumptions about health in the past. This is, however, the nature of archaeology and

anthropology, where factors leading to the preservation and presence of the evidence are not only complex, but the very interpretation of the evidence can be endlessly debatable.

Alternative evidence can be sought. Secondary evidence for diseases in the past can be found in the form of iconography and documentary evidence (Roberts and Cox 2003:21). This is also, however, subject to bias, as representation is affected by the perception of disease and the stigma attached to it by the society or author at the time, and that misinformation and ignorance cannot provide us with reliable and useable data (Roberts and Cox 1993:22). For example, the London Bills of Mortality of 1775 name 'evil' (11 deaths), 'lethargy' (6 deaths), 'mortification' (169 deaths) and 'gripping of the guts' amongst others as a cause of death (Cox 1996:74).

We cannot abandon our attempts to understand the past because our tools are imperfect, but we must use what is available and be aware of the limitations of assessing health and disease in the past by using skeletal remains. As we make advances in diagnosis by using more refined and complex tools (imaging, biochemistry, etc.) a greater degree of confidence will be achieved.

5.2. Non-specific stress indicators

Non-specific stress indicators refer to skeletal and dental lesions that arise from exposure to pathogens and demonstrate the ability of individuals to adapt to stresses and the environment (Larsen 1997:6). The capacity to recover from stress is determined by both genetic background and health status (e.g. immunity) (Roberts and Cox 2003:3-4). When a person is unable to resist a stressor, then a biological response will appear and the effects of some of these can be observed on the skeleton. If survival is successful, the healing process will gradually remove the scars, although some, such as enamel hypoplasia are indelible evidence.

It is not within the scope of this thesis to explore all stress indicators, but instead it will assess the level of exposure to infectious diseases. We are therefore only interested in non-

specific indicators of infectious disease origin, rather than, for example, those reflecting poor nutrition and food deprivation. Infection of bacterial origin, such as staphylococci and streptococci (Roberts and Manchester 1995), is the most commonly observable on dry bone. However, the pathological changes to bone brought on by one type of bacteria are not always distinguishable from another.

Non-specific infection appears to increase in frequency with the transition to agriculture and urbanisation. It is linked with population growth and density, poor sanitation and changes in nutrition, as well as increased contact between people, through trade and population movement, which leads to increased susceptibility to infection (Roberts 2000:147). The relationship between stressors is an interactive one. Larsen (1997:8) emphasises the synergistic relationship between malnutrition and diseases, whereby malnutrition increases the susceptibility to infection, and infection impairs the ability to absorb vital nutrients from food. Non-specific lesions provide an incomplete picture of the health of a population (Larsen 1997), but calculating their prevalence does provide us with an investigative tool for comparative studies between populations and changing patterns within a population.

The table below provides an overview of the main stress indicators, their description and some of their origins.

Stress indicator	Appearance	Cause
Main stress indicators		
Dental enamel hypoplasia	Areas of decreased enamel thickness caused by disturbances of ameloblast deposition on the developing crowns of teeth.	Fever, infection, malnutrition, congenital syphilis, tuberculosis
Harris Lines	Transverse lines of radiopacity which occur in the growing bones of juveniles. Each line corresponds to a period of arrested growth.	Malnutrition, rickets, scurvy, congenital syphilis, poisoning.
Cribra Orbitalia Porotic Hyperostosis	Porous lesions on the orbital roof and cranial vault caused by the thinning of the outer table of the skull, a widening of the inner diploic space and hair-on-end appearance of the trabecular surface.	Anaemia, iron-deficiency, malnutrition and malabsorption, parasitic infestation

Other stress indicators		
Periostitis	Inflammation or injury of the periosteum elicits bone production in the shape of plaques. This can happen anywhere on the skeleton, but is usually on the tibia and fibula. Periostitis on the ribs is indicative of chronic chest disease.	Disease, including tuberculosis, syphilis, leprosy, infection, local inflammation, trauma.
Stature	Interaction between genetic potential and environmental factors. Growth retardation can be reversed if growth is not slowed for too long or too near puberty.	Malnutrition, disease, socio-economic status.
Infant mortality	Neonatal mortality reflects the genetic and maternal influences, whereas post-natal mortality reflects the child's external environment.	Disease, fever malnutrition.

Table 5.2. Overview of the main non-specific stress indicators, their description and some of their origins.

Harris lines and height were not assessed in this study. Harris lines were not included in this project as they can only be observed using radiography, for which resources were not available. Height was also eliminated from the study. Femoral length data had been collected but it was felt that there is considerable natural variation between individuals, which is influenced first by their genetic make-up and then by environmental factors, the most important of which is nutrition. The data would not be comparable when using collections from various parts of Europe, as genetic origin might play an important role in the development of height. Height criteria would be better applied when assessing changes in health in a locality over a period of time, such as that carried out by Mascie-Taylor and Boldsen (1985), rather than a range of areas during the same period.

The following indicators were retained for this project:

- cribra orbitalia
- dental enamel hypoplasia
- periostitis

Dental enamel hypoplasia are easily observable macroscopically and the inter-observer variability is low when relying on reports. Enamel hypoplasia is now established as an indicator of non-specific stress in archaeological populations. Nigel James' recent research at the University of Leicester (James unpublished), proved that disruptions causing enamel hypoplasia could be only a few days long, and thus represented short-term insults on the body, such as fevers and infections. Cribra orbitalia indicates evidence of chronic disturbances and is thought to be indicative of total pathogen load in a population (Stuart-Macadam 1992). Periostitis is very much the underdog of paleopathology but it occurs so commonly that it cannot be ignored. Present in all major infectious diseases such as tuberculosis, syphilis, leprosy and osteomyelitis, as well as at the site of localised infection, it is my belief that its link to non-specific infectious disease cannot be disputed. The view is also supported by Ribot and Roberts (1996).

5.2.1. Hypotheses

1. There might be some differences between English and non-English sites in the distribution of the lesions.
2. If non-specific stress indicators reflect total pathogen load in a population (Stuart Macadam 1992), we might therefore expect prevalence rates to reflect population density and size, whereby a larger settlement should display a higher prevalence rate.
3. Differential health in males and females might show differing patterns in prevalence rates.
4. As cribra orbitalia is formed before the individual reaches puberty, it is subject to bone remodelling and consequently it is expected that the lesions should be more prevalent in younger individuals. The data are divided between younger adults (18-35 years) and older adults (35 years old and over). Enamel hypoplasia and periostitis are treated in the same way for comparative purposes.

5.2.2. Methodology

For all sites, prevalence rates were calculated by dividing the number of individuals displaying the lesions by the number of individuals with the appropriate bones observable and are also presented in percentages. The data is also presented in the form of clustered column charts.

Chi-square and T-test analysis were used to assess the significance of these results. The chi-squared (X^2) statistic is used to investigate whether a data set differs from the expected value. The Student's T-test assesses whether one data set differs significantly from another.

Where possible, the results will be compared to prevalence rates calculated by Roberts and Cox's (2003) study of health and diseases in Britain. The study seeks to reconstruct health and disease patterns in Britain from prehistory to the present day and contains extensive information on (mostly) crude prevalence rates for each health indicators. The calculated prevalence rates in this study should probably be an conservative estimate of true disease frequency as they are expressed by total numbers of individuals with lesions (sub-adults included) divided by total number of individuals in the assemblage, which could include

large numbers of fragmentary skeletons. The periods relevant to our period of study were the early medieval period (AD410-1050) and the later medieval period (1050-1550).

5.3 Cribra orbitalia

5.3.1 Introduction

Cribra orbitalia (or orbital osteoporosis) and porotic hyperostosis are porotic lesions in the skull situated on the skull vault in porotic hyperostosis, and on the orbital roof in the case of cribra orbitalia, and they develop before puberty. They are not caused by one disease, but rather are the morphological symptoms of various diseases (Schultz 2001).

An adaptation from Schultz's (2001:124) list of the pathological processes that can contribute to a morphological syndrome include:

1. Inflammatory processes, e.g. inflammation of the sinuses, of the lacrimal glands and meningeal reactions.
2. Haemorrhagic processes, e.g. subperiosteal hematoma from scurvy, parasites, cancer.
3. Tumours and tumerous processes.
4. Dietary anaemia. These include:
   a) Various kinds of anaemia, such as nutritionally caused iron-deficiency anaemia. Stuart-Macadam has been a leading figure in linking cribra orbitalia to iron-deficiency anaemia, arguing that it was caused by severe nutritional stress, with low meat intake and an over-reliance on cereal crops (Stuart-Macadam 1985, 1987 and 1989). However, such an attribution has come under much criticism recently and as a result, it is no longer used as an indicator of nutritional stress (Stuart-Macadam 1992). Indeed, it has come to be understood that the body does not rely specifically on ingested food for its iron intake. In addition, it would require being in a sustained state of near starvation for up to three years before skeletal lesions appeared (Stuart-Macadam 1992).
   b) Scurvy
   c) Rickets

5. Genetic causes, such as sickle-cell anaemia, thalassemia
6. Other disease, whereby the body lowers its iron levels as a natural defence against pathogens. Neoplastic and inflammatory conditions, especially arthropathies, can induce this hypoferremic response, eventually leading to anaemia. This makes cribra orbitalia an ideal indicator of the total pathogen load of a population (Stuart-Macadam 1992).

The microscopical appearance of the lesions differ according to their origin (Schultz 2001:132-34):

- In anaemia, cancellous bone space is used to produce more bone marrow and red blood cells, giving the bone trabeculae a 'honey-comb' appearance (Aufderheide and Rodriguez-Martin 1998). Two features are easily observable. They are the thinning of the external lamina, which creates porosity because the cancellous bone becomes visible; followed by the enlargement of the cancellous bone by regular radial growth of the bone trabeculae, which reduces the thickness of the external lamina by pressure atrophy.
- In scurvy (and lesions caused by subperiosteal bleeding), the lesion is caused by a subperiosteal haemorrhage, which is organised from a haematoma into calcified fibrous connective tissues and then built into the woven bone, without affecting the external lamina or underlying cancellous bone.
- In rickets, however, the external lamina is built up of squamous plates, a spongy substance that is completely irregular, and the internal lamina is splintered.
- Osteomyelitis presents extensive bone apposition, which is represented by gracile, branching out trabecular bone, while the cancellous bone is eaten away by inflammatory processes.

It is impossible macroscopically to differentiate what causes the lesion in each individual. Promoted by Schultz (e.g. 2001), it is now accepted that histological analysis is required to assess the cause of the lesion (rickets, anaemia, calcified haematoma etc), as macroscopic analysis cannot differentiate between lesions. Despite histology providing accurate diagnosis, the technique is lengthy (4 weeks are required to prepare a single specimen), it

requires specific machinery and is destructive. It is also more accurate when assessing severe lesions. As a result, histological analysis is not routinely used.

Porotic hyperostosis is rarely found in northern Europe, which suggests a genetic sensitivity to it. When it does appear in our specimens, it is considered to represent acquired iron-deficiency anaemia rather than a genetic disorder or predisposition to (Stuart-Macadam 1992, Roberts and Manchester 1995). Because of the low occurrence, it was decided not to use porotic hyperostosis in this project.

Research undertaken by Wakely, James and Morgan (1999) on two late medieval rural populations sought to establish differential prevalence of cribra oribitalia and enamel hypoplasia. They observed that the two lesions were rarely present in the same individual. They concluded that these stress indicators reflected different aspects of response to infection: cribra orbitalia was indicative of a chronic disorder, whereas enamel hypoplasia was indicative of acute infection or fever. It is, of course, possible for individuals to have suffered from both.

5.3.2. Methodology

Aufderheide and Rodriguez-Martin (1998) state that cribra orbitalia is bilateral in 90% of cases. In addition, Duncan (2000:173) found no statistically significant association between lesion prevalence and orbit symmetry, meaning that results were the same whether only one orbit was used rather than both. Therefore, in this study, the prevalence rates were calculated as follows: total number of individuals with cribra orbitalia present in at least one orbit /the total number of individuals with at least one orbit observable. The presence or absence of the lesion was noted, but not the degrees of severity of the lesion. Two sets of percentages were then calculated, %1 which is the percentage of individuals (males or females) which display cribra orbitalia in at least one orbit out of the number of individuals with at least one orbit observable. %2 looks at the sex distribution of the total number of individuals with cribra orbitalia.

5.3.3. Results and discussion for cribra orbitalia

Site	*Males*	*%1*	*%2*	*Females*	*%1*	*%2*	*Total*	*%1*
Wing	6/16	37.5	50	6/10	60.0	50	12/26	46.1
Abingdon	18/30	60.0	60	12/18	66.6	40	30/48	62.5
Cherbourg	13/24	54.1	59.1	9/20	45	40.9	22/44	50.0
Arras	2/11	18.2	33.3	4/12	33.3	66.7	6/23	26.1
Ipswich	6/12	50.0	66.7	3/14	21.4	33.3	10/29	34.5
Fishergate	7/25	28.0	58.3	5/10	50.0	41.7	12/35	43.2
Lund	55/298	18.5	49.5	56/207	27.0	50.5	122/516	23.6
St Nicholas	9/23	39.1	52.9	8/31	25.8	47.1	17/54	31.4
Rouen	42/93	45.1	59.2	29/57	50.8	40.8	80/165	48.4

Table 5.3. True prevalence rates of cribra orbitalia per site and per sex (arranged in estimated ascending order of population size).

Total means males + females + adults of indeterminate sex. %1 is the percentage of males of females displaying the lesions over the total number of males or females with orbits observable. %2 is the percentage distribution of the lesion by sex.

In this table, the sites were first arranged in ascending order of population size, then the prevalence rates were calculated for males and females. The order of population size was not based on the total number of individuals excavated, but rather on the estimated comparative population size and density of each town, based on historical information (see chapter 2 for a description of the sites. This was undertaken to assess the impact of population size and contact on the observed prevalence rates.

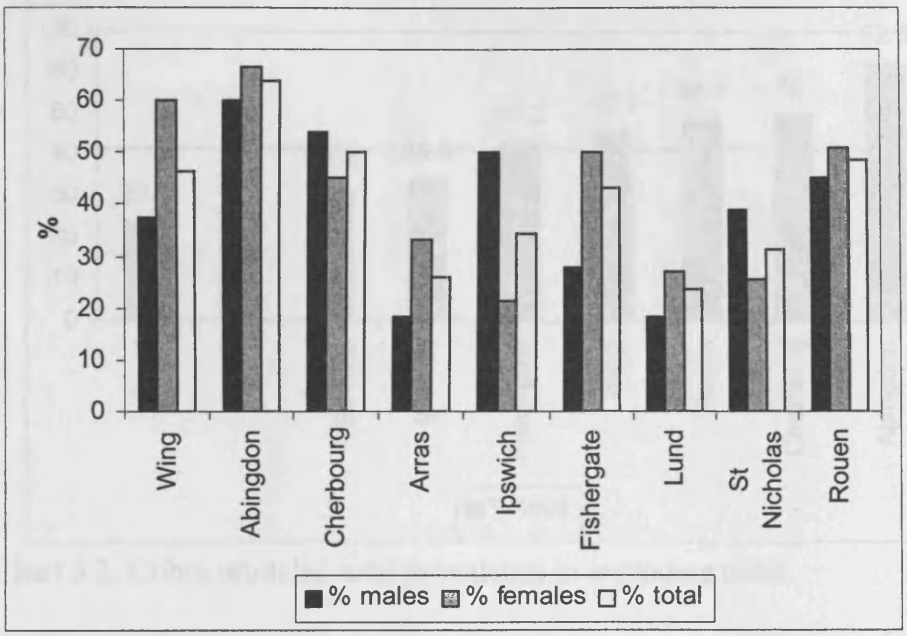


Chart 5.1. Cribra orbitalia: male, female and total prevalence per site in ascending order of population size (estimated).

Prevalences calculated by individuals displaying lesions in at least one orbit over total number of individuals with at least one orbit observable. Total means males + females + adults of indeterminate sex. (Data from Table 5.3)

The chart 5.1 shows the distribution of the cribra orbitalia prevalence rates for males, females and total adults in each assemblage, ordered according to ascending estimated population size and density. It is immediately evident that prevalence rates do not rigorously follow the estimated population density. Indeed, Rouen, St Nicholas (London) and Fishergate (York) were some of the biggest towns in Europe at the time, and yet their prevalence rates do not seem to reflect this. The cribra orbitalia (true) prevalence rates vary from 23.6% of the population (Lund) to 62.5% (Abingdon). Of the large urban centres Rouen displays the highest prevalence rate at 48.4%, Fishergate at 43.2% and St Nicholas, the lowest at 31.4%.

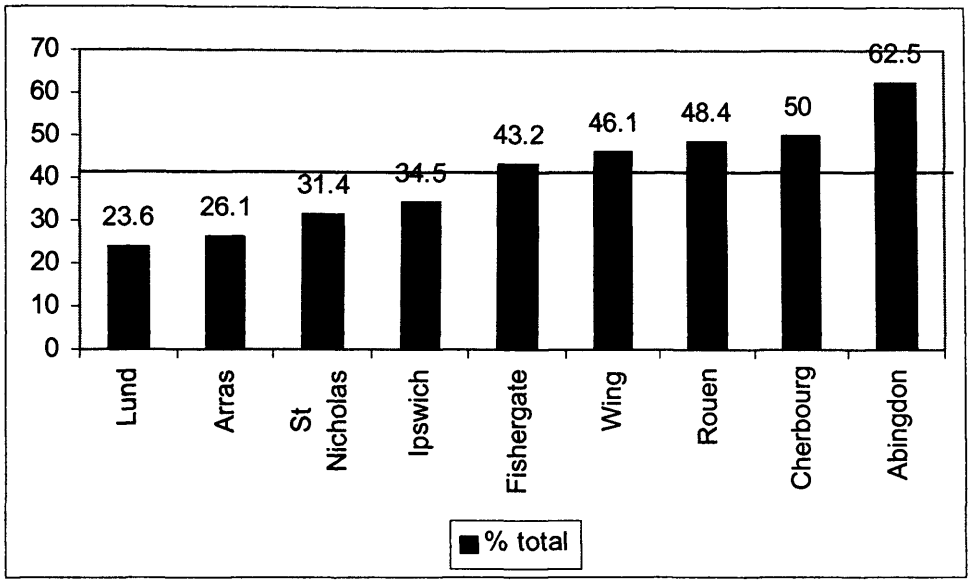


Chart 5.2. Cribra orbitalia: total prevalence in ascending order.

Chart 5.2 shows the percentage of individuals displaying cribra orbitalia lesions in each site. The average percentage for the sites investigated in this study lies at 40.6% (as illustrated with the horizontal bar across the chart), and four of the assemblages have prevalence rates that are below that average. Wing, with the estimated smallest population of the assemblages and our smaller samples shows frequency above the calculated average at 46.1%. Lund, our largest assemblage here and a large urban centre with extensive contact displays the lowest prevalence rate. Rouen, another large assemblage, shows a slightly higher prevalence rate of 48.4%. In Abingdon, where we would not expect extensive contact with non-local peoples, the prevalence rates is the highest of the assemblages, whereas Arras, St Nicholas Shambles and Ipswich, large towns with extensive contact show the some of the lowest prevalence rates (*ca.* a quarter and a third of the population).

Lund and Arras have the lowest prevalences and Rouen and Cherbourg some of the highest, with all the English sites apart from Abingdon in between. There is no obvious reason for this geographical distribution, it might have been caused by genetical or environmental factors.

The two charts below investigate the male and female distribution of the lesions.

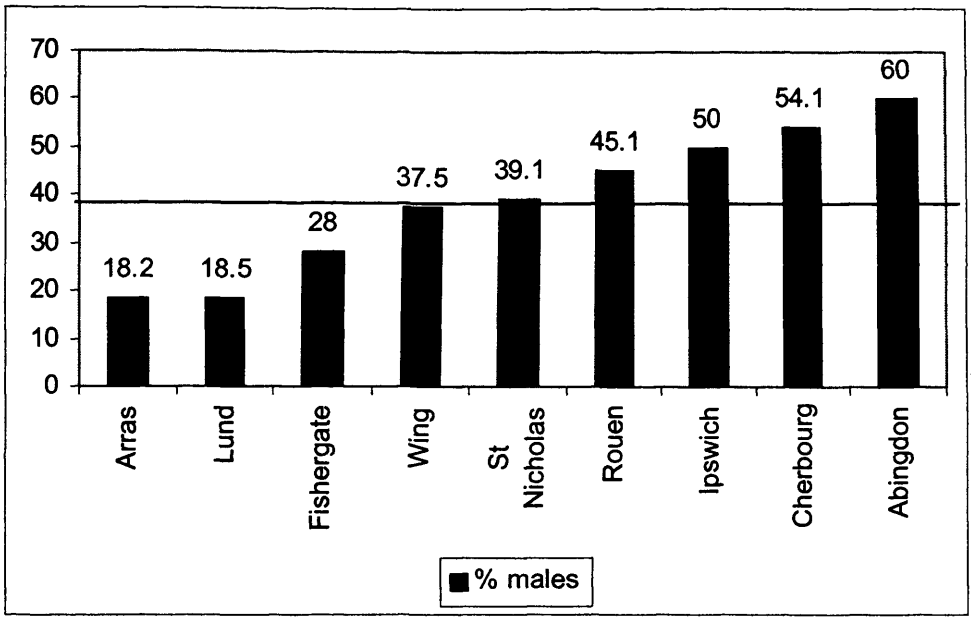


Chart 5.3. Cribra orbitalia: male prevalence in ascending order.

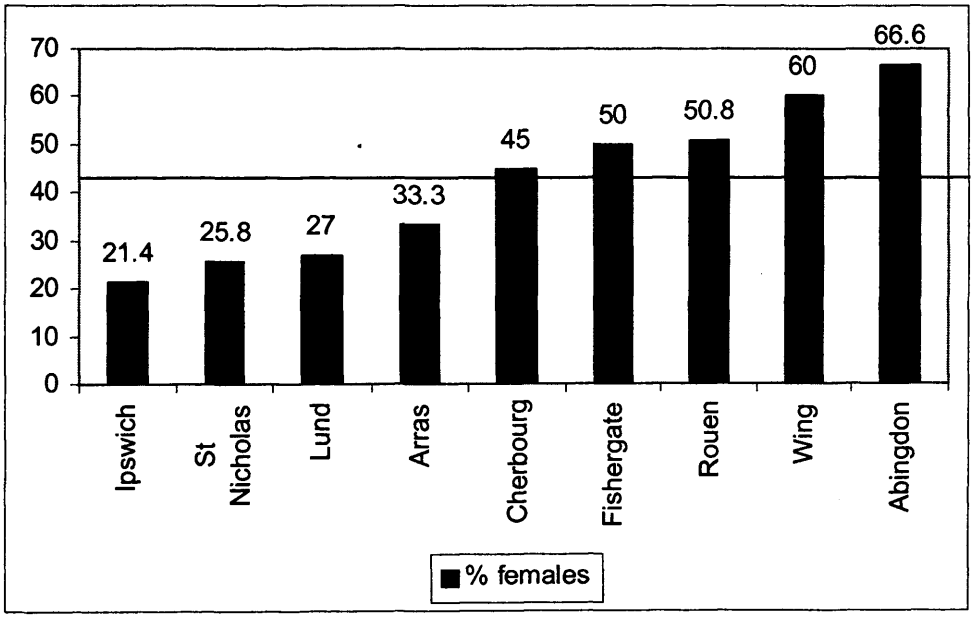


Chart 5.4. Cribra orbitalia: female prevalence in ascending order

Charts 5.4 and 5.4 show different prevalence rates between males and females, with the male average prevalence calculated at 38.9% and the female prevalence rate calculated at 42.2% (as illustrated by the horizontral bar across the charts). It is instantly noticeable that Abingdon shows the highest prevalence rates for both males and females. Arras displays the lowest prevalence rate of all the assemblages with 18.2% for its males. Ipswich has the lowest prevalence rate for females. Whereas the males in Fishergate have below average

prevalence rates at 28%, the females have an above average prevalence rate at 50%. The same is reflected in Wing, with the male prevalence at 37.5% and the female prevalence at 60%. The opposite is also true of Ipswich, where the females have below average prevalence of 21.4% and the males have an above average prevalence of 50%. Rouen, Cherbourg and Abingdon are the only assemblages that have prevalence rates that are consistently above the average for both males and females. Arras, Lund and St Nicholas are the only assemblages that have prevalence rates that are consistently below the average. This is also reflected in chart x showing total prevalence rates per assemblage.

A T-test was undertaken using the data from table 5.3 to assess if there was a significant difference between the proportion of males and females displaying cribra orbitalia lesions. The T-score was 0.583 (df=8) with a p value of 0.576, meaning that the null hypothesis was accepted for this data set. Statistically, the differences between male and female cribra orbitalia distribution are therefore not significant.

Next, the age distribution of the lesions was assessed in each assemblage. The table below shows the distribution (N.B. There is no data available for Lund). Of the individuals displaying cribra orbitalia, 41.3% are aged 18-35 years and 58.7% are aged over 35 years, showing a slight preponderance for lesions being present in older individuals.

A T-test was undertaken using the data from table 5.4 (%1) to assess if there was a significant difference between the proportion of individuals aged 18-35 years and individuals aged 35 years and over showing the disease. The T-score was 0.499 (df = 7) placing it at a $p = 0.644$, meaning that the null hypothesis was accepted for this data set. When the same test was carried out with the data from %2, which looks at the age distribution of the lesions, the null hypothesis was still accepted with t = 0.351 (df = 7) and $p = 0.735$.

		$n_{18/35}$	$\%_1$	$\%_2$	n_{35+}	$\%_1$	$\%_2$
Wing	T_1	1/7	14.2	8.3	11/19	57.9	91.6
	Males	0/3	0.0	0	6/13	46.1	100
	Females	1/4	25.0	16.7	5/6	83.3	83.3
Abingdon	T_1	9/16	56.2	33.3	18/27	66.6	66.7
	Males	4/7	57.1	25	12/20	60	75
	Females	5/9	55.5	45.5	6/7	85.7	54.5
Ipswich	T_1	6/17	35.3	66.7	3/11	27.3	33.3
	Males	5/7	71.4	83.3	1/5	20.0	16.7
	Females	1/8	12.5	50	1/5	20.0	50
Fishergate	T_1	10/27	37.0	83.3	2/8	25.0	16.7
	Males	7/21	33.3	100	0/4	0	0
	Females	3/6	50.0	60	2/4	50	40
St Nicholas	T_1	9/28	32.1	52.9	8/26	30.7	47.1
	Males	4/11	36.4	44.4	5/12	20.0	55.6
	Females	5/17	29.4	62.5	3/14	21.4	37.5
Arras	T_1	2/5	40	33.3	4/18	22.2	66.7
	Males	1/2	50	50	1/9	11.1	50
	Females	1/3	33.3	25	3/9	33.3	75
Cherbourg	T_1	5/12	41.6	22.7	17/29	58.6	77.3
	Males	3/5	60	23.1	10/17	58.8	76.9
	Females	2/7	28.6	22.2	7/12	58.3	77.8
Rouen	T_1	21/50	42	30	49/98	50.5	70
	Males	14/32	43.7	34.1	27/58	46.5	65.9
	Females	6/16	37.5	22.2	21/38	55.2	77.8

Table 5.4. Age and sex distribution of cribra orbitalia, true prevalences and percentages.

T_1 means the total number of males and females displaying cribra orbitalia in at least one orbit over the total number of individuals with at least one orbit observable per age group. %1 means the percentage of individuals of that age group with at least one orbit observable displaying cribra orbitalia in at least one orbit. %2 means the percentage of individuals displaying cribra orbitalia in that age group.

5.3.3. Discussion

The prevalence rates of cribra orbitalia in the investigated assemblages are calculated at between 23.6% at the lowest (Lund) and 62.5% at the highest (Abingdon). The prevalence rates across the sites encompass a wide range. It is unclear whether there seems to be a regional-specific distribution between the countries, with the Flemish and Swedish sites displaying the lowest frequencies and the sites from Normandy displaying some of the highest, with all the English sites apart from Abingdon in between.

It was expected that the prevalence rates would match population size, whereby the larger towns with the maximum exposure to pathogens would probably display the higher frequency of the lesions. This study did not reflect this. Some of the largest sites showed some of the lowest frequencies, notably Lund with 23.6% and St Nicholas Shambles with 31.4%. The reasons for such results are not straightforward, but three arguments can be put forward:

1) The size of the settlement may not have a direct influence on the contraction of a disease. Larger settlements might result in substantial exposure to various pathogens, but if immunity is possibly the main deciding factor, we cannot suppose that individuals living in an urban environment necessarily had a weaker immune system.
2) Population density, rather than size, could have been a more important factor. We have images of past urban accommodation as overcrowded, but it does not consequentially mean that villagers had more living space, and accommodation (e.g. sleeping quarters) might have been as cramped as it the towns, providing continuous exposure to a specific pathogen if a family member had contracted a disease.
3) Our established understanding of exposure to pathogens, contraction of diseases and their effects on the skeleton has been oversimplified and that much more complex mechanisms are involved.

Diet-related iron deficiency is still a possibility. Assumptions cannot be made that medieval diets were uniform throughout northern Europe at the time. Pearson (1997:27) in her study of early medieval diets, established that diets consisting of mixed agriculturally based

foodstuffs (for those who could access it). Regardless of urban or rural environment, however, the majority of individuals suffered from malnutrition due to the irregular availability of foods necessary to a balanced diet (Pearson (1997:28). In addition, the food was frequently contaminated by insects, parasites, rodents, fecal matter, poisonous weeds harvested with the crops and moulds (Pearson 1997:31), all of which must have contributed to poor health.

Infectious disease must also have been a leading cause for cribra orbitalia. Møller-Christensen (1978) observed a frequency of cribra orbitalia of 63.1% among individuals from the Næstved cemetery with leprosy. Arcini in her study of Lund also found a statistical significant increased prevalence of the lesions in the part of the cemetery where individuals with leprosy were buried (Arcini 1999:130). It is likely therefore that the prevalence rates we observe in the assemblages is not so directly linked to population size and general pathogen exposure, but rather exposure to specific infectious diseases with an immunity weakened by malnutrition.

It is not easy to compare prevalence rates with other sites as reports often report crude prevalence rates (total numbers affected / total numbers in the population) rather than true prevalence rates (total number affected / total number observable). In addition, they do not usually provide separate prevalence rates for adults and sub-adults, even though juveniles often display higher prevalence rates than the adults. In Raunds, 29.3% of the population displayed cribra orbitalia lesions (Powell 1996), of which 55% were juveniles (Lewis 1999).

Roberts and Cox (2003:185) have reported cribra orbitalia lesions prevalence rates to be of 6.1% for adults in the early medieval period, which they considered to be a decrease from the Roman period by *ca* 2%. This is much lower than our sample, and the possible explanation is that prevalence rates were calculated using crude values. In the later medieval period, the prevalence rate seemed to increase to 9.33%. This would rise to 10.82% if the hospital sites were taken into consideration, as their prevalence rate was much higher at 25.6% (Roberts and Cox 2003:234). This would strongly support Stuart-

Macadam's (1992) theory of cribra orbitalia being an indicator of total pathogen load in a population. Arcini (1999:117) in her study of medieval Lund found that the frequency of cribra orbitalia decreased throughout the Middle Ages, and that the highest frequency (30.8%) was found between *ca.* 990-1100. These results were confirmed statistically.

Although it was expected that younger individuals were more likely to display cribra orbitalia than older individuals because of bone remodelling, this was not found to be the case, as 58.7% of individuals with cribra orbitalia were found to be 35 years old and over. It would therefore seem that sub-adults and older individuals more commonly display the lesions, rather than young adults. Although the results are not statistically significant, a possible theory is that individuals who die before reaching adulthood are more likely to display the lesions, showing evidence of at least one period of ill-health. If the individuals survive childhood, however, they have an increased likelihood of dying at an older age. In addition, the data did not suggest statistical evidence for differential prevalence between males and females in the prevalence rates of cribra orbitalia.

5.4 Enamel hypoplasia

5.4.1 Introduction

Enamel hypoplasia are enamel defects on the teeth and has long been established as non-specific indicators of physiological stress (Goodman and Rose 1990:279, Larsen 1997:44). (See plate F appendix C). Because dental enamel is durable and does not remodel, hypoplastic defects provide a permanent record in older individuals of systemic physiological stress experienced during early childhood (Malville 1997).

Enamel covers the crowns of teeth. It is 96% mineral, making it very strong, and the remaining 4% is organic material and water. Ameloblasts (enamel prism forming cells) are highly vulnerable to local and systemic disturbances during amelogenesis (the elaboration of dental enamel by ameloblasts) (Langsjoen 1998:396). During crown formation, the crown begins with a matrix, which is secreted by ameloblasts and then becomes

mineralized. This is followed by another matrix, which is also mineralized. Hypoplastic lines are formed between matrix formation and its mineralisation. Amelogenesis is an incremental phenomenon and its formation is recorded by a sequence of regularly spaced grooving which runs around the circumference of a tooth. Each individual junction on the enamel, seen microscopically in the form of a groove, is called a perikyma (perikymata are eventually worn off with age and can only be seen in younger individuals). Each groove or perikyma represents 7-9 days growth of enamel and has a different appearance according to its location on the crown. There are three types of perikymata (occlusal, mid-crown and cervical) (see Plate F picture 2). Enamel also shows Tomes' process pits which mark the position of an ameloblast (i.e. enamel forming) cell (see Plate F picture 4).

The formation of a line of enamel hypoplasia is viewed as an arrest of amelogenic growth during a period of stress, halting the completion of that particular increment. Because enamel cannot repair itself, when growth restarts a new increment begins leaving the previous one incomplete and with a reduced enamel thickness. This results in a sharply-defined, horizontal, linear groove extending circumferentially around the tooth crown, a permanent feature and record of a severe disruption of growth. The enamel defects are known as linear or furrow-form defects and are the most common type of enamel hypoplasia. The other two forms of enamel hypoplasia are pit-form defects, where clusters of ameloblasts cease enamel matrix formation prematurely; and exposed-plane-form defects (See Plate F picture 1 and 3), where the plane of brown striae of Retzius (which mark out successive positions of the enamel matrix forming front) are left partially or wholly exposed (Hillson and Bond 1997:94-95).

Ensor and Irish (1995:515) propose that the width of the lesions suggest the time frame of the insult, whereas their depth indicates its severity. In all cases however, the stress must be severe and near fatal enough for the body to divert energy away from non-vital processes such as ameloblastic physiology to processes essential for survival (Langsjoen 1998:405). Chronic nutritional stress seems to be one of the most widely accepted primary causes of enamel hypoplasia (Goodman *et al.* 1989) and many studies use enamel hypoplasia to draw health comparisons between hunter-gatherers and agriculturalists on the basis of

sedentarism and diet changes (e.g. Goodman 1989). Factors that might cause disruption in enamel formation include malnutrition, infectious diseases, parasitism and weaning (Goodman and Rose 1990:109). Neiburger (1990:231) comments on the variety of causes for enamel hypoplasia. He recognises that diet and poor nutrition is one, but insists that primarily there is a predisposition to acquiring enamel hypoplasia, and that some individuals even under severe environmental stress will not produce enamel hypoplasia. He also suggests ingestion of toxic substances (e.g. excess fluoride), actual injury to the tooth or its pulp (e.g. ceremonial trauma), individualised trauma (e.g. tatooing, tonsillectomy) and diseases (especially when accompanied by fever), such as gastroenteritis, could also result in enamel defects. This relationship between extreme ill-health in childhood and enamel hypoplasia makes it a useful health marker in skeletal studies.

Determining environmental stress by using enamel hypoplasia is achieved by analysing the frequencies of the number of hypoplastic events. Ensor and Irish (1995:507), however, warn that the method assumes uniformity between all defects and does not account for the range of variability in the duration of stress. A later paper by Hillson and Bond (1997) draws attention to the difficulties in recording and interpreting enamel hypoplasia. They demonstrate microscopically what can be perceived macroscopically and explain the differences in appearance of the lesions and their type according to their location on the tooth. The complexity of the amelogenesis process and the changes in the appearance of the perikymata across the crown both affect the appearance of the defects. Indeed, at the tip of the crown (occlusal type, which occupies a third to half of the crown), the perikymata consist of broad shallow waves. The cervical type however (which occupies a quarter to a third of the crown), has an imbrication line form where there are no waves and the spacing much shorter. The mid-crown type has some wave-like impressions and sharp lines between the waves (see plate F in the appendix for an illustration). Because the enamel hypoplasia is a defect of the perikymata, it would be more obvious in the cervical part of the crown, where the waves are much shorter, making the line sharper than in the occlusal part of the crown, where the waves are wider and shallower, giving the furrow a less well-defined appearance (Hillson and Bond 1997:97-8). There is also an appositional zone at the tip of the crown which hides a large proportion of enamel layers which do not appear at the

surface of the tooth and can thus hide 10-20% of crown formation time in anterior teeth (equivalent to seven months, and up to 50% [10 months] for cheek teeth) (Hillson and Bond 1997:101).

Hillson and Bond (1997:98) also emphasize that the bulk of defects are usually of microscopic size and would not be picked up in routine macroscopic analysis, thus grossly underestimating the prevalence of the defects. Lighting will also influence the shadow of a groove and make it appear wider than it really is, potentially overestimating the duration of the growth disturbance. All these problems make inter-observer variability a high-risk in comparative studies, especially when using archive reports and databases. Because of the above difficulties, Hillson and Bond (1997:101) suggest that rather than measuring the duration of an enamel defect by its width, it would be better to measure the number of perikymata involved in the lesion. Pit-form lesions present another difficulty as they always occur on the edge of the disturbed growth layer, so assigning an age to them can be difficult and pit-form and exposed-plane-form defects tend to represent a pronounced disruption rather than a lengthy one. Hillson and Bond suggest that to be exact, the study of enamel hypoplasia should become purely microscopic, which of course is a lengthy process that is expensive and time-consuming, as well as often damaging to the teeth analysed, making it unsuitable to be carried out on a routine basis.

Hypoplasia occurs most frequently on the mandibular canine and the central maxillary incisors and the cervical and middle third of tooth crowns. It has been determined that 95% of the total growth disruption of an individual, as indicated by hypoplasia, can be accounted for by using these four teeth (Goodman *et al.* 1980:527, Lanphear 1990:42, Larsen 1997:46). Unfortunately, they are also the teeth most likely to detach themselves from their socket post-mortem due to their single roots. In addition, the lines can be obliterated through excessive attrition or hidden under calculus build-up.

Results were calculated as followed: total number of individuals with at least one enamel hypoplasia line visible macroscopically divided by the total number of individuals with teeth available for study.

5.4.2. Results

Site	*Males*	*%*	*Females*	*%*	*Total*	*%*
Wing	10/18	55.5	5/10	50.0	15/28	53.6
Abingdon	5/24	20.8	5/10	50.0	10/34	29.4
Cherbourg	20/23	86.9	17/22	77.3	37/45	82.2
Arras	1/15	6.6	1/9	11.1	3/26	11.5
Ipswich	6/12	50.0	3/14	21.4	10/30	33.3
Fishergate 4	29/31	93.6	20/21	95.2	49/52	94.2
Lund*	28/201	13.9	26/158	16.4	54/359	15.0
St Nicholas	25/31	80.7	32/47	68.1	57/78	73.1
Rouen	61/112	54.5	39/71	54.9	105/198	53.0

Table 5.5. Enamel hypoplasia: male, female and total prevalence.

Corrected prevalences (at least one line per individual / individuals with teeth) and percentages. Sites arranged in estimated ascending order of population size and density. Total means males + females + adults of indeterminate sex.

* In Lund data was only available for adults ages 20-39 years as Arcini found that the teeth of older individuals' were substantially worn or damaged by tooth attrition and carious lesions (Arcini 1999:113).

The results from table 5.5 are displayed in the chart below.

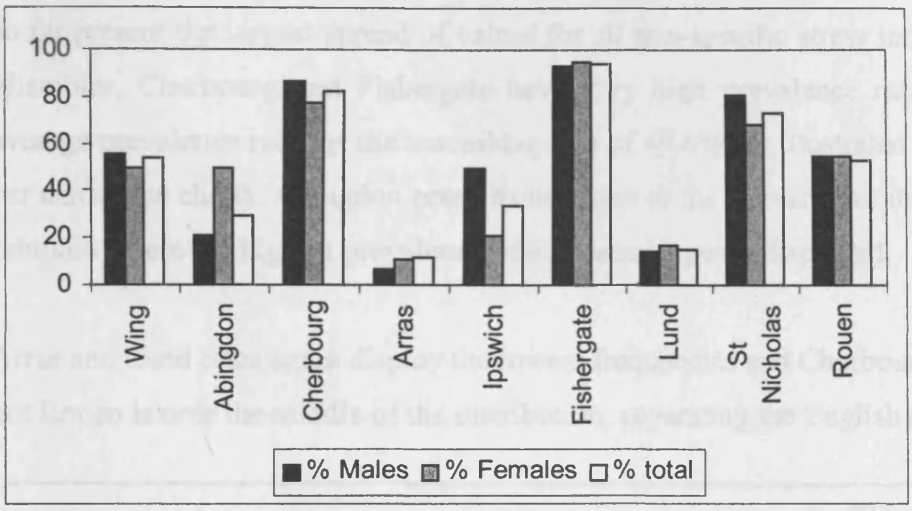


Chart 5.5. Enamel hypoplasia: male, female and total prevalence rates.

As for cribra orbitalia, enamel hypoplasia prevalence rates do not seem to directly correlate with population size and density. Fishergate and St Nicholas Shambles, some of the largest towns in our assemblages, do present some of the highest prevalence rates whereas the other large towns such as Rouen and especially Lund, present average or below average prevalence rate.

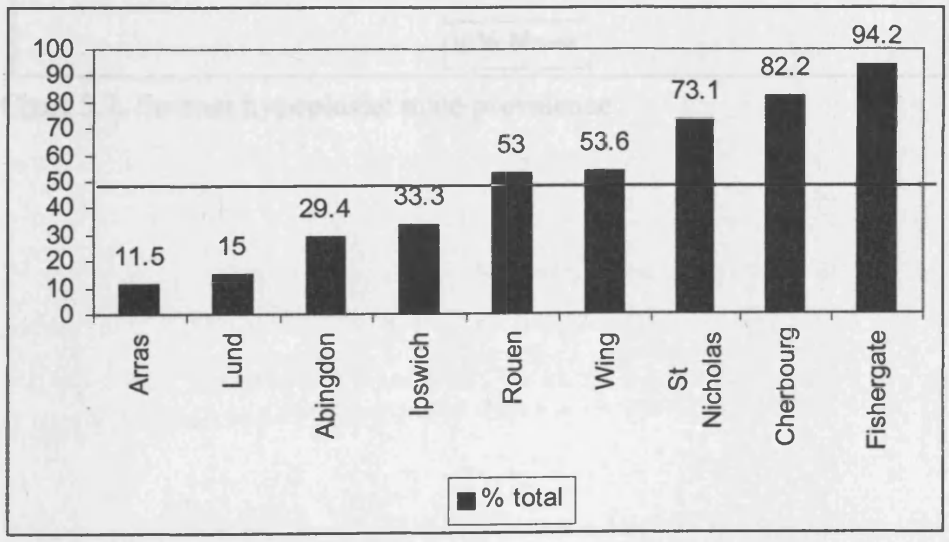


Chart 5.6. Enamel hypoplasia: total prevalence.

The values for enamel hypoplasia range from 11.5% (Arras) to 94.2% (Fishergate), which so far present the largest spread of values for all non-specific stress indicators. St Nicholas Shambles, Cherbourg and Fishergate have very high prevalence rates above 73%. The average prevalence rate for the assemblages is of 49.6% (as illustrated with the horizontral bar across the chart). Abingdon presents here one of the lowest rates in contrast with cribra orbitalia where the highest prevalence of all assemblages is displayed.

Arras and Lund once again display the lowest frequencies and Cherbourg one of the highest but Rouen is near the middle of the distribution, separating the English sites.

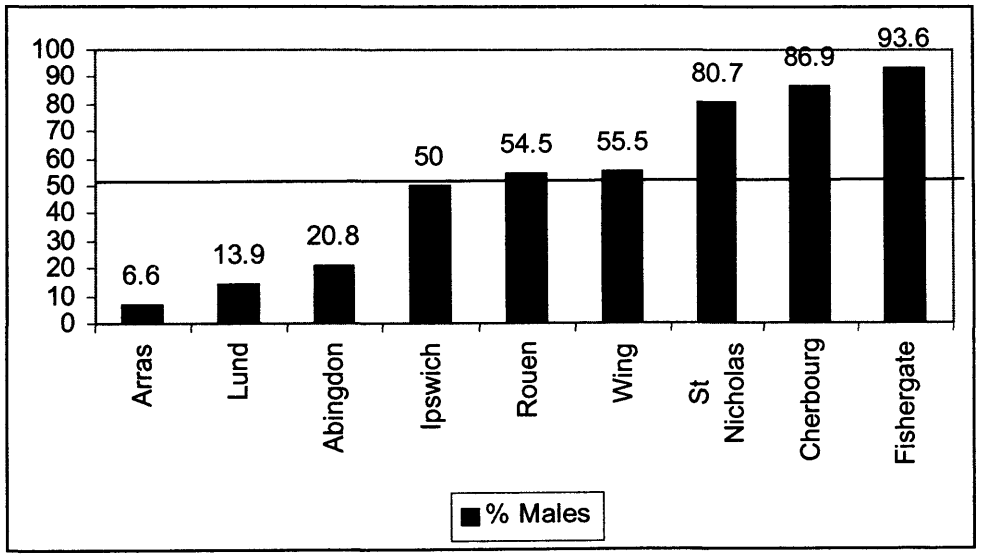


Chart 5.7. Enamel hypoplasia: male prevalence

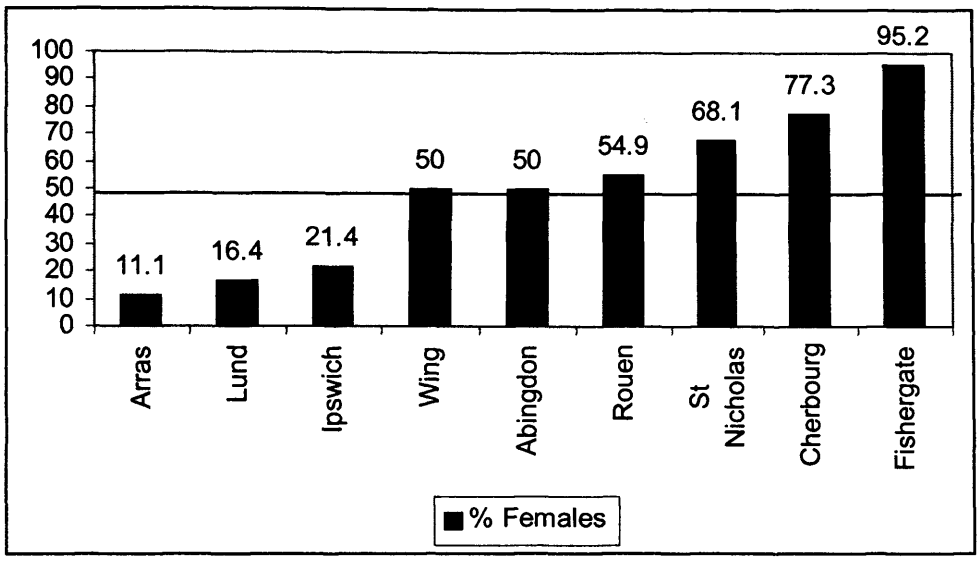


Chart 5.8. Enamel hypoplasia: female prevalence.

Apart from Ipswich, Abingdon, Wing and Rouen where the order is slightly altered, rank order of prevalence is the same for both sexes. Males and females in Arras, Lund, Ipswich and Abingdon all present around average or below average enamel hypoplasia prevalence rates.

For both sexes, data seem to be arranged into three groups: the first group has values ranging from 6.6% and 21.4%, then a second group with values from 50% to 55.5%, and a last group with values of 68.1% and over. In this last group the males show much higher prevalence rates than the females with frequencies of 80.7%, 86.9% and 93.6% for St Nicholas Shambles, Cherbourg and Fishergate respectively. T-test analysis was undertaken to assess if males and females differed significantly in their prevalence rates for enamel hypoplasia. T score = 0.708 (df = 8), $p = 0.498$ meant that the null hypothesis was accepted and that the differences observed between males and females were not statistically significant.

		$n_{18\text{-}35}$	%	N_{35+}	%
Cherbourg	T_1	10/13	77.0	26/31	83.9
	Males	5/6	83.3	15/17	88.2
	Females	5/7	71.4	11/14	78.6
Rouen	T_1	35/61	57.4	62/115	53.9
	Males	23/40	57.5	35/67	52.2
	Females	11/20	55.0	27/46	58.7
Ipswich	T_1	6/17	35.3	3/12	25.0
	Males	5/7	29.4	1/5	20.0
	Females	1/8	12.5	1/5	20.0
Wing	T_1	6/9	66.6	9/19	47.4
	Males	¾	75.0	7/14	50.0
	Females	3/5	60.0	2/5	40.0
Abingdon		6/13	46.1	3/19	15.7
	Males	1/7	14.2	3/16	23.0
	Females	5/6	83.3	0/3	0

Table 5.6. Age and sex distribution of enamel hypoplasia.

The frequency data was then separated into age groups as shown in table 5.6 (no information was available for Lund, Arras, Fishergate and St Nicholas Shambles).

56.5% of individuals between the ages of 18-35 and 45.2% of the individuals over 35 years showed the lesions, showing a slight predominance of enamel hypoplasia in younger individuals.

A T-test was undertaken to assess if there was a significant difference between the proportion of individuals aged 18-35 years and individuals aged 35 years and over showing the enamel hypoplasia. The T-score = 0.152 (df = 4), p = 0.886 supports null hypothesis and means that the differences observed between the age groups are not statistically significant.

5.4.3. Discussion

The prevalence rates of enamel hypoplasia in the assemblages range from 11.5% in Arras to a colossal 94.2% for Fishergate, Such a spread in frequency calculations may have been introduced by inter-observer variability, where extreme frequencies might suggest high observer variability. This is unlikely, however, as no site seems to stand out and isolate itself from the others.

In Roberts and Cox's (2003:187-8) assessment of health in Britain, prevalence rates that were calculated as number of teeth affected / number of teeth present (including sub-adults) displayed a 7.4% frequency in the early medieval period. For the late medieval period, prevalence rates were calculated slightly differently as affected dentitions / total dentitions (including sub-adults) from 28 sites (which included hospitals). This presented a higher prevalence rate of 35%, with a majority of sites having prevalence rates between 20 and 40% (Roberts and Cox 2003:264), which although lower is closer to the 49.5% frequency displayed by our assemblages. It is clear that inconsistency in recording and reporting lesions hinders comparative work.

In Lund, Arcini found that the prevalence of enamel hypoplasia, contrary to cribra orbitalia, was at its lowest in AD 990-1100, increasing to 26.1% in the later periods (Arcini 1999:181), which would reflect Roberts and Cox's observations for early and late medieval Britain. Prevalence rates for sub-adults were also much higher, at 25% for our period and increasing to 45.4% for the period 1100-1300 (Arcini 1999:181).

As for cribra orbitalia, no statistically significant differential prevalence rates were found between males and females or age groups. Abingdon displayed the highest prevalence rate for cribra orbitalia and one of the lowest for enamel hypoplasia, suggesting that it suffered more from chronic childhood diseases rather than acute and shorter periods of illness. The distinction between the English and non-English sites is not as marked here as it was for the cribra orbitalia, although Lund and Arras still display the lowest frequencies.

5.5. Periostitis

Periostitis is rarely found as a single disease process, but is more commonly observed as a reaction to pathological changes around the bone (Ortner and Putschar 1985:129). Not commonly cited in medical literature, it is, however, frequently observed in archaeological skeletons as undifferentiated and non-specific lesions. They are considered to reflect trauma or infection, and are associated with infectious diseases such as tuberculosis and leprosy (Roberts and Cox 2003:58). Goodman *et al.* (1988:200) describes the periostitis often seen in the lower legs as a non-specific response to a stress, a basic inflammatory reaction that usually has a systemic bacterial origin, making periostitis an indicator of generalised stress.

Periostitis is essentially inflammation of the periosteum with new bone formation. The periosteum is a connective tissue that covers the bones and which retains bone-forming capacities. It consists of two layers. The external layer is a network of dense connective tissue containing blood vessels; the internal layer is composed of collagen bundles with connective tissue cells and elastic fibres. Some of the cells of the inner layer have the ability to develop into osteoblasts (bone forming cells), if stimulated, for example, by infection or injury. Plaques of new bone are formed, initially from woven bone that, once healed, is incorporated into the normal cortical bone (Larsen 1997:83-84).

Periostitis of a traumatic origin, the most common form today, can be brought on by both sudden and chronic insult to the bone. The lesions are usually localised and limited to a single limb. Periostitis usually occurs: 1) by extension of an adjacent soft tissue infection; 2) by involvement of the surface of the bone from osteitis or osteomyelitis; 3) as a manifestation of a generalised disease (Morse 1978). The lesions are associated with a wide range of infectious diseases such as leprosy, tuberculosis, hypertrophic osteoarthropathy, treponemal diseases and osteomyelitis to cite the most common, as well as some metabolic diseases such as scurvy and rickets (Ortner and Putschar 1985:131-132, Aufderheide and Rodriguez-Martin 1998:311). It is, however, usually impossible to determine which condition caused the lesion in dry archaeological bone (Ortner and Putschar 1985:131, Capasso 1985). It is also not always possible on dry bone to differentiate between

osteomyelitis, which is a bacterial infection of the bone, and periostitis caused by other conditions. Osteomyelitis usually presents a cloaca for pus drainage and changes in the marrow cavity and the bone is usually noticeably thickened. Periostitis is also usually superficial to the bone cortex but deposits of new bone can be quite thin. Periostitis can also be indicative of poor blood circulation, either caused by varicose veins (venous stasis) (Resnick and Niwayama 1988) or poor circulation caused by living in cold and damp conditions (Wakely *pers.com*).

In archaeological specimens, periostitis is most frequently present on the lower legs (tibiae and fibulae, often bilaterally) with various degrees of severity (Roberts 2000), ranging from a bark-like appearance (slight) to a molten, irregular and spiky appearance (severe). It is observed as fine pitting, longitudinal striation and plaque-like new bone formation on the surface of cortical bone (caused by hypervascularity) (Roberts and Manchester 1995:129-30). It rarely covers the whole bone surface and never the articulations. Periostitis occurs most frequently on the tibiae because of their extensive vascularity and physiologically inactive surfaces, slower blood circulation and lack of soft tissue covering (Roberts 2000:148). The new bone is woven and sits on top of the cortical surface of the bone. Eventually, it becomes incorporated into the cortical bone and is remodelled into lamellar bone and no trace of the initial bone formation remains visible. New bone can be deposited over a long period of time, giving it an uneven appearance with successive layers of periostitis thickening the affected bone, and it can be apparent microscopically (Ortner and Putschar 1985, Schultz 2001). The periostitis visible in human skeletons means that it was still active or in the process of being remodelled at the time of death.

For this study, periostitis was recorded in the following way:

1. Presence or absence of the lesions on the lower limbs (tibia and fibula).
2. The lesion had to cover a sufficient area of the bone or be present bilaterally to exclude cases brought on by trauma.
3. Both healed and new lesions were recorded, from moderate to severe cases. Slight periostitis was not recorded, as inter-observer variability is too high when relying on

reports, as well as being associated with normal age-related changes in older individuals.

4. Whenever a specific cause for the lesion could be established (trauma, tuberculosis, hypertrophic osteoarthopathy, osteomyelitis, etc), the individual was not included in the sample.

Results were reported as total number of individuals with periosteal lesions on the lower legs divided by the total number of individuals with lower legs available for study. The Student's T-test was used to statistically assess whether one data set differed significantly from another. Data was not available to group the frequency by age groups.

5.5.1. Results

Site	*Males*	*%*	*Females*	*%*	*Total*	*%*
Wing	5/21	23.9	3/15	20.0	9/37	24.3
Cherbourg	7/20	35.0	4/22	18.2	11/42	26.2
Arras	5/13	38.4	4/15	26.6	9/28	32.1
Ipswich	1/18	5.5	3/20	15.0	6/43	13.9
Fishergate	8/47	17.0	4/33	12.1	12/80	15.0
Lund	41/408	10	12/303	4.0	59/1104	5.3
St Nicholas	12/91	13.2	11/74	15.9	23/165	13.9
Rouen	13/116	11.2	5/88	5.7	24/268	8.9

Table 5.7. Lower limb periostitis (tibia and fibula) in corrected prevalences and percentages. Hypertrophic osteoarthopathy and osteomyelitis cases are not included. Total refers to males + females + adults of indeterminate sex.

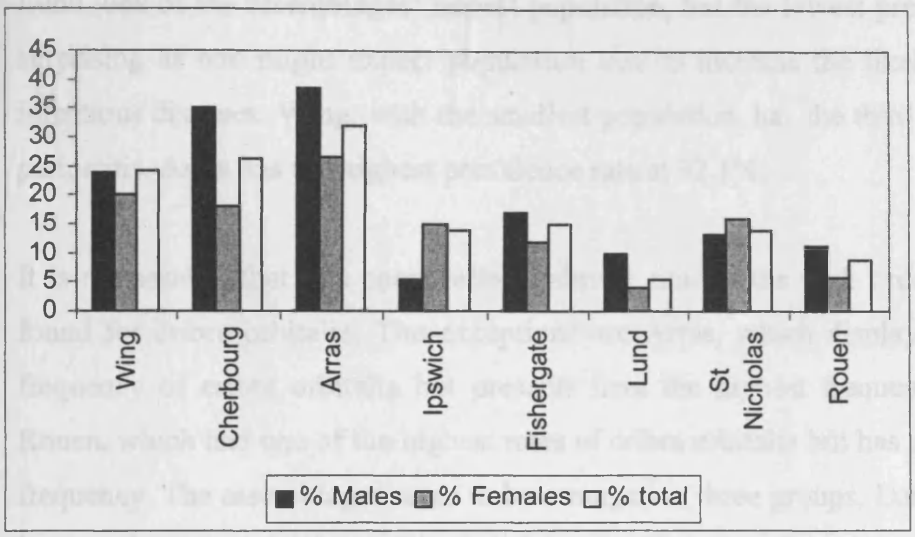


Chart 5.9. Periostitis: male and female and total prevalence rates in increasing estimated population size

Chart 5.9 and Table 5.7 clearly demonstrate that the prevalence rates of periostitis is not directly linked to population size, suggesting that population size alone is probably not a factor in the development of periosteal lesions.

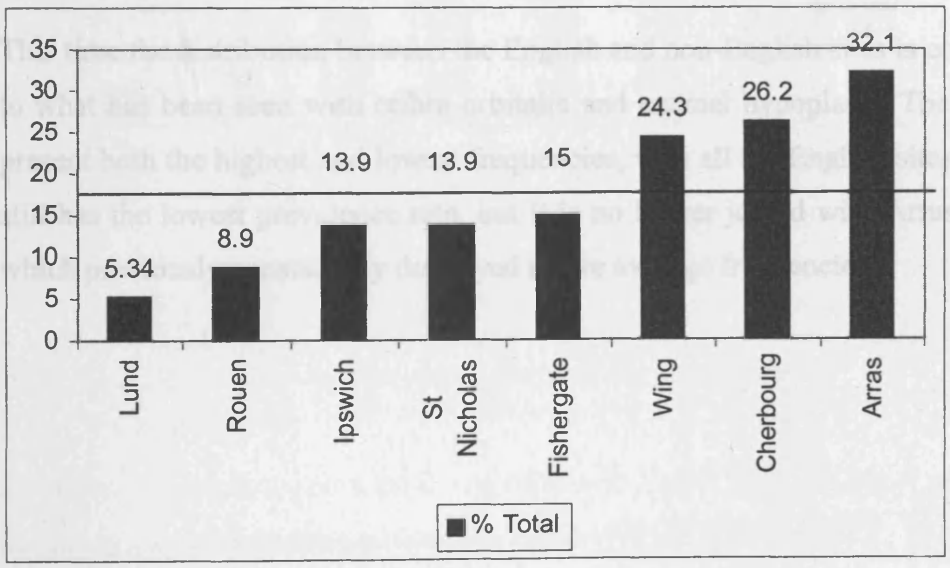


Chart 5.10. Total prevalence of periostitis in the lower limbs.

The average total prevalence rate for the assemblages is 17.5% (as illustrated with the horizontal bar across the chart), which is lower than the cribra orbitalia frequency of 40.6%.

Lund, one of the assemblages' largest population, has the lowest prevalence rate, which is surprising as one might expect population size to increase the likelihood of exposure to infectious diseases. Wing, with the smallest population, has the third highest prevalence of periostitis. Arras has the highest prevalence rate at 32.1%.

It is remarkable that this chart reflects almost exactly the rank order of prevalence rates found for cribra orbitalia. The exceptions are Arras, which displayed the second lowest frequency of cribra orbitalia but presents here the highest frequency of periostitis; and Rouen, which had one of the highest rates of cribra orbitalia but has now the second lowest frequency. The assemblages seem to be arranged in three groups, Lund and Rouen with the lowest frequency under 10%, Ipswich, St Nicholas Shambles and Fishergate with prevalence rates around 15%, and Wing, Cherbourg and Arras with prevalence rates between 24% and 32%, which are also above the assemblages' average frequency. Had time constraints allowed it, it would have been interesting to analyse the number of individuals displaying both cribra orbitalia and periostitis, since they both reflect the pathogen load of a population.

This time the distribution between the English and non-English sites is completely different to what has been seen with cribra orbitalia and enamel hypoplasia. The non-English sites present both the highest and lowest frequencies, with all the English sites in between. Lund still has the lowest prevalence rate, but it is no longer joined with Arras, but with Rouen, which previously consistently displayed above average frequencies.

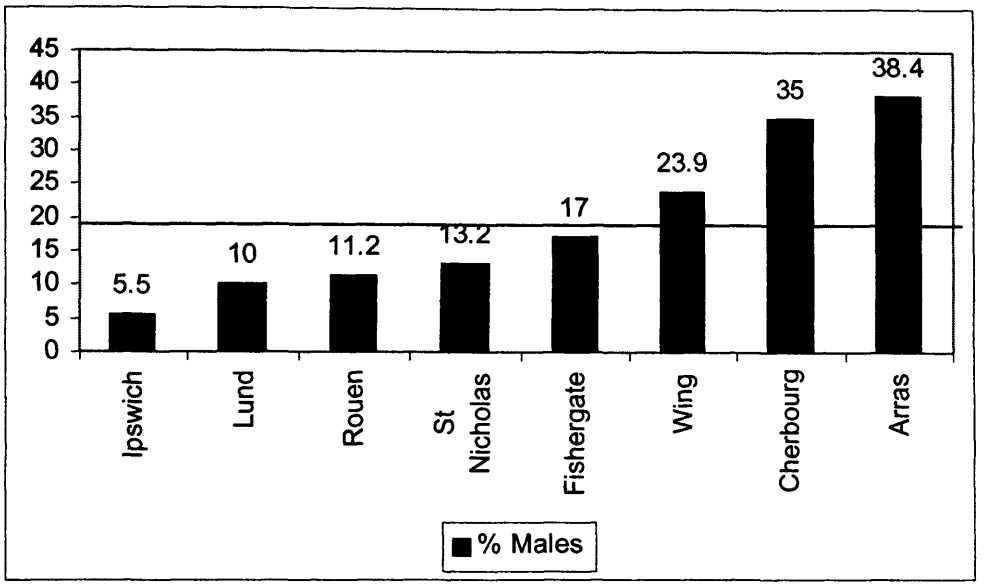


Chart 5.11. Male prevalence of periostitis in the lower limbs.

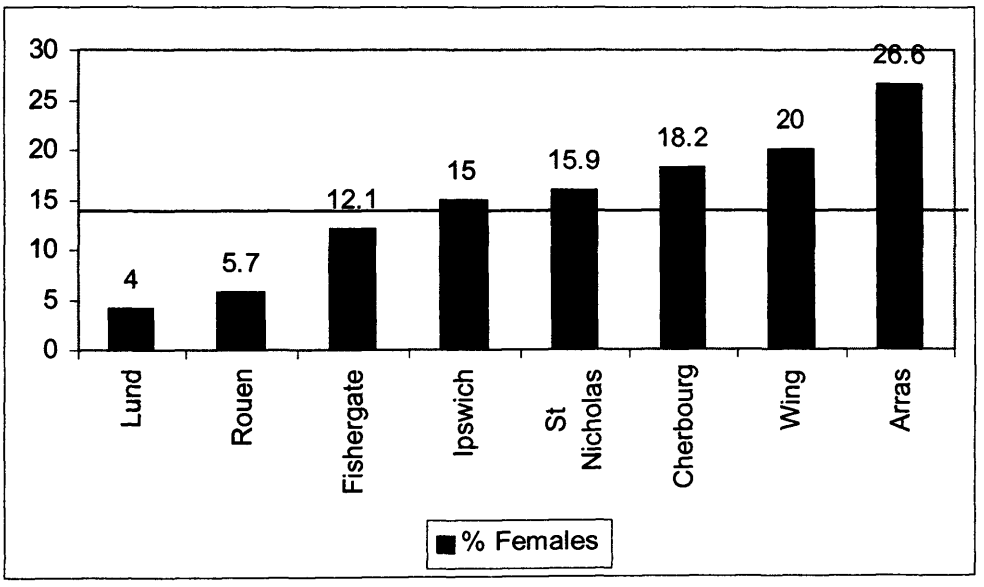


Chart 5.12. Female prevalence of periostitis in the lower limbs.

Arras has the highest prevalence rates for both males and females. Lund has the lowest frequency for the females and Ipswich for the males. Ipswich and St Nicholas are the only assemblages where females have higher prevalence rates than males.

The prevalence rate for females ranges from 4% to 26.6% and has an average frequency of 14.7% (as illustrated with the horizontral bar across the chart); only Lund and Rouen are

substantially below that rate. The male prevalence rates range from 5.5% to 38.4% and have an average frequency of 19.3% (as illustrated with the horizontral bar across the chart) of which Wing, Cherbourg and Arras are above that rate.

T-test analysis was undertaken to assess if males and females differed significantly in their prevalence rates for periostitis. The T-score = 0.152 (df = 7) $p = 0.883$ meant that the null hypothesis was accepted and that the differences observed between males and females were not statistically significant.

The frequency data was then separated into age groups as shown in table 5.6 (no information was available for Lund and Arras). 19.6% of individuals in the younger age groups showed evidence of periostitis and 16.1% in the 35+ age group, showing a slight preponderance for the lesions in younger age categories. The T-test statistic did not find the difference in lesion distribution statistically significant.

		n_{18-35}	%	n_{35+}	%
Cherbourg	T_1	5/13	38.5	5/19	26.3
	Males	3/6	50.0	3/8	37.5
	Females	2/7	28.6	2/11	18.2
Rouen	T_1	7/59	11.9	8/127	6.3
	Males	5/35	14.3	5/68	7.3
	Females	1/20	5.0	3/56	5.3
Wing	T_1	3/12	25.0	4/22	18.2
	Males	1/7	14.3	4/14	28.6
	Females	2/5	40.0	0/8	0
Fishergate	T1	2/32	6.2	4/21	19.0
	Males	1/25	4.0	4/11	36.4
	Females	1/7	14.3	0/10	0
St Nicholas	T1	11/37	29.7	5/22	22.7
	Males	6/19	31.6	1/10	10.0
	Females	5/18	27.8	4/12	33.3
Lund		33/514	6.4	11/265	4.1

Table 5.8. Age and sex distribution of periostitis.

5.5.2 Discussion

The prevalence rates for periostitis in the assemblages range from 5.34% in Lund to 32.1% in Arras and have an average prevalence rate 17.5%. This rate roughly matches the crude prevalence rate of 14% calculated by Roberts and Cox (2003:235) for late medieval Britain.

Although the range of prevalence rates is not as large as for cribra orbitalia, it is still fairly substantial. A possible cause for such a spread is that periostitis is possibly one of the most difficult lesions to record accurately. The lesions can be so diverse in appearance and location, as well as ranging in severity, that it is more likely to be affected by substantial inter-personal variability in recording them than lesions that can be recorded as

present/absent, such as enamel hypoplasia. This makes it very difficult when relying on reports to compare assemblages.

Like cribra orbitalia, population size and density does not appear to have a direct correlation for prevalence rates of periostitis. The male-female distribution of the lesions suggests that males display a higher prevalence than females, but it was not found to be statistically significant. The English vs. non-English distribution is quite different here, with the non-English sites providing both the highest and the lowest frequencies. Lund and Arras are no longer displaying the lowest prevalences.

In the cemeteries of Lund, Arcini (1999:183-4) has found that the prevalence rates of periostitis were statistically higher in the earlier periods, and were significantly higher in the areas favoured for burials of lepers. In her study, a quarter of the individuals suffering from leprosy also displayed periostitis. In Møller-Christensen's (1953) study of the Næstved leper cemetery, 80% of individuals with leprosy showed periostitis of the lower limbs. This would suggest that periostitis does reflect the prevalence of some infectious diseases. Although periostitis in lower limbs is part of the changes due to leprosy, its aetiology is different and the lesions cannot be compared the non-specific stress indicators.

5.6. Conclusion

Site	*% cribra orbitalia*	*% enamel hypoplasia*	*% periostitis*
Wing	46.1	52.6	24.3
Abingdon	65.2	29.4	Na
Cherbourg	50	82.2	26.2
Arras	26.1	11.5	32.1
Ipswich	34.5	33.3	13.9
Fishergate	43.2	94.2	15
Lund	23.6	15	5.3
St Nicholas	31.4	73.1	13.9
Rouen	48.4	53	8.9
Mean	40.6	49.5	17.5

Table 5.9. Summary table showing total prevalence rates of cribra orbitalia, enamel hypoplasia and periostitis per site, given in percentages. Average is the arithmetic mean for all sites.

The hypotheses set out at the beginning of this chapter have been tested and not found to be an accurate description of the skeletal assemblages observed here.

When the English and non-English sites are compared they do not immediately suggest a completely different pattern in lesion frequency, apart from the prevalence rates displayed for periosteal lesions where they display the lowest and highest frequencies of all assemblages. Lund and Arras often display the lowest prevalence rates. For Arras, it could be caused by the fact that there is an increased likelihood that the sample is not random and represents a very particular part of the buried population (Arras also displayed the highest prevalence rate of tuberculosis, see chapter 6). Lund, however, displayed numerous cases of leprosy and yet has the lowest prevalence rates of all non-specific stress indicators.

The three non-specific stress indicators examined in this project have not been found to increase in frequency with estimated higher population size. This does not mean that they

do not accurately reflect total pathogen load, but rather that total pathogen load does not necessarily go hand in hand with total population size. The bigger towns might require from its inhabitants a more adaptable and stronger immunity, but it does not follow that they should be more diseased than smaller settlements simply because they have more exposure to diseases. Population density does not necessarily imply population size, and it is quite possible that the living quarters of villagers were just as cramped (and squalid) as those living in cities, some of whom might be able to afford relatively spatious accommodation. In cramped conditions exposure to a pathogen could be continuous if one member of the family had contracted an infectious disease. It is also possible that the link between diseases and resulting skeletal lesions is more complex than has been previously assumed.

The sizeable range in prevalence rates between sites cannot be explained other than as a real phenomenon indicative of wide divergence in pathogen load between localities or by factors which differ between sites such as diet, genetics, etc.

The second hypothesis of potential differential male and female health being visible through the study of non-specific stress indicators has also proved to be unfounded, as statistical analysis has found no significant sex distribution of the lesions. In addition, differential age distribution in the lesions of enamel hypoplasia and cribra orbitalia in adults has not been found to be statistically significant, suggesting that they are no remarkable differences in longevity between people with different childhood health status.

There is substantial variability in the prevalence rates of the non-specific stress indicators suggesting that they show different aspects of pathogen load. Unfortunately no pattern seems prevalent.

The following summaries can be made for each population:

- Cherbourg, a small town of purely local importance has, surprisingly, displayed the second highest prevalence for cribra orbitalia, enamel hypoplasia and periostitis frequency.

- Wing, a rural settlement with the estimated smallest population size, displayed above average prevalence rates of all non-specific stress indicators.
- Abingdon, of which so little in known, displayed the highest prevalence of cribra orbitalia but a comparatively low rate of enamel hypoplasia.
- Fishergate, and to a lesser extent St Nicholas Shambles, displayed very high prevalence rates of enamel hypoplasia but relatively low frequencies of cribra orbitalia and periostitis by comparison.
- Arras displayed some of the lowest prevalence rates for cribra orbitalia and enamel hypoplasia but presented the highest prevalence of periostitis. The low prevalence rates can be partially explained by the poor preservation of the material and the possible lack of representivity of the excavated material.
- Ipswich produced under average prevalence rate for all non-specific stress indicators.
- Lund consistently presents some of the lowest prevalence rates for all non-specific stress indicators observed. The low enamel hypoplasia frequency can be partially explained by the fact that only younger adults were included in the sample, as processes of attrition and tooth decay excluded older adults from the study.

Chapter 6. Specific Infectious Diseases

In this chapter, three types of infectious diseases will be investigated. They comprise tuberculosis and chronic chest infection, and leprosy. Other specific infectious diseases can be observed on the skeleton. The most common affecting adults include: trepanomatoses (of which syphilis is the most common in Europe), osteomyelitis and brucellosis (Aufderheide and Rodriguez-Martin 1998). They were not investigated here because syphilis is unexpected in populations before the 15th century, the most common form of osteomyelitis results from injury, and brucellosis is uncommon in northern Europe.

6.1 Tuberculosis

6.1.1 Epidemiological background

There is worldwide paleopathological evidence of tuberculosis. The first cases have been reported dating from the Neolithic (Aufderheide and Rodriguez-Martin 1998:126). In Britain the first case of tuberculosis was discovered in 2003 in an Iron Age man buried *ca.* 300 BC in Dorset, which contradicts the original belief that the Romans brought tuberculosis to Britain (Mays and Taylor, forthcoming). Tuberculosis is thought to have been a major cause of morbidity and mortality throughout medieval Europe (Mitchell 1999:45), but Britain was most heavily affected in the later medieval and post-medieval periods. In seventeenth century London, 20% of all deaths were reported to be due to tuberculosis (Clarkson 1975 in Roberts and Manchester 1995:135). However, the prevalence of tuberculosis in British skeletal material so far has been quite low, suggesting that diagnostic criteria are inadequate and might need to be reviewed (Roberts 2000:152). Yet, Mays *et al.* (2001:303) found that biomolecular analysis often confirmed the diagnosis of tuberculosis made on dry bones (see below section 6.3 on nucleic acids). This suggests in fact that tuberculosis has so far been reliably diagnosed using traditional osteological methods, despite the variations in the appearance of the lesions, which might also be consistent with other infections such as brucellosis (Ortner and Putschar 1985:140).

As with all infectious diseases, tuberculosis is population-density dependent: increasing urbanisation, poverty, malnutrition, close contact with animals and their products would

have affected its prevalence (Roberts and Cox 2003:40). Today, it is estimated that one undiagnosed case of pulmonary tuberculosis can infect approximately 10 people a year (Lee 2002:3). Because of its virulent infectious nature, the disease was particularly prevalent in large populations living at very close quarters to each other. Although tuberculosis has always been associated with poverty, in the 17th-18th century (when prevalence rates were very high, Aufderheide and Rodriguez-Martin 1998:129) it affected all classes. While poverty was a major factor, poor living and working conditions combined with an inadequate and unhealthy diet do not wholly account for the very high incidence among the labouring population. Physical and psychological strain might also be a factor (Cartwright and Biddiss 2000:137-8), but epidemiological factors influencing the prevalence of tuberculosis include environmental features, differences in biology of the organism itself and host variation (Aufderheide and Rodriguez-Martin 1998:125). Although the prevalence of the disease became particularly high in the eighteenth and nineteenth century in large towns, it had existed earlier in smaller ones too. The new factors might simply have been an exacerbation of previous evils (Cartwright and Biddiss 2000:138).

The majority of people in medieval Britain lived in the countryside in small, relatively self-sufficient family clusters and villages, with limited opportunities for extensive social contact with large groups, which minimised aerial human to human transmission of the disease (Aufderheide and Rodriguez-Martin 1998:129). Its reservoir must have been a small but constant fraction of pastured cattle. Transmission of tuberculosis to humans occurred, but the lifestyle of both human and cattle kept its prevalence low (see below) (Aufderheide and Rodriguez-Martin 1998:128). We must not, however, underestimate human transmission potential as markets and migrant workers must have played their part in the transmission of the disease, and once one individual was affected, the whole family was likely to suffer too (Mays *et al.* 2001). Roberts and Cox (2003:119) suggest that increased trade and contact with the continent must have allowed the infection to establish itself in Britain in the Roman period. Much of the European continent is believed to have differed little from this pattern (Aufderheide and Rodriguez-Martin 1998). The medieval presence of tuberculosis is established, but its prevalence, particularly in the Middle Ages, is difficult to calculate. Surprisingly, there are not many cases of tuberculosis found for our

study period, the 10th-12th centuries, the period that we are observing (Roberts and Cox 2003:395). It might be that most sufferers died during the early, acute stages of the disease before the disease became chronic in nature and skeletal lesions could form.

A rough prevalence rate can be calculated in the later medieval period when records were kept of customs such as the 'king's touch' for sufferers of scrofula (tuberculous infection of the lymph node of the neck) (Aufderheide and Rodriguez-Martin 1998:128-9, Cartwrright and Biddiss 2000:136). From the eleventh to the sixteenth century, levels of attendance to the king's touch are constant, but low. From the seventeenth to the nineteenth century, these levels increase rapidly (Ackerknecht 1972:103). This raised frequency would seem to have coincided with a time of geographical shift of population from countryside to town, attracted by the promises of labour in trade and industry. As a result, the percentage of the English population living in an urban context rose from 5% in the sixteenth century to 50% in the nineteenth (Whyte 1999, Scott and Duncan 1998). To feed the population and supply it with milk, cows were kept in rather insalubrious conditions inside city walls, which were ideal for inter- and intra-species contamination (Aufderheide and Rodriguez-Martin 1998:129). This matches the abrupt rise in scrofula in the seventeenth century (*ibid*). Humans were not always better off, as cities burgeoned and expanded everywhere, attracting more people; living conditions were equally insalubrious and overcrowding posed a real threat and offered ideal conditions for aerial transmission of the tubercle bacillus, causing lung infection (Aufderheide and Rodriguez-Martin 1998).

The introduction of a new infection into a human population to which it has no or only limited immunity, can produce a disease that is very acute and, potentially, lethal. This is usually a disease that is already endemic in a different group (Roberts and Manchester 1995). The immigrants, usually young individuals, often still in their early teens, employed as apprentices and servants exposed their limited immunity to a whole range of pathogens, which made them extremely vulnerable to infectious disease (Roberts and Cox 2003). The frequency of diagnosed tuberculosis-related deaths in relation to deaths from all causes in London rose to 15% by the mid-seventeenth century and reached almost twice that figure a century later (Aufderheide and Rodriguez-Martin 1998:129).

Historical studies have shown that although tuberculosis rates are higher in the young adults, both sexes are equally affected in any age cohort (Aufderheide and Rodriguez-Martin 1998:125). This means that in a community disturbed by a tuberculosis epidemic, it is likely that a demographic bias will be observed towards younger adults and sub-adults. Direct progression of the primary infection to death is more common in sub-adults, and especially in infants (Aufderheide and Rodriguez-Martin 1999:132). Until the 1950s the typical age of onset for skeletal tuberculosis was in childhood around the ages of six or seven, but in the last two decades it has been reported in patients of all ages (Ortner and Putschar 1984, Ortner 1999). Although children commonly display multiple skeletal lesions, the speed at which the disease progresses often means that lesions do not have time to form before death, hence children constitute the minority of all patients with skeletal evidence of tuberculosis (Aufderheide and Rodriguez-Martin 1998:132).

The mortality of 35-40% within 5 years after diagnosis, seen in individuals with major pulmonary involvement, was probably as common in medieval times as it was in the eighteenth century (Aufderheide and Rodriguez-Martin 1998:132). Chronic, but active illness of one or more decades' duration can be expected to have affected a significant fraction of infected persons. In such cases, the disease was likely to have had a disabling impact on the lives of such individuals. The alternation of periods of acute infection with those of healing reduced work capacity, bone and joint involvement, as well as breathing difficulties in the pulmonary form of the disease, could have limited physical effort, and the spinal lesions could have cause paralysis. Farmer (1998) examined, through medieval written sources, the plight of 13th century women struck down by disease, most of which were likely from their symptoms to have suffered from tuberculosis, and the effects of the disease on their socio-economic status. To survive, they had to rely on outside help of various forms to create a support network. These included: 1) family and close friends (who could rarely afford it, and the women were often reduced to begging to bring some income); 2) hospitals and charitable institutions (were they could often only stay if they were bed-ridden); 3) if they were professional women, some guilds also offered support; and if lucky, 4) their employers, usually if they lived with them before becoming ill; 5) the

neighbourhood or the parish, although few had the means to support the cripple even if they had wanted to.

Emaciation and the general effects of major chronic illness undoubtedly reduced fertility. Individuals developing tuberculosis at an age when childbearing and child rearing is expected would also have had an affect on demography. Fewer children of tuberculosis sufferers would reach childbearing age than those of individuals remaining free of the disease, and the birth/death equilibrium of a population would have been affected (Davies *et al.* 1999:91).

The analysis of skeletal materials can assist in the assessment of the prevalence of the disease. Skeletons can inform us about the development of tuberculosis and how its prevalence has varied in time, and whether the changes in prevalence are of social, climatic or another origin (Waldron 1999:471). Epidemiologically, it should be a straightforward equation, where the prevalence *P*, a ratio expressed as a percentage, is obtained by dividing the number of cases from the number in the total population (Waldron 1999:471). In the same paper, Waldron highlights the difficulties linked to paleoepidemiology, which do not only apply to tuberculosis, but are true of most diseases observable on the human skeleton.

Two problems cloud this issue: the denominator and the diagnosis. It is customary to consider that presence of a lesion is evidence of the disease, but it is also true that absence of lesions does not necessarily mean evidence of lack of disease, but only of its skeletal manifestations. Traditionally, as we have observed in the non-specific stress indicators chapter 5, anthropologists have simply given the number of cases found over the total number of individuals excavated. This is not a satisfactory method as skeletons are in actual fact rarely complete, and bones needed to establish a diagnosis could be missing. Only using complete skeletons is not an acceptable alternative either as it ignores a large portion of the assemblages, especially in a disease that causes bone destruction. Waldron warns that no summary statistics can be obtained to express the prevalence of the disease in a group (Waldron 1999:472). He suggests that the best way to operate is to give prevalence of affected joints over available/examined joints. This, however, is difficult to accomplish,

especially when working on reports. It requires the creation of special databases, which are not commonly used. Thus, the evidence is rarely presented in reports, which makes comparative work difficult. New guidelines recently published by English Heritage as Mays *et al.* (2002b) have attempted to redress the problem by suggesting standards to be used to record, archive and present information in order to improve access to the data. It will be a while though, until these become standard procedure and until then our access to skeletal data will remain limited. In spite of the problems associated with using the traditional prevalence rate calculations mentioned above, we will have to employ them here to compare the skeletal assemblages.

Another issue raises the representativity of the skeletal remains of the living population. Calculated prevalence rates are likely to be a minimum, or a conservative estimate. Calculating prevalence is further complicated by the fact that not all scholars agree on the terminology used to describe bone lesions in an archaeological context, and when a lesion becomes "tuberculosis" rather than "an indeterminate lesion of possible infectious origin". In addition, reports are severely lacking in the anatomical descriptions they provide of the type of lesions encountered (Ortner 1999:257). This makes the task of inferring prevalence rates from reports very difficult, and only standardisation in the way that data is reported can improve matters. Until such approaches become common place, anthropologists will have to rely on the extensive perusal of reports and archives as was done here to calculate some sort of prevalence rate by extrapolation for observed sites. As diagnostic tools develop (the use of DNA, etc.) and our diagnostic criteria are refined, scholars such as Bennike (1999:516) urge others to constantly re-evaluate the diagnoses established long ago in key collections by re-examining the skeletons.

6.1.2 Disease process

In 1882 the German bacteriologist Robert Koch discovered the bacillus responsible for tuberculosis (Roberts and Manchester 1995:137). We now know that there are several types of this bacillus, which, including the bacillus of leprosy, belong to the genus *Mycobacterium*. Of all these types, the bovine (*M. bovis*) and human (*M. tuberculosis*)

types affect humans. *M. tuberculosis* accounts for the majority of the cases of human tuberculosis today. The two species are biochemically very similar and the difference in pattern of organ involvement is primarily a product of the route of infection (Aufderheide and Rodriguez-Martin 1998:118).

The species *M. bovis* affects cattle, and can be transmitted to humans via drinking milk or, to a lesser extent, eating meat from tuberculous cows. In 1917 about 25% of dairy cattle in Britain were tuberculous (Cartwright and Biddiss 2000:142). Because the infection was transmitted through the ingestion of unpasteurized milk, this bovine type tended to be a disease of childhood. In 1931, 20% of bone and joint tuberculosis in children was caused by *M. bovis* (Griffith 1937 in Aufderheide and Rodriguez-Martin 1998:118). *M. bovis* affects mainly the cervical lymph nodes, but can also produce a gastrointestinal infection (Aufderheide and Rodriguez-Martin 1998:118). In some cases it can also reach the lungs and give similar lesions to *M. tuberculosis* lesions. In England in 1932 only 2.3% of pulmonary tuberculosis was caused by *M. bovis* but 35% of extra-pulmonary sites were due to the same organism (Griffith 1932, *ibid*). This strain is now rare in the Western world as farmers have virtually eliminated the disease from their herds and milk is now pasteurised (Lee 2002:1), but it must have been of significance in the past, especially in rural environments. Although the bovine type of tuberculosis in childhood could be lethal (in some cases) and could lead to deformity, it often only produced temperature and swelling of the glands. Most importantly, it gave immunity against another attack of the bovine type and also protection against the human type, which could be advantageous in urban settings, when exposure might have been repeated (Cartwright and Biddiss 2000:135).

The human type, *M. tuberculosis*, is usually acquired by direct spread from one infected person to a healthy one via bacilli-ridden droplets, causing at first a respiratory infection. The classic site of tuberculosis is the lung, where oxygen concentration is highest, with pulmonary tuberculosis still accounting for the majority of cases today (Cartwright and Biddiss 2000:140, Aufderheide and Rodriguez-Martin 1998:119). The lung alveoli are protected by macrophages, but the complex waxy and lipid coat of the bacillus prevents it

from being digested by the macrophages, which allow it to survive inside them and proliferate freely (Gernaey *et al.* 1999:276; Aufderheide and Rodriguez-Martin 1998:119).

Tuberculosis is a biphasic disease, with a primary infection phase and a re-infection or reactivation phase (Aufderheide and Rodriguez-Martin 1998:119-120). Initial infection (primary TB) is triggered when an individual inhales the bacilli. In 95% of cases the immune system successfully wards off the bacillus (Lee 2002:2), but if the volume of bacilli is large, or the exposure repeated, a lung infection can be initiated and bacterial multiplication follows (Aufderheide and Rodriguez-Martin 1998:120).

The infection and proliferation of the bacilli can be successfully halted by the immune system, but the potential remains for later reactivation of the infection on the event of changes in the lung environment or immunological status (Aufderheide and Rodriguez-Martin 1998:120). Infants and children, the elderly, the malnourished or those already suffering another disease are at greater risk (Lee 2002:2). The outcome for a patient who has contracted TB depends crucially on the balance between the slow but persistent attack of the tubercule bacilli and the success of the immune system in restricting their spread and eliminating them. Variations in the dosage of inhaled organisms, host immune response, nutrition or other factors can impair the host defence sufficiently to permit progression of the primary infection to spread into the internal organs (Aufderheide and Rodriguez-Martin 1998:121).

Secondary infection is either caused by re-activation (a breakdown of the primary lesion that releases the tubercule bacilli) or re-infection by exposure. The most common site of reactivation is the lungs, but since the bacteria might have dispersed during the primary phase of the disease, virtually anywhere in the body might be affected, including bones and joints (Lee 2002:2). About 85% of people who get tuberculosis have the disease in the lungs, 15% have disease outside the lungs and 4% have both (Lee 2002:3). Large-scale tissue breakdown caused by the tubercules infecting airways and blood vessels can be combined with erosion of the cavity lining of a branch of the pulmonary artery, producing haemorrhages with episodes of coughing up blood which are often fatal (Aufderheide and

Rodriguez-Martin 1998:120). At this stage the individual is highly infective to others and his chances of long-term survival low.

6.1.3 Effects of tuberculosis on the skeleton

Primarily the spine, hip and knee joints are those parts of the body most affected the disease (Aufderheide and Rodriguez-Martin 1998:124; Steinbock 1976). It is believed, however, that only *ca.* 5% of individuals with tuberculosis will display skeletal changes (Roberts 2000:152, Aufderheide and Rodriguez-Martin 1998:133), hence the difficulty in assessing the prevalence of the disease in a population and the possible underestimation of the disease in our skeletal material. Modern clinical reports indicate that skeletal tuberculosis is observed in about 1% of all patients with tuberculosis, however in the pre-antibiotic era, the incidence of skeletal involvement averaged 5-7% (Zimmerman and Kelly 1982, Steinbock 1976, both in Aufderheide and Rodriguez-Martin 1998:133).

The archaeological diagnosis of skeletal tuberculosis is not easy, and the task is further complicated when only dry bones are present. Because the diagnosis is difficult, the chance for error is increased. As a result, researchers have often only used a Pott's spine to diagnose the disease as other lesions, such as the involvement of a joint, can be caused by other diseases (Aufderheide and Rodriguez-Martin 1998:133). However, the lesions and their distribution can help to formulate a diagnosis. Buikstra (1976) suggest the following parameters to diagnose the disease in a skeletal population:

- Lesion morphology. Tuberculosis is characterised predominantly by destruction of the skeletal tissue, appearing as a pattern of resorptive lesions with little evidence of proliferative, perifocal reactive changes. Healed areas should show some remodelling. The lesion must be primarily or exclusively a lytic process with concave, smooth-walled reaction areas that are oval, ranging from 5 to 32 mm diameter in vertebral and long bone articular areas, but less than 3 mm in rib and non-articular surfaces.
- Lesion location. Soft tissue involvement of neighbouring bone is common. Joint structure might be preserved, but infection through the perforation of the metaphyseal abscess will commonly lead to severe anatomic disruption or ankylosis.

- Extra-vertebral location. In long bones the process is localysed in the epiphyses or the metaphyses. Because the bacillus can travel through the blood (hematogenous transmission), it is particularly attracted to areas of hematopoietic marrow (trabecular bone) rather than the cortex or medullary cavity of the diaphysis, and this explains the frequency of involvement of the spine at all ages.

a) Involvement of the spine

More than 40% of skeletal tuberculous lesions involve the spine (Aufderheide and Rodriguez-Martin 1998:121). The trabecular bone and the high oxygen tension of the arterial blood rich vertebrae attract the bacteria. In 80% of cases, the foci occur on the anterior aspect of the vertebral body (Westermark and Forssman 1938:213) (see plate A photo 3). Less commonly, the posterior part of the vertebral body can be affected, which can lead to dysfunction and even paralysis (Aufderheide and Rodriguez-Martin 1998:123). The focus' erosive nature causes the intervertebral disk to herniate through the cartilage into the vertebral body with resulting narrowing of the affected vertebral disc space (Aufderheide and Rodriguez-Martin 1998:122). The anterior longitudinal ligament slows the progress of the abscess, which develops around the disk and vertically. The pressure against the ligament seems enough to cause localized bone resorbtion of a spherical or oval shape of the vertebral body (Aufderheide and Rodriguez-Martin 1998:122), visible radiologically as a 'gouge defect' and what physical anthropologists describe as a 'scalloped' appearance (see plate A photo 2a and 2b). Eventually the abscess may reach the next vertebra, also producing a scalloped appearance where the anterior vertebrae have been eroded. Usually two to four vertebrae are involved (Roberts and Manchester 1995:138). In some cases the abscess may pierce the ligament and extend into the paravertebral musculature such as the psoas muscle in the pelvis.

The spread of the abscesses in a vertebra, together with bone necrosis caused by lack of vascularisation, will eventually lead to the destruction of the body and its collapse, causing both shortening of the trunk and anterior bending of the spine above the collapsed vertebra (kyphosis). The posterior part of the vertebrae is usually intact (Aufderheide and Rodriguez-Martin 1998:122-3) (see plate A photo 1). This deformity is called Pott's

disease. A Pott's spine can appear at all ages, but peak incidence is usually cited at 20-30 years (Aufderheide and Rodriguez-Martin 1998:135). Commonly, only two or three vertebrae are affected, rendering the angulation of the kyphotic deformity very acute, especially in the thoracic spine. If more vertebrae have collapsed, this tends to produce a more rounded, obtuse angulation. This spinal deformity is then usually consolidated with ossification. In spite of the gross spinal deformity, paraplegia only occurs in 10% of cases (Aufderheide and Rodriguez-Martin 1998:123). The medical literature reports a 50% mortality rate after five years if the patient is left untreated, half of which is often caused by tuberculous infection of tissues other then bone (*ibid*). Such a spinal deformity will also reduce lung capacity and increase the likelihood of respiratory malfunction (Aufderheide and Rodriguez-Martin 1998:132). A third to a half of patients with skeletal tuberculosis vertebritis would undergo spontaneous healing in favourable conditions of nutrition, socio-economic factors and hygiene.

When only skeletal material is at hand, diagnosing tuberculosis can be difficult. Non-spinal lesions are often not pathognomic. Aufderheide and Rodriguez-Martin (1998:133) suggest that although all bony lesions must be taken into account, Pott's disease must be the main determinant in diagnosing tuberculosis. It must be borne in mind, however, that several pathological processes can result in destructive spinal lesions, such as brucellosis, syphilis, aneurysms, tumors and fractures (Ortner 1999:256-7, Ortner and Putschar 1985:176). Differential diagnosis is often impossible. According to Ortner (1999:257), the best diagnostic features for tuberculosis of the spine are: 1) kyphosis; 2) monofocal versus polyfocal involvement of the spine; 3) the amount of reactive bone formation; and 4) involvement of the transverse and spineous processes. Brucellosis for example often has more than one focus and affects the vertebral arches (Ortner 1999:257). In fractures, only one vertebra is usually affected and there is less destruction of the body. In ostemyelitis, the angulated gibbus (hump) is unusual (Ortner and Putschar 1985:141).

b) Joint involvement

About 90% of tuberculous skeletal lesions involve a joint and in 85% of cases, only one joint is affected (Aufderheide and Rodriguez-Martin 1998:124,138). Bilateral involvement

of the same joint is rare (Jaffe 1972:953). In joints, bone destruction is usually substantial and repair minimal (Ortner and Putschar 1985:143). Bones are most commonly infected by hematogenous dissemination of the bacilli (Ortner and Putschar 1985:141). The bacilli are deposited in the trabecular bone, located in the metaphysis in long bones. Because the active epiphyseal growth plate blocks the passage of the vessels, the source of vascularisation (which is the site where the bacilli could be deposited) of the metaphysis varies with age according to metaphyseal fusion (Aufderheide and Rodriguez-Martin 1998:124, 137). The destruction of the joint is similar to that of osteoarthritis, with the joint crumbling through cancellous bone destruction and ensuing bone necrosis if blood vessels are injured. The process is so destructive to joint structures that it often results in complete obliteration of the joint with ankylosis. If untreated, the persistence of the infection, frequently with draining sinuses, leads to a chronic, disabling condition (Aufderheide and Rodriguez-Martin 1998:138) (see plate B photo 1).

The hip represents 20% of cases with skeletal involvement, making it the second most frequent skeletal lesion after vertebral involvement. 80% of modern patients with hip lesions are under the age of 25 years (Schinz *et al.* 1953; Ortner and Putschar 1985:150). The infection spreads through hematogenous dissemination or by direct extension from an adjacent paravertebral or pelvic abscess (Aufderheide and Rodriguez-Martin 1998:139). The destruction seems more localised in the acetabulum, although the head, neck and trochanter of the femur can be affected, especially in the later stages of the disease. The destruction can lead to dislocation, and bony ankylosis is a common feature.

The knee is involved in 16% of cases of skeletal tuberculosis (Aufderheide and Rodriguez-Martin 1998:139) (see plate B photo 1). There is some disagreement regarding the prevalence of tuberculosis in the knee in adults and children, where scholars such as Turek (1982) estimate adults to be more affected while Ortner and Putschar (1985:154) regard it as purely sub-adult phenomenon. The lesion is initiated in the synovium in the majority of cases but it can also originate from the metaphysis. Both are the product of a primary or simultaneous hematogenous osseous focus (Ortner and Putschar 1985:154-5).

The following joint involvements, although not rare, are not as common as the spine, hip and knee, and their prevalence rates are around 5% each (Aufderheide and Rodriguez-Martin 1998:139-40). The tibiotalar joint (ankle) is more commonly affected in children and the talar bones (feet) in adults (Ortner and Putschar 1985:155). The sacro-iliac joint involvement is often bilateral and is usually associated with spinal involvement. It presents destructive lesions and the presence of abscesses. Prolonged survival almost always leads to bony ankylosis, often with asymmetrical deformities (Ortner and Putschar 1985:149). The elbow is the most frequent joint tuberculosis in the upper skeleton, starting as a focus in the distal humerus and is more prevalent in individuals up to 20 years (Ortner and Putschar 1985:157-8). Other joint involvements are less common and include the shoulder (more prevalent in adults) and the wrist.

c) Rib involvement.

There seems to be increasing evidence to suggest that the localised plaques of subperiosteal new bone deposition situated on the visceral surface of ribs are indicative of tuberculosis, although it is still the subject of some controversy (Roberts 1999:313).

Tuberculous lesions in the ribs occurs in 1-8% of total cases where the skeletal system is involved (Ortner and Putschar 1985:162) although individuals with chronic tuberculosis tend not to have extrapulmonary lesions (Kelley and Micozzi 1984:386). Rib lesions can be found in two forms: diffuse periostitis and less frequently, localised abscess (Kelley and Micozzi 1984:381). They may arise via three different pathways (Mays *et al.* 2002a:27):

1) by extension from spinal lesions in which case the rib lesions are near the head and neck of the rib. The costal head and neck are not usually affected.
2) by hematogenous spread from a soft tissue focus which will produce lytic changes with little or no reactive bone regeneration. These lesions emerge from the trabecular bone of the costo-chondral junction, causing an enlargement of the rib and in some cases producing marked destruction.
3) by direct extension from subjacent disease in the lungs, pleura or chest-wall lymphatic system.

Tuberculous pleuritis, often with empyema (pleural effusion containing pus) formation is an extremely common part of active pulmonary tuberculosis (Aufderheide and Rodriguez-Martin 1998:120). The primary infection can disseminate from the lung tissue through the pleura to the visceral surface of the ribs where infection can produce an inflammatory response on bone and may stimulate reactive new bone formation (Roberts 1999:312). This periostitis is restricted to the internal side of the ribs and can involve several adjacent ribs (see plate B photo 3, plate C photo 2; plate D photo 5).

Wakely *et al.* (1991) looked at rib lesions microscopically using a scanning electron microscope. This showed that the lesion was clearly separate from the original rib cortex, but if the new bone formation was closer to the head of the rib, the lesion sometimes blended with the cortex. Some ribs displayed just one layer of new bone, others multiple layers, in a gallery-like formation which the authors believed was suggestive of repetitive deposition of bone in consecutive layers. The lesions had a spongy appearance with many vascular grooves, holes and channels. The periosteum has deep cellular layers that can become activated by trauma. The periosteum is highly vascular with blood vessels feeding the bone. An inflammatory reaction of the lung or pleura could stimulate osteogenesis, with increased vascularity of the periosteum with active deposition of new bone around and over the vascular channels, eventually roofing them completely and creating a new external surface (see plate D photo 6). When the patient recovers, remodelling might occur but the new bone is not resorbed and instead will be eventually integrated to the cortex. If the inflammation of the underlying soft tissues is chronic, then multiple layers will be created for each episode of ill health, causing thickening of the bone (Wakely *et al.* 1991:186).

Kelley and Najjar (1980) analysed skeletal lesions from 26 individuals of the Hamman-Todd Collection in Cleveland, Ohio (over 3,000 individuals assembled between 1893 and 1938) which had suffered from well-documented (by medical records and autopsies) tuberculosis. Of the 26 individuals, 19 of them had lesions clustering in and near the thorax (spine, ribs, sternum and clavicle), and, overall, rib involvement came second in frequency after the vertebrae. Many of the individuals with rib lesions also had vertebral lesions. In addition, Kelley and Micozzi (1984:382-3), who also studied the Hamman-Todd collection,

felt that the reactive periostitis occuring on the visceral aspect of the ribs is distinctive enough to be predictive of the disease when found in skeletons. They found that up to 9% of individuals who had died of tuberculosis exhibited periosteal lesions, whereas it occurred in only 0.2% of those who had died of pneumonia. Baker (1999:306) proposed that the pattern of rib and vertebral pathology was likely to represent an early stage of skeletal tuberculosis.

The use of periostitis on the ribs as a diagnostic feature of tuberculosis is still the subject of debate. Roberts (1999:312) suggested that the reason rib lesions were so 'unpopular' among scholars is because they are not always noticeable radiographically in living patients. They are also easy to miss in skeletal examination as time pressures do not always permit detailed scrutiny of every rib fragment. Many scholars also claim that any infectious conditions that involved the lungs could create these lesions (e.g. Cremin 1999). The finds of Roberts *et al.* (1994) would concur with such an argument. When they analysed individuals in the Terry collection in Washington DC (over 1,700 individuals collected in the 1920s) with well–documented medical histories, they found that although 62% of individuals who had died of tuberculosis displayed rib lesion, 22% of individuals who had died of non-tubercular pulmonary disease (e.g. pneumonia, pleurisy) also had rib lesions. It has been argued, however, that in the past and without modern medicine, few people would have survived long enough to produce chronic periosteal reaction from diseases such as acute pneumonia (Auderheide and Rodriguez-Martin 1998:124). It is therefore likely that, in historical populations, tuberculosis and other chronic chest infections mostly caused rib lesions.

In an attempt to investigate the link between rib lesions and tuberculosis, Mays *et al.* (2002a) used polymerase chain reaction (PCR) assays aimed at detecting traces of DNA from infecting microorganisms of the *M. Tuberculosis* complex. Seven individuals from medieval Wharram Percy (Yorkshire Wolds) with proliferative lesions on the ribs along with a group of age- and sex-matched control skeletons displaying no bone lesions were analysed. They reported that "biomolecular analysis indicated that PCR-positives [samples in which the *M. Tuberculosis* genome is found] were no more frequent in pathological

cases than in controls, and failed to demonstrate any convincing general association between visceral surface rib lesions and the presence of *M. tuberculosis* complex DNA" (Mays *et al.* 2002a:31). Two individuals displaying rib lesions and PCR-negative were thought to have suffered from cancer and hypertrophic osteoarthropathy (see below 6.2). It was unlikely that the mycobacterium had not survived in the bone in Wharram Percy as nine individuals exhibiting classic spinal and joint bone lesions had proved to have unambiguous indications of the presence of the *M. tuberculosis* complex DNA previously (Mays *et al.* 2001:303).

Until more studies are conducted and a consensus is reached, visceral rib lesions can only be considered non-specific indicators of intrathoracic infection. It is accepted by most scholars that even though the lesions are not pathognomonic of the disease, they are most likely, although not exclusively, to be of tubercular origin, and can support differential diagnosis for vertebral lesions (Roberts 1999:315; Baker 1999:301, 305-6; Ortner 1999:257; Mays *et al.* 2002a:35; Aufderheide and Rodriguez-Martin 1998:124).

6.2 Hypertrophic osteoarthropathy (HOA)

Ortner and Putschar (1985:245) describe hypertrophic osteoarthropathy (HOA) as a "somewhat obscure affliction of the skeleton" which presents itself as diffuse periosteal lesions throughout the appendicular skeleton, bilaterally distributed, with no osteomyelitis or lytic lesions (see plate C). HOA is classically related to intrathoracic pathology. The most common causes of HOA are cancer and chronic infection, specifically tuberculosis (Rothschild and Rothschild 1999:296-7). In the early part of the 20th century, tuberculosis was considered the most common cause of HOA. Rothschild and Rothschild's work on the Hamman-Todd, Grant and Terry collections validated this. They found that individuals with periosteal reaction characteristic of HOA suffered primarily from tuberculosis (20%) and non-tubercular chronic pulmonary disease (17%). Other diseases included endocarditis (16%), and metastatic tumours (12%) (Rothschild and Rothschild 1998:2222). By the 1950s, however, the link between tuberculosis and HOA was attenuated and Engels *et al.* in 1980 famously declared that HOA was no longer combined with tuberculosis. However,

Pineda *et al.* (1987:777), working on living patients with cardiopulmonary disorders (primary HOA, cyanotic congenital heart disease and lung cancer), found HOA to be a good indicator of chronic pulmonary disease, since tubercular and nontubercular pulmonary disease represented 90% of cases studied. It is therefore justified to use HOA as an indicator of chronic pulmonary disease, especially when studying historical populations.

HOA may be classified as primary or secondary. In primary HOA there is no underlying disease. Only 3 to 5% of all cases of hypertrophic osteoarhtopathies fall into this category and are usually accompanied by skin lesions (Aufderheide and Rodriguez-Martin 1998:91). The secondary form, also called Marie-Bamberger disease, was originally called pulmonary hypertrophic osteoarthropathy but ceased to be called so when it was realised that extrapulmonary conditions can also cause this condition. Today, secondary HOA is caused by a variety of serious thoraco-abdominal conditions, such as bronchogenic carcinoma, congenital cyanotic heart disease, pulmonary fibrosis, tuberculosis, empyema, etc. In children the lesions are usually related to congenital intrathoracic lesions (Pineda *et al.* 1990:626, Aufderheide and Rodriguez-Martin 1998:91). The lesions are not indicative of infection of those specific bones. The periosteal manifestations of HOA seem to appear principally dependent not on the primary or secondary nature of the disease, but rather on its duration and the age of the patient at onset (Pineda *et al.* 1987:776-7).

Primary and secondary HOA display similar changes. The periosteal proliferation is symmetric in distribution, being more prominent at the distal parts of the lower extremities (Pineda *et al.* 1987:777) and usually thickest mid-diaphysis in long tubular bones. It consists of mono-layered, linear periostitis that increases the circumference of the affected bone without otherwise altering its shape. As the disease progresses, the periostitis becomes more prominent and presents a multi-layered appearance, with increased thickness and irregular surface. As it is not an inflammatory arthropathy, the tendon insertions, the joint spaces and the surfaces are not affected (Rothschild and Rothschild 1999:297, Ortner and Putschar 1985:246) (see plate C).

The periostitis is initiated by a lymphocytic infiltration of the periosteum and it is believed that altered neurocirculatory reflexes are probably the underlying cause (Ortner and Putschar 1985:246). The new bone is fibrous at first, then remodelled into lamellar bone. In a cross-section, the new bone appears separated from the old cortex by a thin, fibrous layer. In later stages the old cortex shows resorption with widening of the Haversian canals and sometimes of the medullary cavity (Ortner and Putschar 1985:246).

HOA is an orderly evolving process that, depending on the chronicity and the underlying stimuli, progresses in three dimensions in: 1) the number of bones affected, 2) the area of involvement of a given bone and 3) in the shape of the periostitis (Pineda *et al.* 1990:776-7). Thus in mild and early cases, few bones are affected (usually tibiae and fibulae) and the periosteal bone apposition is limited to the diaphysis with a monolayer configuration. Advanced cases are characterised by involvement of practically all tubular bones. In addition to the diaphyses, the metaphyses and epiphyses are affected and the periostitis takes an irregular shape.

Tibial involvement occurs in 98-100% of cases and seems to be universal in tuberculosis-related HOA. The lesions are symmetrical in 97% of cases, with the radii infected if the tibiae are not (Rothschild and Rothschild 1999:297). The other most common sites are the ulna and fibula. The femur, humerus, metatarsals and phalanges are much less frequently involved, and only in the most advanced cases are the clavicles, ribs, scapula, pelvis, spine and talar bones affected (Aufderheide and Rodriguez-Martin 1998:91). Localisation and diffuseness of the lesion on a bone do not seem to correlate with the severity of the disease (Rothschild and Rothschild 1999:297). Pineda *et al.* (1987:777), working from a radiological perspective on living patients, found a direct relationship between the duration of the disease and its morphology as well as the extent of the radiographic abnormalities, the disease duration and the number of affected bones.

Differential diagnoses include principally chronic venous stasis, hypervitaminosis A, DISH, periostitis deformans and non-specific periostitis of the lower limbs. However, in HOA, the surface appearance, symmetry and localisation of the lesions distinguish it from

treponemal diseases and other diseases with periosteal manifestations (Rothschild and Rothschild 1998:2226-7).

HOA was used in this project as an indicator of chronic pulmonary disease. This will be done in relationship with other chronic chest diseases such as tuberculosis. The disease has not been widely reported in the literature and osteological reports, and it is likely that this is caused by an inability or unwillingness from human bones specialists to report it (Mays, pers. com.). The prevalence rates presented here are therefore likely to be an underestimate of the true frequency of the lesions in skeletal assemblages.

6.3. Future directions for the diagnosis of tuberculosis: nucleic acids and mycolic acids

DNA fingerprinting has now been widely used for confirmation of disease in human remains, sparking considerable interest not only in the field of paleopathology as molecular techniques have the potential for being more specific than observations of structural changes. DNA seems to survive reasonably well in bone. DNA from the mycobacterium tuberculosis complex has been isolated and identified in many specimens since 1992 by using the polymerase chain reaction (PCR) to amplify the traces of DNA (Spigelman and Donoghue 1999:353).

Current studies rely on the identification of the IS6110f sequence for diagnosis of *M. tuberculosis*. IS6110 is a repetitive insertion sequence that is usually present 6-20 times in the MTB genome. Certain regions of IS6110 are reported to be species-specific for MTB complex bacteria, but there are suggestions that this might not always be the case and that there might be a 3% rate of false-positives (Mays *et al.* 2001). IS6110 identification has also been questioned as the amplification steps required for PCR may be too sensitive and does not allow the disease-state to be recognised from superficial infection.

In a significant study, Mays *et al.* (2001) analysed some samples from Wharram Percy, a deserted medieval village in the Yorkshire Wolds dating to the 10th-16th centuries and composed of 687 articulated skeletons. Nine individuals (all adults) showed skeletal lesions

attributable to tuberculosis (spinal lesions). Additionally, some cattle showing periosteal lesions caused by an infection were analysed, although it is unclear how specific lesions are in cows. As the bony lesions caused by *M. tuberculosis* and *M. bovis* are anatomically similar (Ortner 1999:255), Mays *et al.* attempted to differentiate the two species. They were confident they would find DNA evidence of the disease in spite of the bones histologically showing some extensive diagenetic alterations. Indeed, it is believed that the nature of the mycobacteria cell wall aids its survival, even in poor quality bone microstructure (Spigelman and Donoghue 1999:354-5). Two individuals with no skeletal lesions were assumed to be free of the disease and were used as controls. None of the cattle showed presence of the disease but the analyses confirmed the presence of *M. tuberculosis* complex in all nine individuals, which means that tuberculosis is reliably diagnosed osteologically.

All nine individuals seemed to be affected by *M. tuberculosis* rather than *M. bovis*. Cattle formed an important part of the economy at Wharram Percy and were the most likely source of meat. The husbandry methods of the site would have suggested close interaction between humans and animals so it is surprising that *M. Bovis* caused no skeletal cases of tuberculosis (although there may have been some soft tissue lesions). Whilst Mays *et al.* suggested that the herds might have been free of the disease, the periostitis on the ribs does suggest some chronic chest disease. *M. Tuberculosis* is usually prominent in densely populated groups, but this was not the case at Wharram Percy, which was sparsely populated (1-6 persons per square kilometer Mays *et al.* 2001:308), even by medieval standards. This possibly suggests that families might have lived at close quarters, even in a small settlement. The results at Wharram Percy prove that tuberculosis could be maintained, even in scattered populations, so that the disease was endemic in rural populations in that area at that time. Large urban centres, however, would act as reservoirs of the disease, so in all probability the diseases depended on interaction between Wharram Percy and other populations. Earlier research had suggested emigration from Wharram Percy to urban centres like York (Mays 1997). There is also evidence of trade in the form of pottery and marine foods, indicating that Wharram Percy was not isolated, but enjoyed social and economic links with other settlements. It may be that in this part of the country

continuous varied contact might have maintained the level of infection person to person, rather than animal to person.

Mycolic acids have been recently investigated as an alternative to DNA analysis. Mycolic acids cannot be amplified, therefore their presence must signify frequency in the original population (Gernaey *et al.* 1999:276). The most complex study is the Newcastle Infirmary, excavated in 1996-1997 and dating to 1753-1845. Infirmary records showed that 27% of the cemetery population had tuberculosis at death, however, only 0.95% individuals displayed a Pott's spine. Rib samples from 21 individuals (10% of the population) were taken for analysis, as well as chest cavity and distal soil samples.

The most characteristic feature of the mycobacteria is their highly complex lipid-rich cell walls. Mycolic acid is a major component of the mycobacterial cell wall, contributing to its thickness. Its unusual long-chain compounds have a good preservation potential (Gernaey *et al.* 1999), and mycolic acids have been found in a specimen over 1,000 years old. The mycolic acids were extracted from the ribs and analysed using high performance liquid chromatography (HPLC). Using this method, 5/21 ribs showed the presence of mycolic acids that were characteristic of *M. Tuberculosis*, correlating to the recorded incidence of 27.1% at the Infirmary (Gernaey *et al.* 1999:279). The soil samples were all negative.

This study established the use of mycolic acids to determine presence and prevalence of tuberculosis in archaeological specimens as an alternative to DNA. Improvements in the technique and its application to leprosy are presently being extensively researched (started in 2003) at the University of Salford by Angela Gernaey using Leverhume funding and should prove to be of great interest to the future of paleopathology.

These new biochemical methods are very exciting and definitely seem to be the way forward to establish prevalence rates of diseases in the past. However, in the case of nucleic acid there is still a major issue of contamination and DNA decay, and the mycolic acids analysis, though certainly promising, is not yet an established method. There is also a major

issue of cost involved, which means that it will be a long time until all collections are routinely analysed biochemically, and only if sampling becomes authorised by museums.

Until then, an experienced set of eyes will have to be the only tool at our disposition and multiple diagnostic criteria using the spine, ribs, HOA and joints will have to be used to maximise specificity.

6.4 Results: description of the lesions for chronic chest infection

Data for tuberculosis will be amalgamated to the data obtained for chronic chest infections (i.e. HOA and rib lesions) and were used in conjunction to assess the prevalence rates for chronic chest infection. Below is a description of the lesions found in each individual from the selected sites. For greater clarity, as skeletons are identified as site code + skeleton number, skeletons referred to in this chapter will be described, for example, as Wing S14 (S for skeleton). (Plates illustrating some of the lesions can be found in the appendix).

Site	*Analysis of the lesions*
Wing	Analysis Tatham
Cherbourg	Analysis Tatham
Rouen	Analysis Tatham
Fishergate	As described by Stroud 1993:221-222
Ipswich	As described by Mays, unpublished:30-35
Raunds	As described by Powell 1996:120
Arras	As described by Blondiaux, unpublished
Lund	As described by Arcini 1999
Löddkökopinge	As described by Persson et al 1984:93-94

Table 6.1. Source of data for chronic chest infection investigation.

Cherbourg and St Nicholas Shambles were the only sites where no spinal or costal lesions indicative of tuberculosis, have been found. In Cherbourg, however, one individual showed evidence of hypertophic osteoarthropathy. To be included in the study, lesions had to include spinal lesions, rib lesions and/or joint involvement.

6.4.1 Description of the individuals displaying lesions suggesting tuberculosis in the assemblages

Arras

Arras was particularly rich in cases suggesting tuberculosis, especially considering the relatively small size of the assemblage.

S7, a young female, displayed lytic lesions on the internal surface of at least three ribs. There was partial destruction of the bodies of the 3rd and 5th lumbar vertebrae and a complete destruction of the 4th lumbar vertebra. Fusion of the vertebral arches had formed a Pott's spine. There was a lytic lesion on the anterior surface of the first sacra vertebra with periostitis on the left wing of the pelvis and destruction of the auricular surface. On the right pelvis there was periostitis and a lytic lesion with irregular borders. There was also a lytic lesion on the lateral condyle of the left femur, surrounded by periostitis and periosteal lesions on the left tibia.

S17 was a senile female displaying erosion of the bodies of the 5th, 6th and 7th cervical vertebrae and of the 1st, 2nd and 3rd thoracic vertebrae, as well as the last thoracic and lumbar vertebrae.

S25 was a mature male. Five fragments of calcified pleura were found, probably caused by tuberculous pleurisy.

S4 was a mature male. The 2nd and 3rd thoracic vertebrae were fused, as well as the 4th and 5th thoracic vertebrae, with the partial destruction of the four bodies resulting in kyphosis. This is likely to be a Pott's spine.

S51 was an 18-25 year old female, showing partial destruction of the thoraco-lumbar vertebral bodies with scalloping and erosion of the anterior surfaces, as well as the destruction of the surfaces of three vertebrae. There was no ankylosis. A possible differential diagnosis could have been brucellosis, however, her

proximity to the graves of other individuals displaying skeletal lesions of tuberculosis would tend to confirm a tuberculosis diagnosis.

S54 was a mature male with complete destruction of the vertebral bodies of the 7th and 8th thoracic vertebrae and a partial destruction of the vertebral bodies of the 5th and 6th and 9th and 10th thoracic vertebrae. There was no fusion of the vertebral arches, but severe angulation was evident. There was also extensive rib periostitis with the destruction of the posterior extremities matching those of the vertebrae. There was periostitis on the right ulna and radius.

It is interesting to note here that individuals 46, 51 and 54 were buried in neighbouring graves and that morphological analysis had already placed them as being possibly genetically linked. A 16 month old child, with evidence of meningitis of possible tuberculous origin, was also part of this possible family cluster. Four of the individuals in this cluster were positively tested for DNA (as well as spoligotyping) in Chuck Greenblatt and Lev laboratory in the Hadassa University in Jerusalem (Blondiaux, pers. Com.). Blondiaux suggests that this highlights the vulnerability of families if one of their members contracts the disease. Although the sample size is small and the prevalence high, and most probably skewed, this indicates beyond doubt the existence of tuberculosis in Flanders in the 10th–12th centuries.

Fishergate 4

Out of 8 skeletons tentatively diagnosed as tuberculous, two were from period 4. One of the individuals was a 4-6 year old child with severe periosteal lesions on the ribs, giving them a thickened appearance, as well as scalloped lesions. Stroud 1993:222 attributed the severity of the lesions on such a young child to differential immunity and micro-evolution in the disease pattern of infection in the past.

The other skeleton was S6248, a young 18-25 year old male who exhibited extensive destruction of the spine and the ribs, made worse by post-mortem erosion. At least 12 rib fragments displayed severe periosteal reactive lesions,

with the greatest degree of change located towards the posterior end of the ribs. Smooth, scalloped lesions were also apparent, suggesting a lytic erosive process, such as a multifocal abscess, with new bone on the inner aspect developing as the result of pleural infection. The spine was very eroded and incomplete, but the first lumbar vertebra showed signs of ante-mortem destruction of the body. The 11th and 12th thoracic vertebrae displayed considerable disruption of the intervertebral facets, with reactive new bone present on the spineous process of the latter.

Ipswich

Mays (unpubl. pp 30-35) described two skeletons with lesions suggesting tuberculosis.

S459 was a 20 year old male. The body of the 12th thoracic vertebra showed a large lytic defect in the right/anterior part of its inferior surface with the destruction of two-thirds of the centrum was destroyed. The borders of the defect were sclerotic and irregular, with negligible bone regeneration. The trochlear joint surface of the left talus was irregular, with pits and clefts in its anterior part. Similar changes are present on the distal joint surface of the left tibia and in the posterior talus facet of the left calcaneus. A circular erosion, *ca.* 7mm diameter and 3mm deep, was present on the left superior articular facet of the axis vertebra and a similar one, though smaller (2mm diameter) perforated the right articular facet of the axis.

S2127 was a male aged 21-24 years. The lower part of the spine saw the most destruction. The superior surface of the first sacral segment was almost completely destroyed. The borders of the erosion had a pitted appearance but were not sclerotic, and there was a negligible amount of bone regeneration. There was, however, some sub-periosteal new bone formation on the anterior surfaces of the first two sacral segments. There was erosion with a pitted appearance and negligible bony regeneration on the iliac face of the right sacro-iliac joint too (the left sacro-iliac joint was normal). The lumbar vertebrae were also damaged. The left/anterior side of the body of the 5th lumbar vertebra showed a scalloped erosion, the margins of which were slightly sclerotic. There was a slight

deposition of sub-periosteal new bone on the anterior part of the centrum of this vertebra and on the inferior part of the neural arch. There was also slight sclerosis around the periphery of the superior surface of the body of the 5th, and inferior surface of the body of the 4th lumbar vertebrae. There was a shallow, pitted erosion on the anterior margin of the superior surface of the body of the 3rd lumbar vertebra. The left ulna displayed a lytic defect beneath the proximal joint surface. The defect pierced the bone transversely and there were some perforations in the joint surface itself. Bone regeneration was negligible. There were slight lytic changes and pitting in the margins of the proximal joint surface of the left radius. The left humerus showed two lytic areas immediately proximal to the distal joint surface on the anterior aspect of the bone. There was a slight reactive new bone formation between the two lytic areas and in the olecranon fossa.

Rouen (See plates A and B in the appendix for an illustration of the lesions)

Many cases of tuberculosis were present in Rouen, which also one of the bigger sites.

S2320 was a male aged 45 years and over, presenting a destructive lesion in the knee. The infectious involvement of the left knee was extensive, with complete joint destruction and consolidation with ankylosis at a 45° angle (sitting position). There was new bone deposition on the distal end of the right tibia and fibula, and on the left tibia. The bodies of the lumbar vertebrae had all collapsed and the spineous processed had fused with a resultant Pott's spine. There was slight periostitis on the ribs.

S4170 was a 25-35 year old male presenting lytic lesions that had destroyed part of the 1st and 2nd sacral vertbrae. New bone formation could also be observed. Spongy, reactive bone was situated over the anterior surface of the thoracic vertebral bodies. Periosteal lesions were distributed bilaterally and symmetrically over the femora, fibulae, humeri, ulnae, patellae, metacarpals and carpal bones, metatarsal and tarsal bones as well as some phalanges. The lesions were at their most severe on the tibiae. There were no lesions on the scapulae or claviculae.

S4547 was a 25-35 year old female presenting scalloped lesions situated on the anterior aspects of the mid to lower thoracic vertebrae. The margins of the lesions did not present a necrotic appearance nor bone regeneration. The ribs also displayed periosteal lesions.

S4571 was an 18-25 year old male displaying spinal lesions in the form of porosity on the anterior aspect of the mid-lower thoracic vertebrae. Periostitis was also present on the tibiae, which had a swollen appearance. Additionally, there were clear new bone appositions endo- and ecto- cranially on the skull vault.

S5014 was a female aged 45 and over, whose spine from the first cervical vertebra to the 12th thoracic vertebra was complete and well-preserved, showing no lesions or abnormalities. Despite its apparent appearance of good health the spine was conspicuous by its lack of osteophytes, or any other expected sign of age and activity-related changes in the spine in spite of the more advanced age of the individual. Only one lumbar vertebra was present and showed extensive destruction. The inferior surface of the body of the lumbar vertebra had a normal appearance, matching the other vertebrae. The superior surface, however, displayed much erosion caused by a lytic process, presenting an irregular, yet smooth scalloped appearance with remaining bone bridges. The height of the vertebra was reduced by 75% with a very irregular surface. There were no ribs available for analysis. Unfortunately, the lumbar vertebra was the only one to be present in the lower spine. The missing vertebrae could have been lost post-mortem due to their excessive fragile state caused by the disease process and could have been too fragmented to be retrieved during excavation. The smooth appearance of the lesion suggests that the erosive action of the lytic process was slow, and that perhaps the individual had been subject to the illness for a long period of time. It is purely conjecture, but it is possible that the woman had been rendered severely disabled by the disease, maybe with some paralysis, which

would explain the lack of activity-related changes in her spine. The surfaces of the long bones were smooth and did not suggest heavy use of the muscles.

Many individuals displayed lesions that could have been caused by tuberculosis but were not specific enough to be included in the probable TB/HOA group.

S5598B was a female aged 45 years and over, showing anterior destruction of the vertebrae. S5651 was a 35-45 year old male displaying lesions on the superior surface of the 11th and 12th thoracic vertebrae with slight flattening anteriorly. S5654, a male of indeterminate age, displayed substantial periostitis on both tibiae and fibulae, with some destruction in the surface of the vertebral bodies. S4520, an adult of indeterminate sex exhibited new bone formation on the external illiac wings of the pelvis, both femora and proximal tibiae. S4492 was a 35-45 year old male displaying new woven bone formation covering parts of the humerus, the right femur, which also showed evidence for hypervascularisation, the sacrum and the pelvis.

S5015A was a young 18-25 year old male displaying periosteal lesions on both tibiae and fibulae, however, an element of trauma was possible as the right proximal head of the fibula had been destroyed and had a porous end. Despite the young age of this individual, its spine displayed osseous changes normally more associated with age and activity related changes common in the older individuals. The vertebral bodies were pitted and showed extensive degeneration. The nutrient foramina on the anterior surface were enlarged with some flattening. The bodies of the lower thoracic vertebrae had also begun to fuse.

Raunds

There was only one individual in Raunds displaying lesions suggestive of tuberculosis.

S5218 was a 17-25 year old male showing evidence for severe infection. Keith Manchester, assisting Faye Powell with her diagnosis of the pathologies for the human bones report of the site, suggested that the individual had had osteomyelitis as a child in the left humerus and right femur and had later in life

developed tuberculosis. The osteitis had destroyed the head of the left humerus and shortened the shaft (but there was no atrophy). The right femur was much shortened and showed evidence of atrophy through lack of use. The knee also showed much destruction with cystic formation and the fusion of the patella. The right fibula showed erosion of the proximal articular surface. The right foot displayed marked degeneration of all the bony material. There was a complete fusion of the 3rd and 4th cervical vertebrae with a slight skewness to the left side. The 11th and 12th thoracic vertebrae showed marked degeneration of their centra and intervertebral facets. The 11th thoracic vertebra was wedged-shaped due to collapsing of the centrum. The adjoining surface of the 10th and 12th centra showed cyst formation, indicating degeneration of the intervertebral cartilage. The non-articular surfaces also displayed reactive new bone formation and ankylosis had begun.

Lund

Arcini (1999:121) only diagnosed tuberculosis on the basis of the presence of a Pott's spine and therefore only one individual was identified.

One individual from the period 1050-1100 fulfilled this criterion. A female aged 20-23 years old displayed clear evidence of a Pott's spine. The vertebrae between the 3rd and the 10th thoracic vertebrae had collapsed, with near complete destruction of the vertebral bodies and subsequent ankylosis with angulation.

A number of cases of septic arthritis and spondylitis (septic arthritis in the spine) were also recorded. The details in the appearance of the lesions were not given in the report, but the frequencies of the lesions were given as follows. The number of adult individuals with at least one large joint affected by septic arthritis is 9/1104 individuals, of which 5/352 are female and 4/468 are male. The frequency of individuals with spondylitis in the spine is 7/1104, of which 3/352 are female and 4/468 are male. The frequency for males with both septic arthritis in at least one large joint and spondylitis in the spine is in total 16/1104. For the purposes of this chapter, the frequencies displayed here will be used as indicative of tuberculous lesions.

Löddeköpinge

Löddeköpinge displayed more cases than Lund.

S1156 was a 45-55 year old male with destruction of the lower spine. The 4th and 5th lumbar vertebrae and part of the first sacral vertebra were fused. There was extensive spongy and reactive new bone formation of the anterior part of the vertebrae and the anterior aspect of the first sacral vertebral arches. There was evidence of destruction. The superior surface of the 4th lumbar vertebra displayed an erosive scalloped lytic lesion surrounded by reactive new bone formation.

S99 was an elderly female with ankylosed 10th to 12th thoracic vertebrae. Extensive periosteal lesions could also be observed on the other lumbar vertebrae. S329 was a 40-50 year old male with complete destruction of the ankle. In place of the joint, the surface showed smooth, scalloped lytic erosions. Extensive periosteal lesions could also be observed directly above the joint on the tibia.

Two additional skeletons, unfortunately incomplete, display evidence of septic arthritis that may have been caused by tuberculosis.

S57 was a 50-60 year old female. A very fragmented skeleton nevertheless revealed extensive destruction of the left shoulder and knee. The bone tissue in the glenoid fossa and the humeral head was deformed and broken up. Destruction was also present in the knee joint with destruction of the distal femur and proximal tibia. The fragmentary nature of the skeleton prevented the recording of other lesions.

S500B was a male aged 40-50 years was badly preserved through what is believed to have been ante-mortem demineralisation. Many joints showed pathological deformation, especially the knee, which showed destruction of the distal femur and proximal tibia and the fusion of the patella to the femur.

Persson and Persson (1984) do not conclusively establish tuberculosis to have been the cause of the observed changes in the two skeletons but suggest that it was likely to have been the case. Aufderferheide and Rodriguez-Martin (1988:178) describe septic arthritis as the destruction of a joint caused by bacterial infection. The hip and the knee are involved in 70% cases, followed by the shoulder, ankle, elbow and wrist. Children and debilitated older adults are more susceptible to it. Septic arthritis is usually less destructive and more rapid than tuberculosis (*ibid* p.141). It is also an uncommon archaeological find (Roberts and Manchester 1995:115). It is therefore more likely that we are observing here joint tuberculosis.

6.4.2 Description of the individual displaying lesions suggesting hypertrophic osteoarthopathy in the assemblages

Wing. (See plates C, D and E in the appendix for illustration of the lesions).
Three individuals showed symmetrically distributed subperiosteal new bone deposits in the upper and lower limbs suggestive of hypertrophic osteoarthropathy, and similar periosteal reactions on the ribs.

S14 was a 35-40 year old male displaying thick periostitis on the posterior part of the ribs and on both tibiae. Although the area covered by periosteal lesions on the tibiae was quite small, the new bone deposition showed a clear woven structure, which was identical to those displayed on the tibiae of S22. The thickness of the rib lesions and its smooth surface suggested some remodelling.

S22 was a 25-30 year old male presenting extensive periostitis on most ribs. The skeleton was complete and well preserved, and displayed extensive periosteal surface deposits on the left femur and fibula, both humerii, radii, ulnae, claviculae and scapulae. The lesions appeared to be active and showed no sign of remodelling.

S54 was a 45-50 year old male, whose skeleton, although incomplete, displayed severe periosteal lesions in the form of a mixture of remodelled and active

lesions, clearly showing the chronic nature of the disease. Periostitis was present on the ribs and all the long bones and scapulae were covered with thick, irregular and active periosteal lesions, which had a crusty appearance. Only a portion of the left femur remained for the lower part of the body and exhibited the worst lesions. A sample from that femur was taken for SEM analysis confirmed this and showed sequential layers of periosteal lesions (see plate D). Some of the areas of the bones (especially visible on the femur) were smooth and showed signs of bone remodelling, with the integration of the periostitis to the cortex, demonstrating a healing process. The other side of the same bone was very irregular and the bone appearance was 'spiky', where the lesions were in a new and acute phase of formation.

Fishergate 4

Two other skeletons displayed periosteal lesions on the ribs and long bones.

S6191, a 20-30 year old male, displayed periosteal lesions on the ribs and both fibulae; and S1909, a 40-50 year old male, exhibited periostitis on the tibia, fibula and radius.

Ipswich

Although Mays (unpbl. pp 30) classified these diffuse perioteal lesions under non-specific infectious disease, the distribution of the lesions is concordant with hypertrophic osteoarthropathy.

S1240 was a male aged 25-35 years. This individual showed depositions of woven bone upon the normal cortex of the right ilium, the wing of the right scapula, the distal part of the left radius, the diaphysis of both femora (especially the posterior surfaces), the posterior surfaces of both tibiae and, to a slighter degree, the medial side of the right calcaneus. The reaction was most marked on the femora.

Cherbourg

One individual, S219, a 25-35 male, exhibited diffuse deposition of woven bone bilaterally distributed on the femora, tibiae and fibulae, suggesting a case of hypertrophic osteoarthropathy.

Rouen

S775A is 25-35 year old male. The lesions present on its skeleton were concordant with hypertrophic osteoarthropathy. No ribs were preserved but periosteal lesions were distributed bilaterally and symmetrically over the femora, tibiae, fibulae and the medial side of the calcanii.

6.4.3. Results and Discussion

The total number of individuals that may have been affected by tuberculosis or other chest infections of a chronic nature are very low and do not lend themselves to statistical analysis. Prevalence rates were calculated to provide some element of comparision between the assemblages. They were calculated as number of individuals affected divided by total number of adults in the assemblage.

Site name	*Lesion Spine*	*Septic arthritis*	*Lesion Ribs*	*Probable cases of TB*	*%*	*HOA*	*%*	***P* chest disease (%)**
Arras	5	-	1	6/49	12.2	-	-	**12.2**
Wing	-	-	3	-	-	3/63	4.8	**4.8**
Ipswich	2	-	-	2/79	2.5	1/79	1.2	**3.8**
Fishergate	1	-	2	1/83	1.2	2/83	2.4	**3.6**
Rouen	5	1	2	5/375	1.3	1/375	0.3	**1.6**
Lund	7	9	-	16/1104	1.4	-	-	**1.4**
Cherbourg	-	-	-	-	-	1/89	1.1	**1.1**
Löddeköpinge	4	2	-	4/694	0.6	-	-	**0.6**
Raunds	1	1?	-	1/191	0.5	-	-	**0.5**

Table 6.2. Summary of the evidence of chest infections of a chronic nature arranged in descending order of frequency. *P* is the total prevalence rate expressed in percentages.

Arras shows the highest values at 12.2% and Raunds the lowest with 0.5%. The average prevalence rates for the assemblages is of 3.3%. The calculated frequencies do not seem to support the notion that chronic chest infections are directly related to population size and density. Relatively speaking, however, with the exception of Wing, the larger towns (Arras, Ipswich, Fishergate, Rouen and Lund) do seem to have a higher prevalence rate than the smaller settlements (Cherbourg, Löddeköpinge and Raunds).

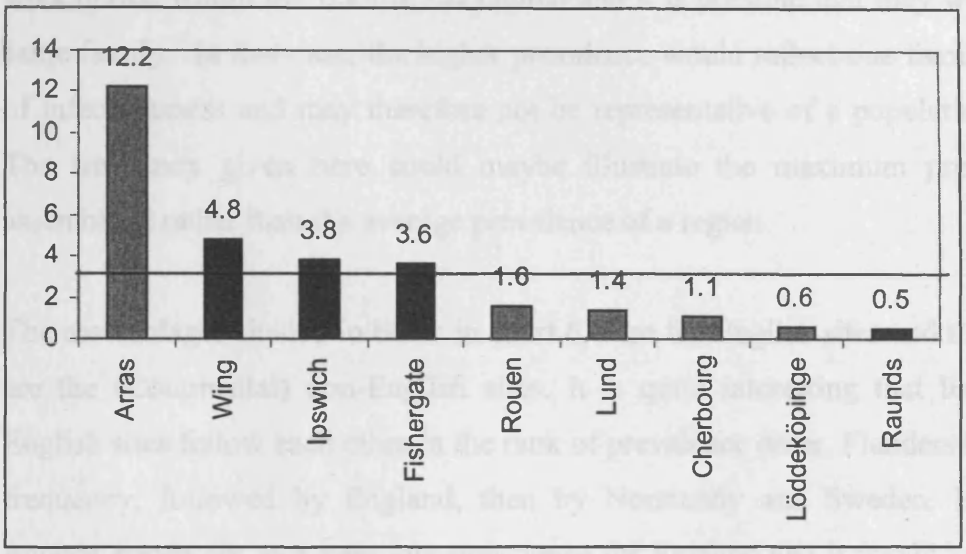


Chart 6.1. Total chronic chest infection prevalence rates in the assemblages.
The assemblages shaded in black are the English sites and the ones in grey are the Continental sites.

The frequencies seem to be split into four groups. Arras stands out with the highest frequencies of 12.2%. The second group includes Wing, Ipswich and Fishergate with frequencies of 4.8%, 3.8% and 3.6%. The third group includes Rouen, Lund and Cherbourg with frequencies of 1.6%, 1.4% and 1.1%. Löddeköpinge and Raunds form the last group with the lowest frequencies at 0.6% and 0.5%.

Care should be taken with such calculated prevalence rates, as a couple of misdiagnosed individuals would have a significant effect on the percentages, even in the larger assemblages. In addition, different observers made the diagnoses for each site, also increasing the risk of high variability in the calculations. Only Wing, Rouen and Cherbourg were analysed by the same observer.

Arras shows, by comparison to the other sites, an extraordinarily high prevalence rate. Many factors could cause this. There could be a certain element of over diagnosis by the observer. The lesions that were observed, however, were very characteristic of tuberculosis and DNA tests confirmed the presence of the mycobacterium in these individuals (Blondiaux, pers. com.). Since diagnosis was accurate, the other factor would be the non-representativity of the excavated skeletal sample. The individuals

were buried within the floor of the church and it is possible that they were part of the same family. In that case, the higher prevalence would reflect one family's high level of infectiousness and may therefore not be representative of a population as a whole. The frequency given here could maybe illustrate the maximum prevalence in an assemblage rather than the average prevalence of a region.

The assemblages shaded in black in chart 6.1 are the English sites and the ones in grey are the (Continental) non-English sites. It is quite interesting that bar Raunds, the English sites follow each other in the rank of prevalence order. Flanders has the highest frequency, followed by England, then by Normandy and Sweden. In that context Raunds stands out as a very low prevalence for England and it would seem to suggest that England has a higher prevalence rate in chronic infections than the continental non-English sites. A T-test analysis was conducted to assess whether the difference in the percentages between the English and continental sites was statistically significant, but they were found not to be significant.

When we compare the prevalence rates obtained from our assemblages with those given in Roberts and Cox (2003:184, 231), the 13 sites in the early medieval period showed prevalence rates of 0.9% and of 0.88-1.89% in the late medieval period. The rates here are lower than those of our assemblages, but they were calculated including sub-adults, who less frequently display skeletal lesions (Aufderheide and Rodriguez-Martin 1998).

If only 5-7% of individuals suffering from tuberculosis will show skeletal lesions (Aufderheide and Rodriguez-Martin 1998:133), then our values are in actual fact quite high. If we use the chronic chest infection (table 6.3) and spinal lesions alone (table 6.4) prevalence rates from each assemblage to indicate possible prevalence of tuberculosis, whereby the individuals with lesions represent 5% and 7% of the total population with the disease, we can attempt to calculate the prevalence rate of tuberculosis in each site.

It is important to note that we are not investigating the number of people who died of tuberculosis, but the number of people who had tuberculosis in their life.

Site	*Arras*	*Wing*	*Ipswich*	*Fishergate*	*Rouen*	*Lund*	*Cherbourg*	*Loddekopinge*	*Raunds*	*Average % of the sites**
Total %	12.2	4.8	3.8	3.6	1.6	1.4	1.1	0.6	0.5	2.2
Total at 5%	244	96	76	72	32	28	22	12	10	43.5
Total at 7 %	174.3	68.6	54.3	51.4	22.8	20	15.7	8.6	7.1	31.1

Table 6.3. Chronic chest infection as a possible indicator of tuberculosis prevalence.
* are calculated means omitting Arras as the site may not be representative of the population as a whole.

Site	*Arras*	*Ipswich*	*Fishergate*	*Rouen*	*Lund*	*Loddekopinge*	*Raunds*	*Average % of the sites**
Total %	10.2	2.5	1.2	1.3	0.6	0.6	0.5	3.1
Total at 5%	204	50	24	26	12	12	10	22.3
Total at 7 %	145.7	35.7	17.1	18.6	8.6	8.6	7.1	15.9

Table 6.4. Spinal lesions alone as a possible indicator of tuberculosis prevalence.
* are calculated averages omitting Arras as the site may not be representative of the population as a whole.

With these calculations, the prevalence rates for Arras become ludicrous, and seem quite high for all the sites whose original prevalence rate exceeded 1%. If we set Arras aside as a non-representative sample, the calculated prevalence rates become a little more plausible, even though still probably too high. The calculated prevalence rates would be of 31.1-43.5% if all lesions suggesting chronic chest infectious diseases were selected as indicators of tuberculosis, and 22.3-15.9% if only spinal lesions are selected

as indicators of tuberculosis. The sites with individuals displaying spinal lesions obtain values that are much closer to the prevalence rate of *circa* 20% of deaths caused by tuberculosis documented in later years. However, this does not mean that people who did not die from tuberculosis did not suffer from it. Indeed, the display of lesions shows a chronic stage of the disease that was much less likely to be lethal than the earlier acute phase.

The prevalence rate for tuberculosis in the Middle Ages is unknown, and we can only attempt to guess it using the evidence from the skeletons. This does not mean that the estimate that between 5 and 7% of the individuals with tuberculosis will show skeletal lesions is necessarily wrong and that it cannot be used as a basis to calculate real prevalence rates. It may be that it is not be applicable to medieval populations or may not be a reflection of the frequency of the lesions at the chronic stage of the disease.

The presence of a Pott's spine is considered the only safe way of diagnosing tuberculosis, however, it is rarely present in skeletal assemblages. It seems very surprising that lesions suggestive of chronic chest disease are not found more commonly in the larger urban centres. The fact that no evidence of chronic chest disease was found at St Nicholas Shambles is very surprising indeed, especially when both Wing and Cherbourg display some. Since the report was published in 1988, and in all likelihood the human bones had been examined in the year(s) preceding the publication, it is possible that rib lesions had not been routinely looked for, especially if the lesions were discrete. As Bennike (1999:516) suggested, it could be useful to re-examine older material.

When we compare the data obtained from the non-specific stress indicators, it is immediately observable that Arras, which displayed the highest prevalence rate for periostitis in the lower limbs is also the site with the most tuberculosis. Arras, however, displayed some of the lowest prevalences for cribra orbitalia and the lowest prevalence for enamel hypoplasia. Wing, which displayed above average values for all non-specific stress indicators has the second highest prevalence rate of chronic chest

infections. Cherbourg, which displayed some of the highest prevalence rates for all non-specific stress indicators, presented quite low prevalences of chronic chest infections. This would seem to suggest that non-specific stress indicators do provide information on infectious disease and pathogen load in a population, but that they cannot be equated with specific diseases such as tuberculosis and chronic chest infections.

It seems almost impossible to draw a prevalence rate for chronic chest infection as there are so few lesions, whether on the ribs or on the vertebrae. Their significance is difficult to ascertain. The non-specificity of the lesions is clearly a problem. From Arras we are able to know that tuberculosis did exist on a large scale as it potentially infected entire families.

Maybe the reason that we are not observing more disease-specific lesions is that early medieval immunity did not allow the disease to reach a chronic stage and that most individuals died in the acute phase of the disease, as the chronic disease indicates survival of the acute stage. The frequency of the disease must have been low enough for the disease not to have been a major killer. The presence of hypertrophic osteoarthropathy also points towards chronic chest infection but we cannot ascertain if tuberculosis was a main cause for it. It is still difficult to understand why only a few centuries later the disease would be so omnipresent. The theory that extensive contact with the people of Europe brought an increased frequency seems unlikely as the continental prevalence rates, with the exception of Arras, are lower than those for the English sites in the observed period. It could have been prompted by changes in the environment such as those brought in by increased urbanisation, prompted by the industries. It also could have been a change in the bacterium itself, rendering it more virulent.

6.5. Leprosy

Because of the relative infrequency of the disease in the skeletal assemblages observed, leprosy will not be investigated in as much detail as tuberculosis.

Leprosy, also known as Hansen's disease, is a chronic infectious disease. It is caused by *Mycobacterium leprae* and principally affects the skin, nasal tissues, peripheral nerves and bone (Auderheide and Rodriguez-Martin 1998:141). The disease has two clinical forms: lepromatous leprosy, the low resistance form, which also exhibits the most severe lesions and tuberculoid leprosy, which is high resistant, i.e. less infectious. The typical lesions are the destruction of the nasal and palatal tissues, and the maxillary alveolar process causing the loss of the anterior teeth, causing disfigurement (Auderheide and Rodriguez-Martin 1998:150). Middle ear infection is also common (Bruintjes 1990). The nerves of the hands and feet are affected by both types of leprosy, the resultant neuropathy causing damage to the extremities, followed by infection and ulceration of the extremities and their eventual atrophy (Auderheide and Rodriguez-Martin 1998:151-2). Serious loss of function and independence follow as motor and autonomic nerve systems are affected. Ascending infection from infected feet can cause osteomyelitis and non-specific infection of the legs (Roberts and Cox 2003). 85% of lepers diagnosed today die before any skeletal changes take place, and it is likely it has always been so in the past (Steinbock 1976:6). It is estimated that between 15-50% of individuals with the disease that are not treated will show skeletal lesions (Aufderheide and Rodriguez-Martin 1998:150).

The majority of the leprosy hospitals (also known as lazar houses) in England were built (up to 19,000) in the 12th and 13th centuries but underwent a decline from the 14th century (Roberts 1986), along with the disease. The disease must have been on the increase to warrant the building of institutions. Roberts and Cox (2003:218) tentatively attribute it to an influx of people with the disease from the continent or that population densities reached a sufficent level to promote the infection's establishment and survival. Leprosy has been described as a disease of villages (Auderheide and

Rodriguez-Martin 1998:143) as the disease is surprisingly difficult to contract. It would not have seemed to have thrived on rapid urbanisation like tuberculosis. Manchester (1984, 1992), however, has proposed that, at first, prevalence of both tuberculosis and leprosy went up with the increasing population density, but that eventually the population became more tuberculin-positive, conferring a degree of immunity to infection by *M. leprae.* In the individiduals then infected with *M. leprae* the tuberculin-positive status caused a population shift along the immune spectrum towards tuberculoid (i.e. low infectious) leprosy, which eventually led to its extinction.

Catching the disease would have been a catastrophy to any individual. The disease was heavily stigmatised, exclusion from the community was enforced and a life of religious penitence ensued (Roberts and Cox 2003:269-9). Treatments, among others just as innefectual involved herbal remedies, blood-letting, dietary regimes, etc. (Roberts and Cox 2003:270)

6.6 Results and discussion

Leprosy was only found in three of the observed skeletal assemblages and as a result only a limited amount of information can be derived from it. It is probable that individuals showing evidence of the disease would have been sent to leper hospitals where they would have died and been buried, rather than be allowed to stay in their parishes.

Ipswich (Mays unpublished:31)

Only one case of leprosy was diagnosed in the Ipswich sample.

> S1392 was a 21-25 year old female. The maxilla showed atrophy of the anterior nasal spine, together with some new bone formation in the anterior part of the nasal cavity and fine pitting of the superior surface of the hard palate. There was some erosion of the pyriform margins and the inferior surface of the hard palate showed markedly increased pitting. There was erosion of the maxillary alveolar bone in the region of the central incisors. The lower leg bones showed

considerable sub-periosteal new bone formation, mainly confined to the distal two-thirds of the tibiae and fibulae. The lesions were particularly pronounced on the interosseous borders. The sub-periosteal bone had a longitudinally striated appearance but was nodular where deposition was at its thickest. The feet were extensively affected with osteitic changes and bone destruction. The nutrient foramina were enlarged and some bones were osteoporotic. The hands appeared normal.

Raunds (Powell 1996):120-124

Two burials were diagnosed as being leprous.

S5046 was a 17-25 year old male. Fascies leprosa was observed with extensive pitting of the surface of the hard palate. Erosion of the alveolar bone had caused the loss of the upper central incisors. The nasal surface of the palate also showed extensive pitting and there was erosion of the nasal spine. Extensive and extreme infections were found in the right femur, tibia and fibula and in the left tibia. There was also degeneration of the pubic symphysis due to osteitis. The right femur showed osteitic development with periostitis of the distal shaft. The tibia displayed moderate osteitis of the proximal and distal shaft while the right fibula displayed gross osteitis of the whole shaft. The left tibia was observed to have gross osteitis and periostitis on the whole shaft.

S5256 was a 25-35 year old male with both lower limbs severely affected by osteitis. The femoral shafts were slightly thickened distally with marked periostitis. Both tibiae displayed marked periostitis of the mid-shaft and distal shafts medially and laterally. There was destruction to the lateral articular surface. Both fibulae shaft, mid- and proximally showed marked periostitis. Osteitis was observed on the lateral surface of the right ilium, anteriorly.

Manchester and Roberts (1986) reported a third case of leprosy in Raunds, also a male. Unfortunately no data were provided on the appearance of the lesions.

Lund (Arcini 1999:120-1)

32 cases of leprosy were diagnosed in Lund in the period 990-1100 of a total of 43. The great majority of cases were situated in the cemeteries belonging to the periods we are observing. There was a clear zonation in the location of the individuals with leprosy, who were found in the outer zones of the cemeteries and in the case of one cemetery in the its northern part. The most commonly observed changes were those of inflammatory nature at the base of the nasal cavity. Two individuals showed so much destruction of the palatine process of the maxilla that there was communication through the nose. Changes in the nasal cavity and in the hard palate were the most common location as well as periosteal lesions in the lower limbs.

Site	*Leprous lesions*	*Prevalence %*
Lund	34/1104	3.1
Raunds	3/191	1.6
Ipswich	1/79	1.3

Table 6.5. Leprosy prevalence rates in Lund, Raunds and Ipswich (individuals affected / total adult population).

In Roberts and Cox (2003:218, 271-2), the crude prevalence rate for leprosy in the early medieval period was calculated at 1.07% and rises to 3.5% in the later medieval period (including sub-adults and data from leprosy hospitals, which would increase the prevalence). This would suggest that our sites provide comparable frequencies to the ones already observed.

With leprosy only present in three of the skeletal assemblages investigated it is not possible to derive much information on the effect of the disease in our populations, or differential health experienced by the various regions observed.

The two English sites seem to show similar frequency rates that are comparable to those observed in other sites by Roberts and Cox (2003). The Lund material, however, has a frequency that is twice that at 3.1%. This does not, however, necessarily mean

that Sweden had a higher prevalence rate of leprosy than did England at the time. In 1984, no cases of leprosy had been observed in Löddeköpinge, in spite of a total skeletal assemblage in excess of 1,400 skeletons. Persson and Persson (1984) at the time commented that no evidence of leprosy had been found in the skeletal assemblages of Lund, which they had used as a comparative measure for Löddeköpinge. The sites they used included the cemeteries of PK Bank (11-12th century), a large skeletal assemblage at St Stefan (11-16th century), a small group from Drottensgatan (probable 11-12th century) and part of a recently excavated site at the time called St Clements (11-12th century). The explanation they offered for the apparent lack of evidence of a disease which they knew to be common in the time period, particularly in the countryside (Fine 1982), was that individuals suffering from leprosy were sent to lazar houses, which had their own cemeteries. To their knowledge, only one individual with extensive leprous lesions was known to have been buried in a parish cemetery. The first legislation in the Nordic Countries concerning leprosy dates from 1294 and it was as late as 1443 that it was decreed that lepers should not be allowed in the cities (Møller-Christensen 1961).

In 1999, Arcini described the sites she analysed (three neighbouring cemeteries: Trinitatis, Kattesund and Drotten) as being remarkable as they provided the highest number of lepers from a city in the Nordic countries in cemeteries that were not connected to leprosy hospitals (Arcini 1999:130). Her explanation was that the first hospital in Lund was not built until 1140-1150, which also explained why only one individual with leprosy was observed from 1100 onwards. In other cemeteries in Lund, notably St Mikael, St Andrea and St Mårten, individuals with leprosy were also only found during the period *ca.* 1050-1100. Lund's first leprosy hospital cemetery was analysed in 1949 but no skeletal changes suggestive of leprosy were found in the 19 individuals, although poor skeletal preservation might have been to blame.

In Arcini's work, the sufferers of leprosy had been clearly segregated from the other burials by being buried in the outer area of the Trinitatis cemetery and the northern part of the Kattesund cemetery. It is unclear whether they would also have been segregated

in life, but it seems likely. Arcini (p.131) comments that the treatment they received in death reflects that that has been observed in other parts of Sweden, notably Fjälkinge (900-1050). In northwest Scania, where three lepers were found in an area peripheral to the burial ground. In Sigtuna (1050-1200), Uppland, one leper was found against the cemetery wall (Arcini 1996, 1997 cited in Arcini 1999:131). Arcini (1999:131-1) argued that the parts of the cemetery were the lepers were found were of low social status, which she interpreted as possible proof that leprosy affected mainly the poorer members of society. It could also mean, however, that individuals with leprosy lost any social status they might have had when they started showing evidence of the disease and were forced down to the lower end of the social spectrum.

6.7. Conclusions

There are many difficulties associated with inferring health and disease prevalence rates from skeletal lesions in historical population. The main difficulty is that few lesions will leave a mark on the skeleton, and that the lesions themselves are not disease-specific though, as leprosy, their distribution may be. In addition, a disease often needs to have reached a chronic stage before any lesions can be observed, meaning that their significance is hard to evaluate. This can explain the observed highly variable prevalence rates. Maybe some not yet understood and quite possibly complex factors, such as diet or the environment, might impact on the presence of absence of lesions. They would cause one site to display a higher frequency of lesions than another, even if their population profiles are very similar, as was the case in this project. The picture is further complicated with the issue of multiple observers.

So how can we infer health and draw useful conclusions using lesions that are a) not disease-specific and b) only present in the skeleton at variable rates? We must concentrate on what we have and we know not to be normal: the skeletal lesions. We have to observe them without attempting to draw too many conclusions as to how they related to specific diseases.

Through this project we have observed that:

- There does not seem to be any distinctive euroregional variation for non-specific and specific diseases, although tuberculosis does show some level of regional grouping.
- There is no increase of observable lesions in relation to increased population size and density. This is particularly true of Wing, showing above-average prevalence rates for all non-specific stress indicators.
- There are no observed male/female differences in lesion prevalence rates.
- There are no age specific differences in the frequency of the lesions.

The sites would appear to be uniform, more comparable by their similarities rather than their differences with the exception of the tuberculosis prevalence rates. This is not unexpected as the sites were selected to remove any possible variation in relation to population type (i.e. monastic/military vs. lay and parish populations) and to represent a wide cross-section of the population. More sites and a higher number of individuals would need to be investigated to ascertain the significance of such finds.

Chapter 7: Conclusion

It was attempted in this research project to carry out an international study using skeletal remains from nearby European regions. They included England, France (historically the Duchy of Normandy and the County of Flanders), and south Sweden (historically part of the Kingdom of Denmark). A total of 2,718 adult skeletons were analysed (and an additional 41 individuals were used for isotope analysis). A mixture of primary analysis of the skeletal material and secondary analysis of reports was used to extract the information needed for this project to assess certain aspects of health and population studies in 10-12th century populations of northern Europe.

The project was foremost an attempt at an international comparison of skeletal assemblages aiming to detect differential health patterns by investigating male vs. female, urban vs. rural, English vs. continental skeletal assemblages. The sites investigated were a mixture of urban and rural sites, all lay and derived from parish cemeteries. Health indicators were obtained using paleodemographic assessments of the population profiles and the paleopathological evidence of non-specific stress-indicators (periostitis, enamel hypoplasia and cribra orbitalia) and specific infectious disease (chronic chest infection, tuberculosis and leprosy). In addition, secondary to the main project isotope analysis from the dental enamel of two sites in Anglo-Saxon Rutland was undertaken to investigate the usefulness of the technique as a migration marker for historical populations, for example in studies of the role of migration in disease transmission.

This project was particularly distinctive for being one of the first truly international studies to have been undertaken when assessing past health. It has been particularly noted that there are very few studies that investigate trends and patterns pertaining to a geographically defined area encompassing neighbouring regions. Many studies are site or time specific. The benefits of extending the area investigated are numerous, and it was sought to portray a more complete representation of the period investigated here. It

has never before, however, been clear whether sites from various regions could be comparable, so one of the main aims was to assess whether the northern European region could be perceived as a single geographical unit.

This study has proved that it is possible to do so, and has revealed the diversity present in early medieval populations in Europe. The disease and lesion prevalence rates showed that there were no distinctive differences between the regions, only a range of variation in the experience of health. The differences that were apparent were more to do with the nature of the settlements and their historical and socio-economic context, rather than their geographical location in Europe. The differences in levels of health were probably due to factors such as different immunity, exposure to pathogen, diet, socio-economic status and population density.

When observing trends in prevalence rates of infectious diseases, migration and population movement can have a noticeable impact on the health in a population. Migration is, however, notoriously difficult to assess, and the abundance of contrary articles assessing the Anglo-Saxon migration, which is one of the most important and potentially substantial migrations of British history, proves the difficulty in interpreting it.

Isotope analysis on archaeological human remains has recently emerged as a new valid tool in the investigation of population movement in the past. It was decided to use it in this project to measure its ability to detect immigrant components in an observed population, one of which was at the end of the Anglo-Saxon migration, and the other firmly in our observed period of the 10-12th century. The main difficulty in using isotope analysis to determine migration, especially to examine an event that took place at a specific period, is that we need to find the cemeteries containing those first generation immigrants. Indeed, second generation immigrants, brought up in the local area, would show values that would not be distinguishable from those of the "true" natives.

Also, the high natural population variability in the values means that large numbers of samples need to be taken to establish a baseline against which to compare suspected immigrants. Animals can be used to supply the range of acceptable values for a locality. The benefit of using contemporary animals to provide this baseline has been successfully attempted here. This worked well for both the strontium and oxygen analysis. For the oxygen isotope analysis, however, animals only provided comparative values when using raw values. The formulae used to translate the oxygen isotope ratio raw values into drinking water values for the animals did not provide satisfactory results, with the exception of the cattle.

Despite no immigrant component being uncovered in Ketton or Empingham, both sites displayed different profiles, showing some differences in the settlement patterns. Empingham values suggested a mainly local population, with a small range of values. Ketton, on the other hand, displayed more variability within the range of local values, suggesting that the individuals sampled had come from the surrounding area. Isotope analysis was successful in demonstrating its potential as a migration and population movement indicator. The advantage of using both strontium and oxygen for such studies was also established, as both techniques measure two different geographical phenomena but presented similar results. They are independent measurements of the same phenomenon.

Paleodemography was used to establish population profiles by assessing sex distribution between the age groups. The results from this study revealed evidence of the migration of young males towards large urban centres such as London and York, possibly at the expense of rural settlements. Apart from Cherbourg, all sites investigated showed a higher number of male skeletons, with an average male:female ratio of 1.3:1. The sex distribution was statistically significant in the largest European urban sites: Fishergate (York) and St Nicholas Shambles (London) for England, Rouen for France and Lund for Sweden. Based the historical information available from these sites, it is clear that the great expansion experienced by towns in the 10-12th centuries was mostly based on the development of trade, so these sites must have offered work

opportunities through, for example, the ports and warehouses. Addyman (1989:244) declared that "town air might have offered freedom to a medieval peasant, but it also brought an early death".

Löddeköpinge, a medium-sized rural trading settlement also showed a significant over-representation of males. This observed imbalance can be partially explained by possible zonation, since only slightly over half of the cemetery was excavated, but the historical and archaeological background reveal other factors. Löddeköpinge seemed to have enjoyed strong trading links. In parts of the settlement there is evidence for seasonal flunctuations in occupation of the site for both housing and a seasonal market place, suggesting that the population might not have been typical in its structure. It could be that Löddeköpinge was an "ordinary" rural settlement for the major part of the year, made up of families as the sub-adult distribution would suggest, and that at specific times of the year, long-distance travellers, for example merchants, temporarily inflated the population, skewing the demographic profile of the buried community. It would be interesting to conduct isotope analysis on the skeletal material from Löddeköpinge to test this theory. Until it can be undertaken, Löddeköpinge is a good example of how essential it is for the human bones specialist to be aware of the archaeological context surrounding the cemetery to be able to interpret the skeletal evidence.

It would have been expected to find more females in the rural sites to make up for the disproportion in the sexes. This has not been found to be the case. Two explanations are likely: firstly, we had just three rural sites in this project, only one of which was fully excavated. These three sites are not likely be representative of all rural sites in the area observed. Secondly, to test the theory of male-led migration to large urban centres, we would need to investigate neighbouring villages from London, York, Lund, and Rouen, preferably within a 15-20 kilometre radius (Nicholas 1997:182) to see if there was a resulting over-representation of females.

It is traditionally expected for females to die young due to poor health relative to males or from obstetrics-related complications. In our investigated sites, however, the only

assemblages to show a higher proportion of females in the under 35 years age group were Ipswich, St Nicholas Shambles and Raunds in England, and Lund and Löddeköpinge in Sweden. None of the French sites showed a predisposition for females to die at a younger age. The young male distribution was similar. Only Fishergate and St Nicholas in England and Lund in Sweden showed an increased number of males dying in the earlier age category. This mirrors the sites that had an overall increased representation of males (with the exception of Rouen). These were also the largest urban sites (apart from Löddeköpinge). It would therefore seem that there are differences in mortality patterns between males and females, whereby urban sites are more likely to have more males in the younger age categories. In rural sites, males would tend to have a higher representation in the older age category, possibly suggesting a better health status. Females do not present such a clear picture in urban vs. rural mortality patterns, suggesting that population size and density is not the leading factor in mortality patterns for females.

Most sites, particularly the French ones, displayed a greater number of both males and females in the older age categories. This could be indicative of successful 'survivorship' and good health status, although zoning for the partially excavated sites and the difficulties associated with accurately ageing adults, especially the older age group, could also have an impact.

There are two concerns that are crucial when attempting paleodemographical reconstructions of past populations. The first raises the problem of whether the buried population is representative of the living population at the time. The second questions whether assemblages from partially excavated cemeteries can be representative of the buried population.

Little can be done about the former apart from discerning very precise chronological phasing in cemeteries and trying to match them to church records where these exist. They are not, unfortunately available for the period under study. As for the latter, it would largely depend on the size of the sample compared to the total population, and

whether there was evidence of zoning. As only two sites had been near-fully excavated and the others were *ca.* 50%, it was expected that for some sites at least, zoning might skew the sample.

One such site was Cherbourg, which was the only assemblage to display a higher number of females than males. In addition, Cherbourg had the largest percentage of juveniles present in the excavated sample (57.6%). Cherbourg was so different from the other investigated sites in this project that it was a strong possibility that the population profile obtained was at least in part due to zoning. The other sites with the highest sub-adult distribution were Raunds and Rouen (47.3% and 43.2%), which were the only two sites to have been near fully excavated, suggesting that this was the adult/sub-adult distribution to expect in both rural and urban settlements. This concords with previous research (see Grauer 1991).

The paleopathology section of this project sought to assess the presence of patterns in pathogenic disease prevalence, and in the case of infectious diseases, to investigate the link between population size and infection. It is indeed the perceived wisdom that the inhabitants of towns suffer poor health and reduced longevity due to the effects of population size and density, extensive settlement patterns and the occupational hazards brought on by specialised craft and industry (Addyman 1989:244).

Three non-specific stress-indicators were selected as evidence of childhood experience of infectious diseases. They included: cribra oribitalia, enamel hypoplasia and tibial periostitis. The prevalence rates of cribra orbitalia were highly variable, with 23.6% to 62.5% of the population displaying the lesions. There did not seem to be a regional tendency in the distribution, and the distribution did not increase with population size. Partially excavated cemeteries did not seem to skew results either. The presence of the lesions did not appear to demonstrate reduced immunity, as 58.7% of the individuals with the lesions were aged 35 years and over, showing no reduction in longevity.

Enamel hypoplasia showed a similar distribution pattern. There were no observed differences between the male and female distribution, or age groups and regions. The prevalence rates of enamel hypoplasia were extensive, ranging from 11.5% to 94.2%. It was possible that such a range in frequency was introduced by inter-observer variability. The sites with high prevalence rates were Fishergate, St Nicholas Shambles and Cherbourg. If these observations were reliable and representative, Fishergate presented the highest frequency, with 94.2% of the population showing at least one period of substantial poor health. Fishergate also presented a slightly higher than the sites' average for cribra orbitalia at 43.2%.

The enamel hypoplasia prevalence rate seems to be particularly high, even for an urban site. York is particularly fortunate in having been able to undertake many excavations that have been able to provide a fairly comprehensive picture of York in the past. One publication by Addyman (1989) depicted the sanitary condition of the town from the Roman times to the late Middle Ages. Addyman described the Viking/medieval city has having densely set streets with a mixture of houses, shops, workshops and warehouses, surrounded by a dense layer of rubbish. The commercial area was likened to "a compost heap" (Addyman 1989:254) and the water supply was poor, with wells adjacent to refuse and cess pits. Preserved faecal matter was rich in human intestinal parasite eggs of whipworm and maw worm. These parasites are common in communities with only primitive methods of faeces disposal (Addyman 1989:257). A slow process of improving environmental conditions including more efficient rubbish disposal began in the city in the aftermath of fires in the 11th and 12th centuries.

It is quite possible that accommodation also left much to be desired and combined with the poor state of sanitation, it did little to moderate disease frequency, especially in children whose immune system is more vulnerable that that of adults. St Nicholas Shambles shows similar distribution patterns, suggesting that living conditions were probably fairly similar. Similar inferences can be made about Cherbourg, which showed high prevalence rates for both enamel hypoplasia and cribra orbitalia.

Periostitis prevalence rate ranged from 5.3% to 32.1%. There does seem to be some pattern in its distribution, whereby the French and Swedish sites surround the English sites and display both the highest and lowest prevalence rates, indicating that continental sites on average had both lower and higher prevalence rates of the lesion than the English ones. Interestingly, the larger urban sites displayed some of the lowest frequencies of the lesions. Since Wing represented the only rural site investigated for pathological lesions, it could not be determined whether the observed frequencies were linked to population size and density.

Periostitis is one of the most common lesions observable on human remains. It is perhaps also one of the most difficult lesions to record and quantify as opinions will diverge widely between what constitutes moderate and severe periostitis, and its appearance can be highly variable, localised or diffuse, unilateral or bilateral. This could result in high inter-observer variability.

It was very surprising to find such differences in the distribution of enamel hypoplasia and cribra oribitalia, and tibial periostitis. Whereas the fist two types of lesions seem to exhibit similar prevalence rates, periostitis does not appear to correlate with these results. It could be quite possible that periostitis is not indicative of similar phenomena to the other two lesions. This would further imply that its value as a non-specific stress indicator is open to doubt. The range of the prevalence rates for non-specific stress indicators is another illustration of the diversity encountered in the experience of health throughout early medieval Europe.

It was expected that sites with high prevalence rates of non-specific stress indicators should display high frequencies of diagnosable infectious diseases. This was, however, not found to be the case. On the whole, sites did not seem to show links between prevalence rates of the non-specific stress-indicators with those of tuberculosis, chronic chest infection or leprosy.

Arras displayed the highest number of cases of tuberculosis but showed some of the lowest prevalence rates for both cribra orbitalia and enamel hypoplasia. It did, however, present the highest prevalence rates of periostitis, with 32.1% of the population affected. This is not completely unexpected as cribra orbitalia and enamel hypoplasia are lesions that form in childhood and not adulthood, whereas periostitis shows non-specific health in the months preceding death. Lund, however, showed the smallest prevalence rate for all non-specific stress indicators, including periostitis, despite the fact that 34 individuals (3.1% of the population) suffered from leprosy.

Lund, Raunds and Ipswich were the only three sites showing evidence of leprosy. Lund particularly had 3.1% of the assemblage displaying leprous lesions. There was clear zonation in the location of these individuals with the disease, showing segregation in life as well as in death. There is no evidence of a hospital during that time period. Although the data from Lund would suggest that leprosy was widespread in Sweden at the time, very few sites of similar date actually show evidence of the disease, so Lund is quite unique in that context. These finds would suggest that the prevalence of leprosy in our observed period was low, especially in parish cemeteries. It is likely that lepers exhibiting substantial soft tissue damage and possibly skeletal lesions might have been buried in hospital cemeteries rather than at their local parish cemetery. In this perspective, parish cemeteries, although composed of the 'normal' population, may not representative of the living population as possibly those rendered disabled or disfigured by their disease were buried elsewhere.

The total number of individuals exhibiting lesions that were evocative of tuberculosis, chronic chest infection and leprosy were too low for statistical analysis. Arras showed the highest percentage of lesions attributable to tuberculosis and chronic chest infection and Raunds the lowest, but was one of the few sites to exhibit leprosy. Ipswich showed comparable numbers of both tuberculosis and leprosy. Rural sites showed the lowest distribution of tuberculosis and chronic chest disease, apart from Wing. Both Wing and Arras reflected high level of infectivity within a small group of people, probably exacerbated by poor sanitary and living conditions.

Aufderheide and Rodriguez-Martin (1998) have established that between 5 and 7% of individuals with tuberculosis will show skeletal lesions in modern contexts. This percentage was used as a basis to calculate prevalence rates of the disease at the population level by calculating how many individuals suffered from tuberculosis based on the fact that 5-7% of the modern untreated individuals displayed skeletal lesions. The results came back as unrealistically high, irrespective of whether rib lesions or only spinal lesions were included in the calculations. This does not mean that the estimate that between 5-7% of individuals with the disease will show lesions is necessarily wrong, only that it cannot be applied to medieval populations.

In addition, it may not be a reflection of the frequency of the lesions at the chronic stage of the disease, i.e. that we cannot equate the presence of lesions with the prevalence rate of the disease in the population. Our methods to diagnose tuberculosis, especially at the population, rather than the individual level, needs to be refined.

There are no observed differences in the age distribution and male/female prevalence in pathological lesions, specific or unspecific, and the affect of population size and regional variation is unclear. It would appear that for the chronic disease at least, population density rather than size would be a more important determinant. Population density is, however, hard to estimate, and to attempt it would probably require the full excavation of the habitat/settlement as well as the cemetery. Also, to assess frequencies, the cemetery would need to be split into clearly defined layers linked to specific time periods.

Analysing skeletal lesions is subject to many limitations. Firstly, it is not often possible to attribute a specific disease to an observed lesion as many lesions can be caused by a variety of pathogens, and the appearance of the lesions can be quite variable. It is also important to bear in mind when viewing skeletal evidence the logic of the osteological paradox as argued by Wood *et al.*. (1992). They highlighted the fact that only the health of the non-survivors was revealed, and that only the state of health at the time of death,

rather than during a lifetime, could be assessed by our investigations. Also, a lack of pathological lesions is not necessarily indicative of a better health status. Rather, it suggests that the lesions imply the capacity to survive rather than succumb in spite of chronic or recurrent ill-health.

Inter-observer variability is also a major difficulty. The lack of standards in the presentation of reports means that there is extensive variability in the diagnosis and presentation of observed lesions (see Jacobi and Danforth 2002) for a discussion on interobserver scoring patterns). This specific problem is particularly evident when using archival reports rather than primary analysis of the bones to assess pathological lesions.

Large and substantially excavated sites would be needed to assess disease prevalence rates, as when only a handful of cases are observed in a small site, the wrong diagnosis of one individual can have a substantial impact on total results. For more modern material, we could assess prevalence rates using records and contemporary written sources, and parallel them with the percentage of lesions observed in contemporary sites to obtain the correlation between lesions observed and total known cases of tuberculosis in a population. It is, however, not a possibility here. The main difficulty is that the lesions only appear on individuals who have reached the chronic stage of the disease, when it is no longer a direct cause of death. Additionally, the number of individuals with lesions indicating a chronic stage of the disease cannot inform us of the numbers who died in the acute phase of the disease, before skeletal lesions could form. If prevalence rates could be calculated from mortality bills or church records, and the diagnosis was accurate, they would only record the people who died from the disease, rather than those who suffered from it. We must also take into account the history of medicine itself. The diagnostic methods and theoretical framework of medieval medicine are totally different from those of modern science, so it is not always possible to equate the name given to an illness in the past with a modern diagnosis.

The analysis of the assemblages was undertaken using methodologies that were widely used at the beginning of this project in 1999. Through this project, however, it has become evident that current methodology and techniques in human bones analysis presented some extensive limitations when viewing the evidence at the population, rather than individual, level. This was particularly evident when attempting to draw prevalence rates of tuberculosis and leprosy based on the numbers of individuals displaying lesions attributable to these diseases. Additionally, calculating disease prevalence based on the known percentage of individuals exhibiting the skeletal lesions as for tuberculosis did not prove satisfactory in this project. This infers that skeletal lesions do not equate with total disease load in a population and that it is inaccurate to infer disease trends by using them. It is therefore suggested here that markers used to diagnose a disease on skeletal material might not necessarily be applicable to population-wide studies, as the aetiology of lesions and their link to specific diseases suggests that there are more complex processes at hand than was possibly originally believed.

Potentially, new technologies can help us understand what we observe and link the lesions to diseases, subsequently enabling us to refine our macroscopic diagnostic criteria. It would be a while, however, before such studies had a substantial impact in our current approach to paleopathology. In the meantime, we can only compare the numbers of individuals displaying the lesions between observed sites.

As a result of this health assessment, it seems prudent to restrict the historical period observed when making comparisons between sites of different geographical origin. Indeed, historical sources suggest that in the case of tuberculosis, prevalence rates of the diseases substantially increased in later periods, culminating in the 18th and 19th centuries. For leprosy, our observed period marked the very beginning of the disease's high incidence in Europe, increasing in the 13th century but declining in the 14th century. We know there is differential disease prevalence between countries for some diseases. It has been established, for example, that in several of the Nordic countries leprosy persisted for several centuries longer than in the rest of Europe, only

disappearing from Iceland and Norway in the 20th century (Bennike and Brade 1999:75). Evidence from Lund would certainly seem to suggest that Sweden had more leprosy in the 10th-12th centuries than France and England. Tuberculosis, on the other hand, has only been found in approximately 20 skeletons from Denmark (Bennike and Brade 1999:75). Although the numbers are also fairly low for England, they are higher than those observed in Denmark. The exact cause for such differences is not particularly clear, but it is possible that genetic differences between populations or bacterial types might be responsible for the disparity, since for most other diseases, rates are comparable.

It is clear from the paleopathological data that disease was an integral part of life in 10-12th century northern Europe. Even though there are not many individuals displaying lesions clearly attributable to leprosy and tuberculosis, the prevalence rates of non-specific stress indicators suggest that infectious diseases were widespread and affecting both children and adults. The majority of the skeletons that were analysed did not suggest long term disability as a result of these diseases, although we can only assess musculo-skeletal ailments, rather than those affecting soft tissues, such as blindness, shortness of breath, painful limbs etc that might have resulted from the diseases. Some individuals in the observed assemblages, such as in Rouen (see p. 268)), did show evidence of the use of physical aids such as crutches, showing that people with disabilities must have been a common sight and that longevity was not necessarilly immediately affected by disability.

The experience of health, or rather ill-health, and disability in the past has started to become of interest to bioarchaeologists, as it tells us a lot about society and its attitude to disease and the disabled. Being diseased is not only a clinical condition, but also one affecting lifestyle and that has extensive social implications. Disability in the past and its treatment is, however, particularly difficult to assess archaeologically, as are the levels of emotional support and compassion that were shown to the disabled.

Iconography and written sources can help and contribute to a better understanding of the disabling effects of diseases. In 2001, three medical specialists (a rheumatologist, an orthopedic surgeon and a neurologist) analysed "The Procession of the Cripples". The piece is a precise and realistic drawing by Hieronymus Bosch of 31 individuals displaying a range of disabling conditions *ca.* 1500 from the Netherlands, giving us a insight into the experience of disability in the medieval period. The specialists analysed the drawing and sought to assign age, sex, socio-economic status, as well as to describe the lesions and suggest a working diagnosis and a differential diagnosis. They also took into account the most common disorders for the period and region (Dequeker *et al.* 2001:864). The males were more represented (84%), and 55% of cases wore a typical leper's cape and were carrying a food-begging scale. The most common crippling disorder, however, was not leprosy; indeed, there were a large variety of crippling disorders ranging from the infectious (including leprosy and tuberculosis), traumatic, congenital and metabolic, to hysterical related aetiologies and ergotism caused by a fungal poison (Dequeker *et al.* 2001:870). Congenital deformities formed a quarter of all cases, and limb amputation was the second most prevalent cause of disability. The drawing, however, is unlikely to be a representative sample of all disabling ailments of the period, but does highlight the sources of human anxiety about disability.

From the clothing and the attitude of the disabled depicted in the drawing, it would appear that whatever the disability, these people had either voluntarily left society, or, as lepers, had been rejected from it and force to a life in marginal conditions, begging, and for some, busking for their daily needs and care. More humiliating perhaps was the need to place withered or diseased limbs on display to attract the compassion of passers-by. Some of the disabled were obviously very poor and had been so for a long time, while others appeared to have been more recently disabled and had clothing still in reasonably good condition. The drawing would suggest that whatever socio-economic status had been enjoyed before the ailment, becoming disabled meant the loss of that status and the descent into the lowest ranks of society. The data from Lund would certainly concur with this, where all the lepers were buried in the fringes of the poorest cemetery. Arcini (1999) could not be sure whether leprosy mainly affected the

poorest inhabitants, or whether the disease irremediably meant a loss of status due to the strong stigma attached to it. This would suggest that in Lund at least health status was more important than socio-economic status prior to the onset of illness in determining where one was buried. We also have to remember that a special stigma was attached to leprosy with patients being ostracised in life.

Coping mechanisms were also shown in the Procession of Cripples, with the depiction of axilla crutches, hand quadripods and sliding boards (Dequeker *et al.* 2001:871). Well-healed lesions and evidence of long-term disease, as for example displayed in Rouen shows that individuals could live a long time with their illness and consequent disability. These individuals would have needed to be cared for, at least for part of their lives. Work by Farmer (1998) on the poor and disabled women in 13th century Paris show complex social networks and charitable institutions that enabled these women to survive despite no longer being able to provide for themselves or their families.

Dequeker *et al.* (2001:871) concluded that even though most disorders can be diagnosed and treated early today, thereby reducing the spread and effect of the disease, there is still today a negative attitude shown to the disabled particularly regarding musculoskeletal disorders. Cancer, heart, pulmonary and gastrointestinal disorders dominate medical and popular attention and research activities, while chronic musculoskeletal diseases, which are more prevalent, cost more and cause longer suffering do not receive the same level of attention.

There is much to learn still about the cultural experience of health in the past and its social implications by using skeletal and archaeological evidence combined with textual and iconographic information. In order to assess disability, it is important to have as much information as possible, and essential information can be gained from careful excavation of the material. The archaeologist should be particularly attentive to cemetery lay-out and the evidence of socio-economic status through burial customs, especially as the skeletal evidence of disability might be lost through bone fragility. Archaeologists are, however, under such time and financial constraints that it is not

always possible, despite the best intentions and competence, to excavate a site as thoroughly as it would be desired. Archaeologists have to work fast and with variable levels of skills in the team. As a result, it has been my experience that skeletons can sometimes be damaged during excavation (trowel indentations, fractured skulls, broken limbs) or incompletely recovered (small bones of the hands and feet, loose teeth, etc. loose pathological lesions such as kidney stones or calcified fibroid are easily lost or not recovered). If the skeletons are incomplete because of poor preservation or rushed excavation, the information with which they can provide us with be limited and incomplete. Reliance on unskilled staff or diggers unfamiliar with human osteology could also mean important information is lost. For the diagnosis of leprosy or rheumatoid osteoarthritis, for example, the small bones of the hands and feet are vital. Sometimes, the skeletons of foetuses and young infants are not recognised and not excavated accordingly, thereby potentially skewing the paleodemographical profile. It is in such cases that early involvement of the human bones specialist can be useful.

Involving the human bones specialist from the onset of the excavation with frequent visits to the site can facilitate the exchange of information and advice. This approach has also been recommended by Mays *et al.* (2002b:1). It might be a while before it becomes standard practice. Often the human bones specialists are only contacted after the excavation has ended and asked to analyse the skeletal material in virtual isolation from the rest of the archaeological data, and their report is similarly presented as a separate item.

Human bones specialists are not blameless in their ways of working either, particularly as they can present fellow scholars with near impossible obstacles to accessing information. One of the main problems with studies involving medium/large sized sites is access to the information, made difficult by the lack of a standardised approach in the recording of the data. So many reports could not be used for this study because there was so little information on the criteria used for diagnosing lesions, or methods used for ageing and sexing individuals. Another problem is that age categories differed between reports. Information on prevalence rates was calculated as crude rates, i.e. the number

of individuals with a particular lesion as a fraction of the total number of skeletons in the collection rather than a fraction of those in which the lesion is potentially observable.

This was less problematic when analysis was restricted to the analysis of a few individuals or small populations. The current trend, however, is for large comparative studies such as this one and the American biocultural approach, where data is viewed in its wider context. Such works have only highlighted the limitations of the established methodologies for undertaking comparative work and their inadequacy. In addition, the increasingly common reburial of excavated skeletal remain after analysis, has required the thorough recording of the material beforehand. Between the start date of this thesis and its submission, the discipline seems to have developed very quickly and a series of key works were published during that period regarding standardisation in the discipline (e.g. Mays and Cox 2000, Roberts and Cox 2003, Mays *et al.* 2002b, Brickley and McKinley 2004). These works highlighted many of the problems that were encountered in this project, especially regarding the paleopathological enquiries. The foundation of BABAO (British Association for Biological Anthropologists and Osteoarchaeologists) in 1998 has also helped bring forward these issues in the United Kingdom.

A main concern for specialists and students alike is to do with the access of the information and the skeletons for analysis. There is currently no central database registering the location of human bone assemblages as well as the reports, and the form in which information is available (published/unpublished reports, unpublished theses etc.). In Scandinavia, for example, most theses are published, e.g. Arcini 1999, Lynnerup 1998). Groups such as BABAO are currently attempting to address this, but no system is in place so far. Efforts should also be made to include costs for publications in excavation tenders for PPG 16. Publication of the material is often not funded and undertaken in the 'spare' time of the researcher.

Publications are particularly crucial in rendering data widely available to scholars, especially at a distance. Comprehensive catalogues are also rarely published, and even

today, it is all too often that publications about the excavation of a particular cemetery place the anthropological data from the skeletons at the end of the publication, almost as an afterthought. Long (and sometimes obscure) essays on the architecture of the building, building materials, phases in construction, stratigraphy, documentary evidence, burial types and practices, their liturgical and social aspect, small finds, ceramic evidence and so on all precede the human bones analysis, even when the skeletons represent the most numerous find. Even in the excellent Raunds publication, for example, the anthropological report is the last (13th) chapter and represents 11 pages of text, graphs, tables and images out of a total of 128 pages, with much of the useful data in microfiches.

This does not mean that such a publication is inferior, quite the opposite, as the Raunds publication remains one of the best in the field, providing excellent holistic information about the context of the graveyard. Indeed, the human bones report, if at all published, is too often presented in isolation from the other analyses of artefacts and the landscape, and it is unclear how the human remains fit with the other finds. The human bones specialist often has not been provided information about the context of the graveyard, or has not sought it.

It is up to the anthropologists to seek a more inclusive frame of work, asking to be involved in the whole archaeological process and in return involving the archaeologists in their work. The very fact that human bones specialists are often reluctant to call themselves archaeologists and prefer to be known as biological anthropologists suggests that they do not regard their work as a sub-discipline of archaeology, but rather as a separate subject. There is still reluctance on the part of human bones specialists to integrate into the all inclusive world of archaeology. It is sometimes suggested that the best human bones specialists should come from a medical background (e.g. Wells 1964, Waldron 2001). This training might make the human bones specialist more skilled at identifying specific skeletal lesions in paleopathological observations, but paleopathology is only part of the study of human remains. In the light of the American-influenced biocultural approach that is so prevalent today in

anthropology, a human bones specialist needs not only good diagnostic/clinical skills, but also a firm understanding of archaeology and its concepts (see Roberts and Cox 2003:22-23 for a fuller discussion on past and current paleopathological study in Britain).

The problems linked to the integration of human bones analysis in a wider bio-context are not recent. For years, archaeologists and historians ignored skeletons as a source of information to reconstruct past societies (Waldron 2001:11, Daniell 1997:116). The current popularity of historic human remains with the public and the media is a very recent event, one that has very likely been created by the plethora of current television programmes about archaeology, forensic science and body parts. *Meet the Ancestor*, a BBC series, has been particularly successful in introducing the general public to the work of anthropologists and human bones specialists, and the use of new techniques in the discipline (mostly expensive 'high-tech' ones). A whole episode was devoted to the excavation of Wing in 1998 and the analysis of skeleton VSW48 (the subject of plate F).

The study of human bones is nevertheless still believed to be a peripheral activity by some archaeologists, deemed to be a somewhat voyeuristic and crowd pleasing discipline. The explanation behind such emotive reasoning can often be associated with anxiety linked to handling human remains and an inherent mistrust of any discipline that is perceived to be trying to be too 'scientific'.

In the introduction to *Digging Up Bones*, Brothwell (1981:III) reflected that "bones are still commonly a problem to archaeologists, even though the human skeleton offers a no less fruitful subject of enquiry than ceramics, metals, architecture or any other field of historical or prehistorical study. It can provide much information on human societies of the past, and in fact no social reconstruction can be complete without examining the health profile of the community. In fact, osteological material also provides interesting information of a more specialised nature, such as the effects of the environment on

modern and earlier populations, or the evolution of diseases". The attitude towards human bones has changed somewhat since 1981, but not radically so.

Another limitation that is characteristic of all sub-disciplines of archaeology is the chronic lack of funding available to undertake projects similar to this one. Human bones analysis needs to develop investigative tools and techniques, and the future of the discipline very much lies in bio- and geochemistry (isotope analysis, DNA profiling), computerised functions (e.g. GIS) and other impressive and 'high-tech' tools. That biological anthropology takes advantage of new techniques that are developed and has them applied to its material is beneficial and to be encouraged, especially for questions that cannot be answered by traditional methods. There are, however, some issues relating to this. The development and application of such tools is protracted and often extremely expensive. Because they are quite impressive, they often catch the imagination of funding panels who might be more eager to spend the little money that is available for research on high cost modernistic projects. This would not matter if there was sufficient money available, but this is never the case. Few grants are awarded to fewer, expensive projects, and it means that individuals are going to seek out new techniques to investigate to increase their chances of funding, which could be at the cost of low profile and more traditional research. Although it is essential to develop new tools and techniques, many questions can still be be resolved using more old-fashioned techniques of macroscopic analysis.

There is indeed still a lot to be learnt from human bones analysis and macroscopic diagnostic techniques, and a lot of groundwork to cover without the need for "high-tech" equipment (e.g. international comparisons, the development of models, etc.). Also, use of complex machinery is never going to become standard practice in post-excavation analysis of human bones analysis, which usually takes place when the budget for the excavation has already been stretched to its limits. Funding available to archaeology is highly unlikely to increase, indeed, the opposite is more likely. This does not mean that 'high-tech' projects should not be undertaken or funded, as some questions will never be answered without their assistance. However, it is perhaps

advisable to concentrate on what is already available and attempt to develop it further, and be realistic in our expectations and selective in the application of newer techniques.

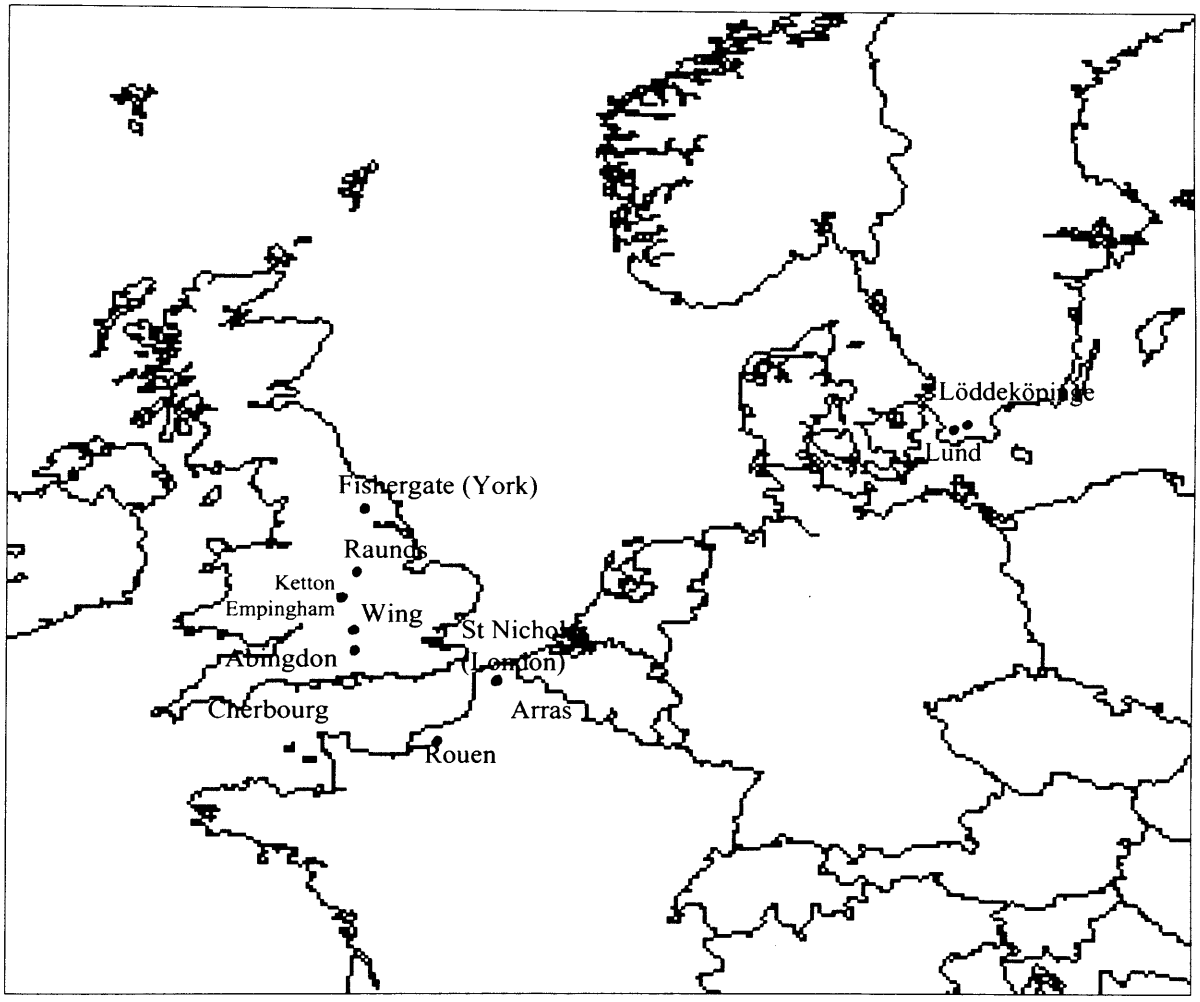
This project has investigated the use of both more traditional and new techniques in the field of human bones analysis. As for the majority of disciplines that form archaeology and the study of the past, biological anthropology is not without its own limitations and sometimes insurmountable difficulties that make drawing any kind of conclusion difficult at best. Human bones specialists are always aware of the level of information that can be derived from skeletons and how it can affect any ensuing reconstruction. There are many factors affecting the preservation, discovery, excavation and the curation of human remains that will have an effect the quantity and quality of the skeletal remains, as well as its analysis. These can make the task of inferring health, or indeed any kind of (useful) information from skeletons even more difficult. Papers on the limitations of using human skeletal evidence for health and disease are plentiful (e.g. Wood *et al.* 1992, Bocquet-Appel and Masset 1982), even with well-preserved skeletons. More positively, however, the literature reporting case studies and more general analyses is far more abundant. As research advances and new investigative tools and techniques are developed, limitations can be circumvented and the future of anthropology looks very promising indeed.

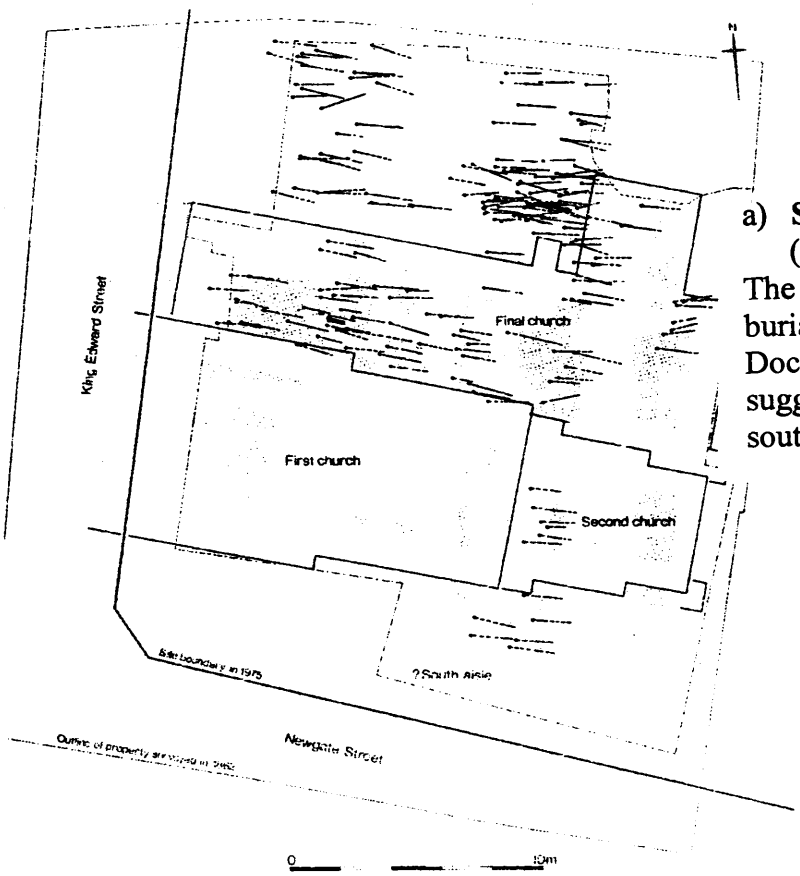
International comparisons of skeletal assemblages of a similar nature and historical period are valid and informative about health in the past, and it is surprising that so few truly international studies have been undertaken previously. Projects such as this one can provide a unique outlook on the range of past human life experience and identified evidence of the diversity that is potentially present in early medieval European populations. There are of course limitations linked to the available data, but as they are identified and it is attempted to solve them the discipline can only progress. If European and international co-operation can continue, and communications between the various fields of the study of the past and its people develop, the science can only be better. It is therefore important and worthwhile to persevere with using human bones to answer questions on health, the life and death of past populations.

Appendix A

Site plans and maps

Map of the sites investigated in this project

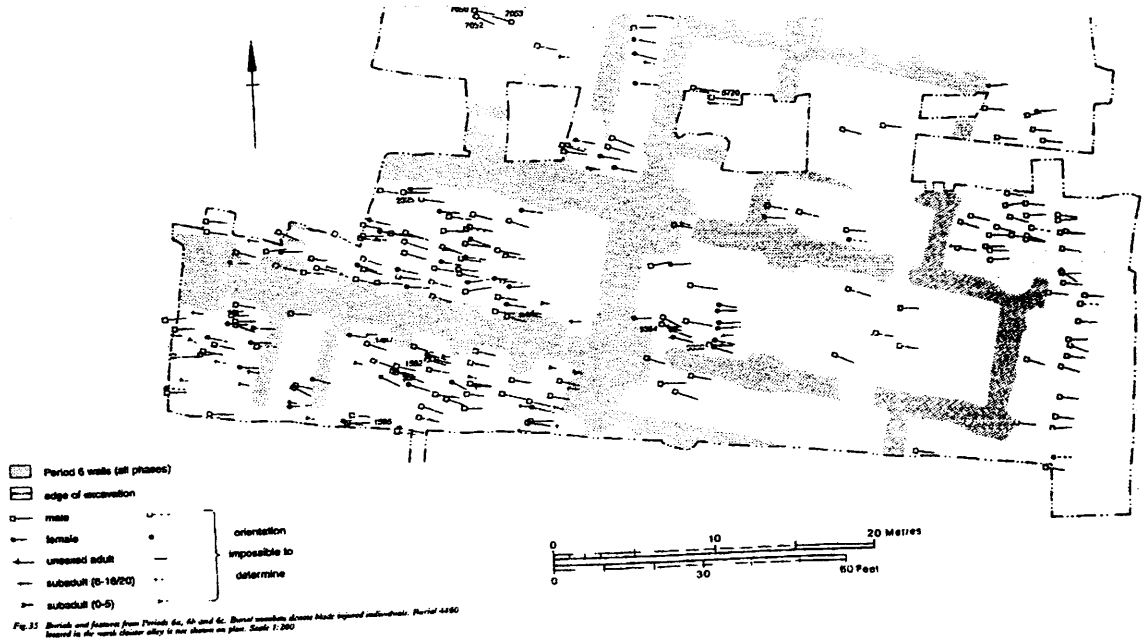




5. *Plan showing distribution of all recorded burials. The length of the symbol indicates the extent of the surviving remains. The tone in this and Figs 6–11 and 34 indicates excavated areas.*

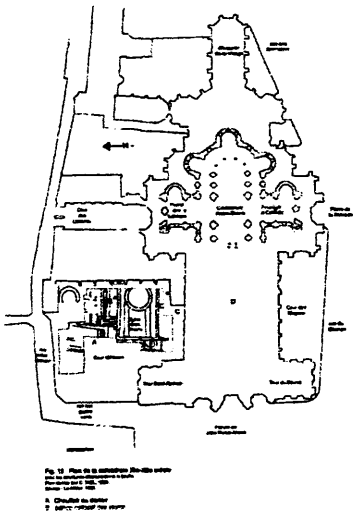
a) **St Nicholas Shambles** (City of London), from White 1988. The excavation comprised mainly the burials to the north of the church. Documentary evidence does not suggest there were more burials south and west of the church.

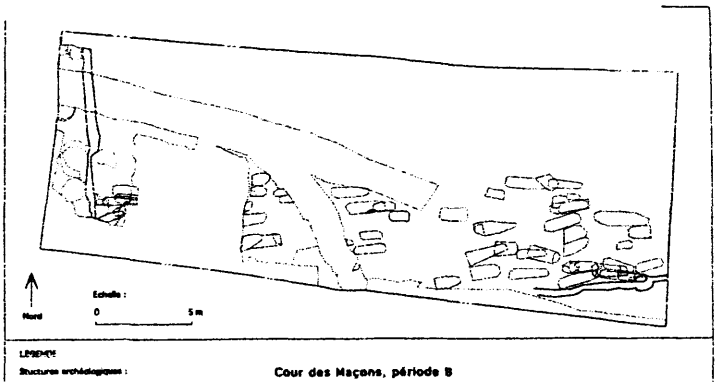
b) **Fishergate 4** (York), from Stroud and Kemp 1993. Originally a parish cemetery, the church eventually became a Gilbertine priory. Overall, the site was used for burials for over 500 years.

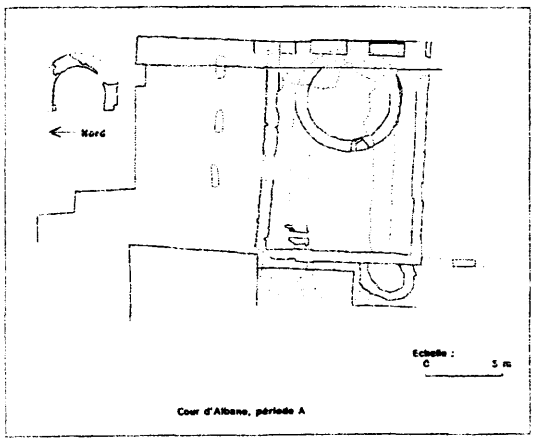


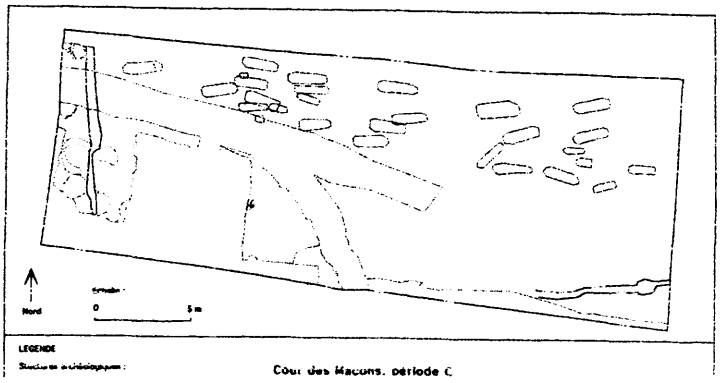
c) **Rouen** (France), courtesy of C. Niel after Le Maho 1994.

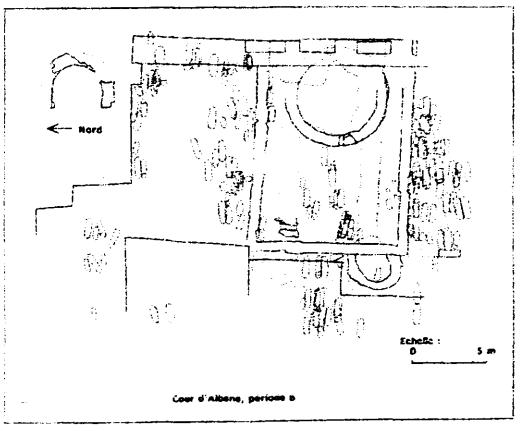
The large urban cemetery is comprised of two sections. Cour d'Albane (to the left), which had archaeology dating back from the 3rd century AD, and Cour des Maçons (to the right), which received some of the latest burials.

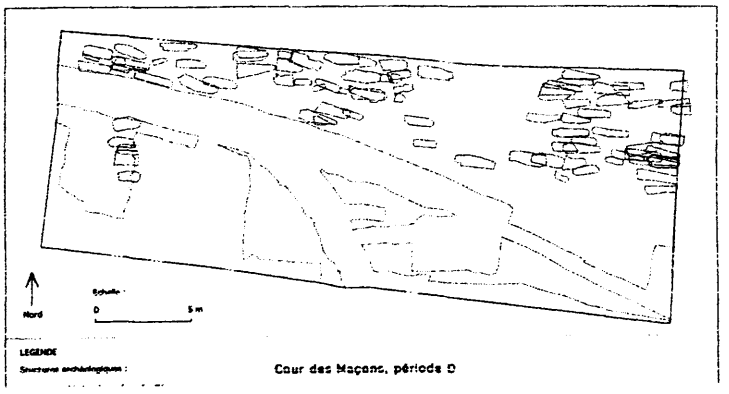


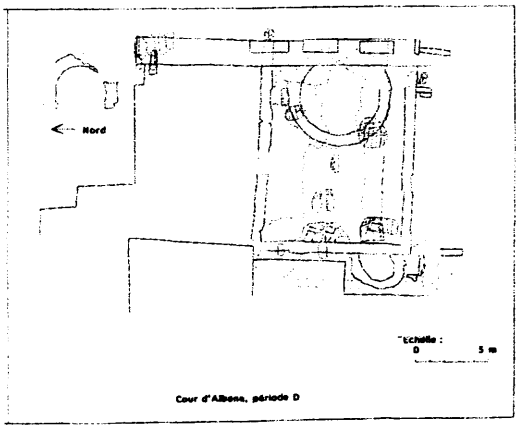


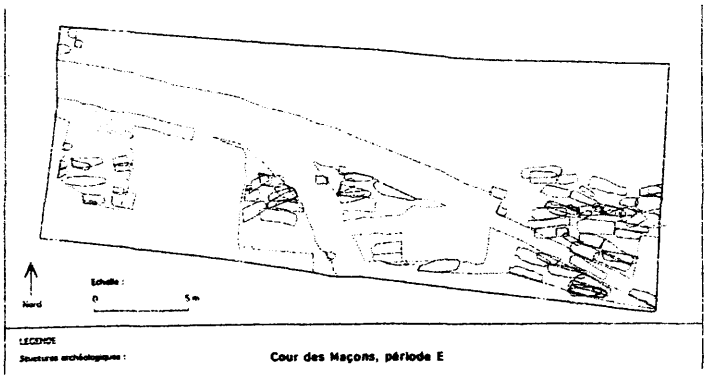


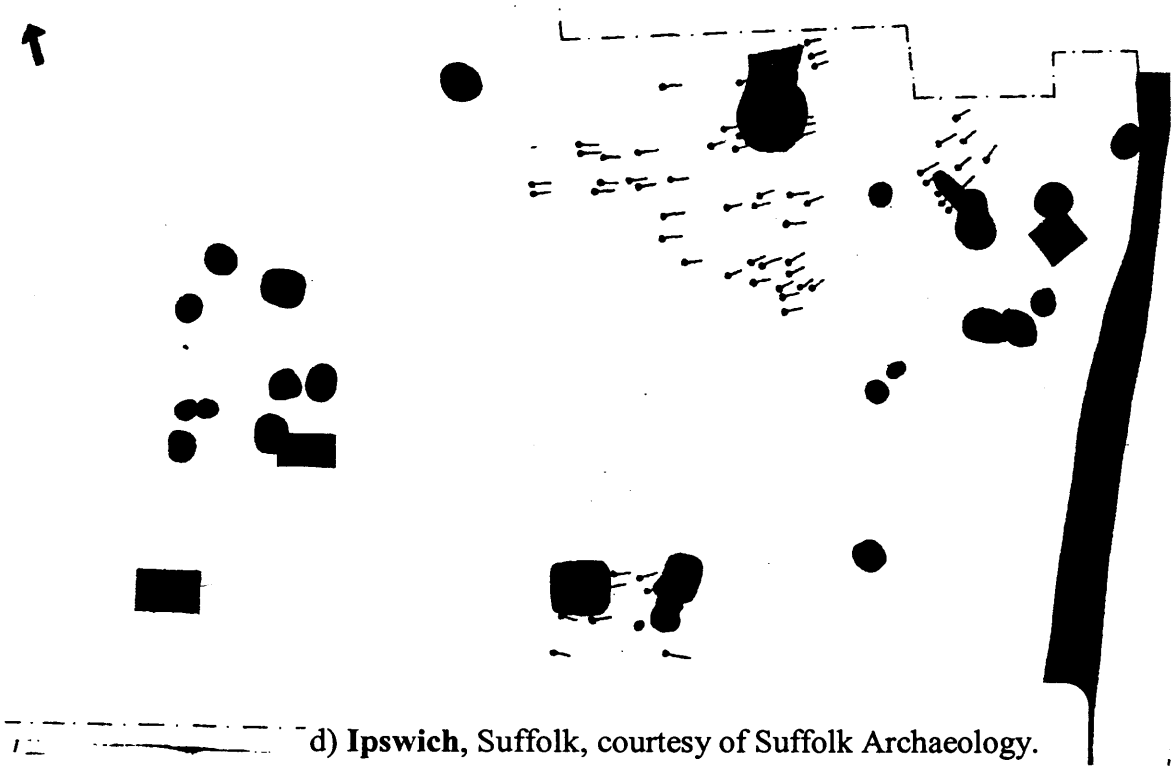






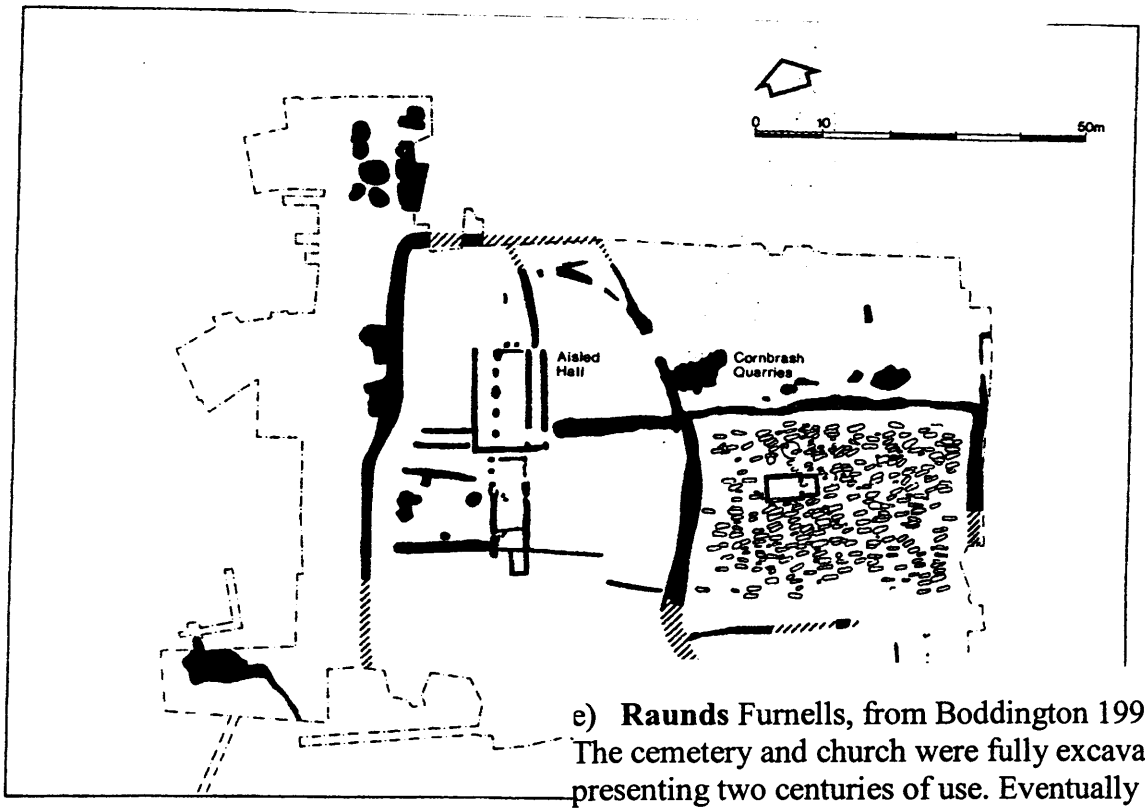






d) **Ipswich**, Suffolk, courtesy of Suffolk Archaeology.

No church or evidence of buildings was located in the excavation area. More burials probably lay further north.

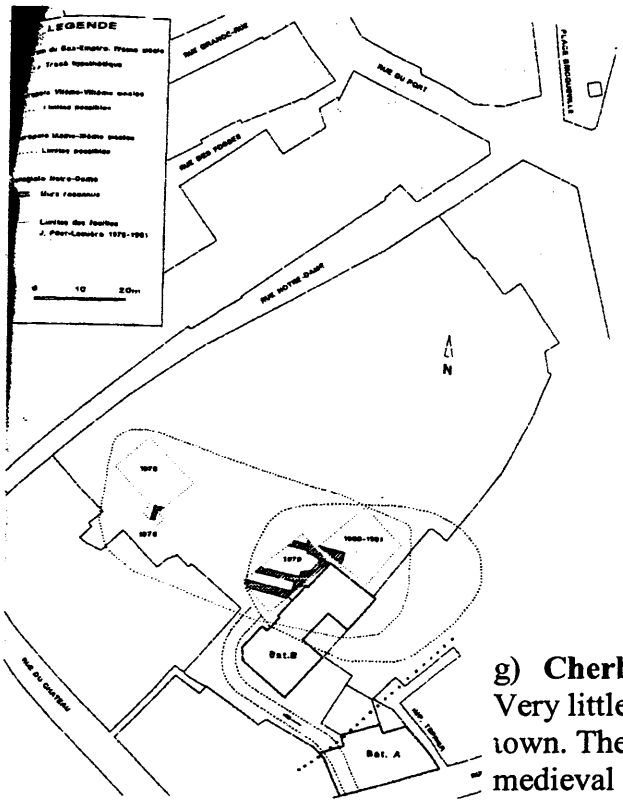


e) **Raunds** Furnells, from Boddington 1994. The cemetery and church were fully excavated, presenting two centuries of use. Eventually the church was converted into a manorial building and the existence of the graveyard forgotten.

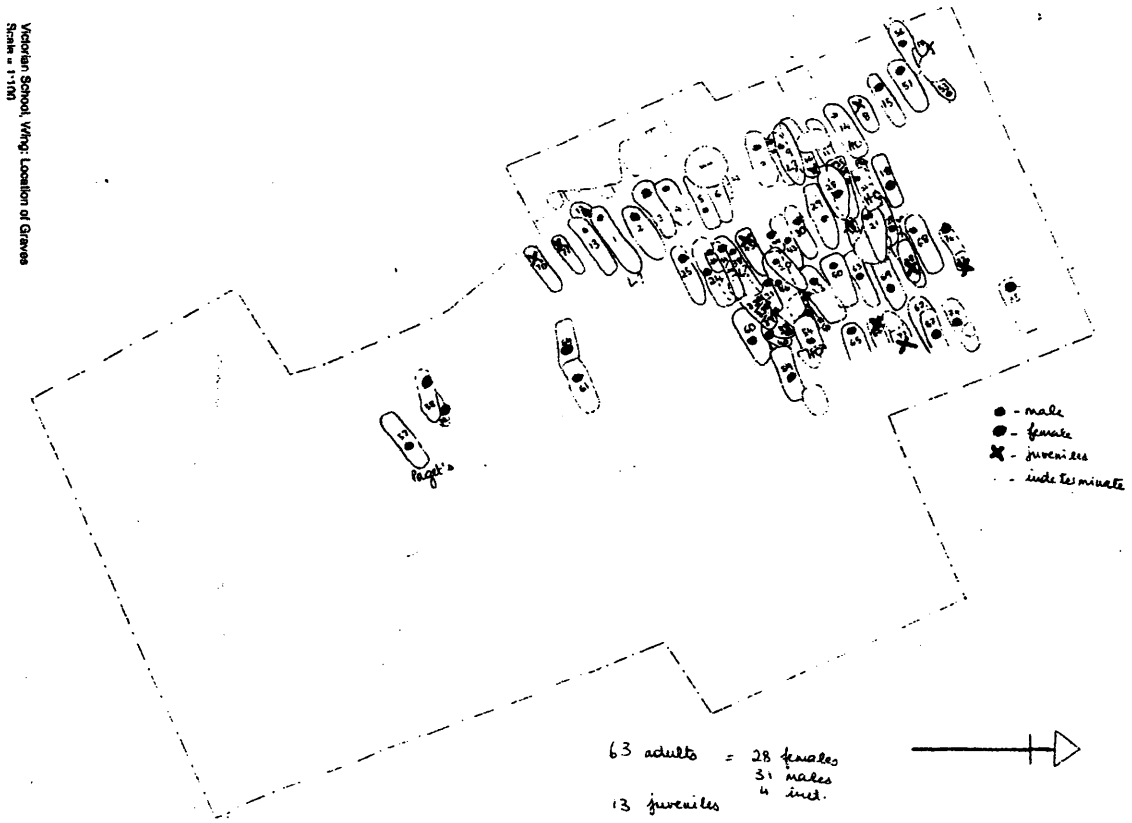
Fig 3 Raunds Furnells in the Saxo-Norman period

f) **Löddeköpinge** (Sweden), from Cinthio 1980.
The late Viking-age rural settlement included a port and a market. Over 1,412 skeletons have been excavated, and it is possible that another 1,000 graves have yet to be excavated.

Fig. 2. General plan of the burial site. Key: 1=modern disturbance, 2=the boundary ditch, 3=stone packing, 4=wood coloration? 5=grave. 6=limits of excavation.



g) **Cherbourg** (France), courtesy of F. Delahaye.
Very little archaeology has been unearthed from this town. The three excavations have revealed half of the medieval cemetery. Until the 11th century, it was the only burial ground in the town.



h) **Wing**, Bucks, courtesy of Northamptonshire Archaeology.

The part of the cemetery excavated is believed to represent a quarter of the total cemetery. All Saints church is located north-west of the excavated area.

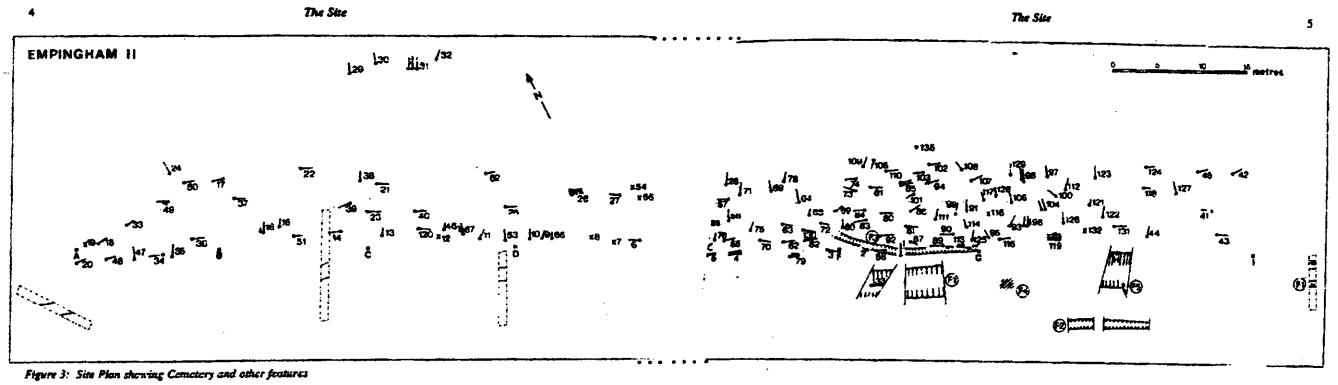
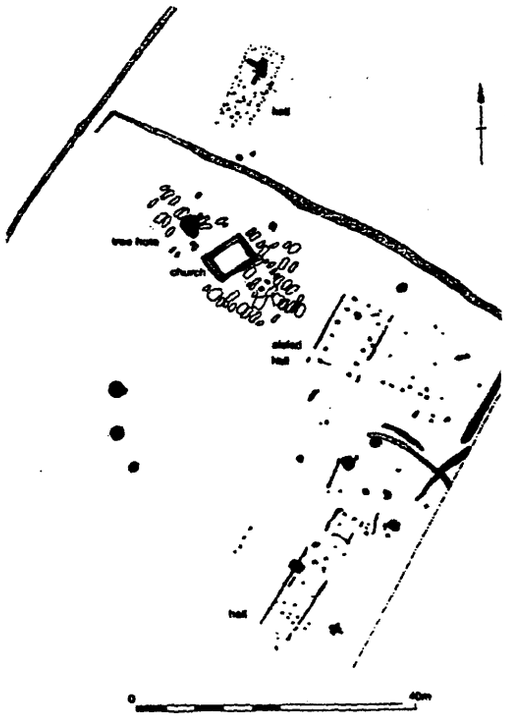


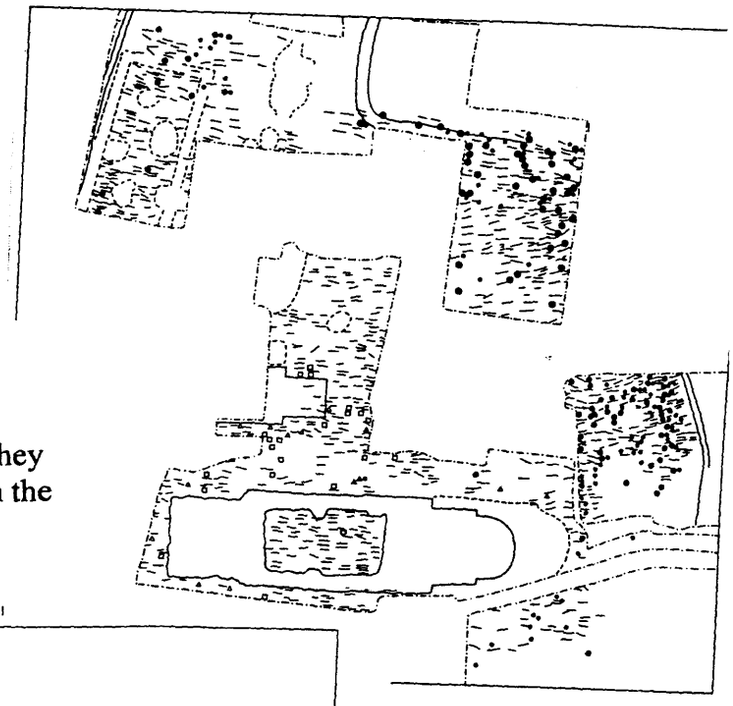
Figure 3: Site Plan showing Cemetery and other features

i) **Empingham** II, Rutland, map montage from Timby 1996.

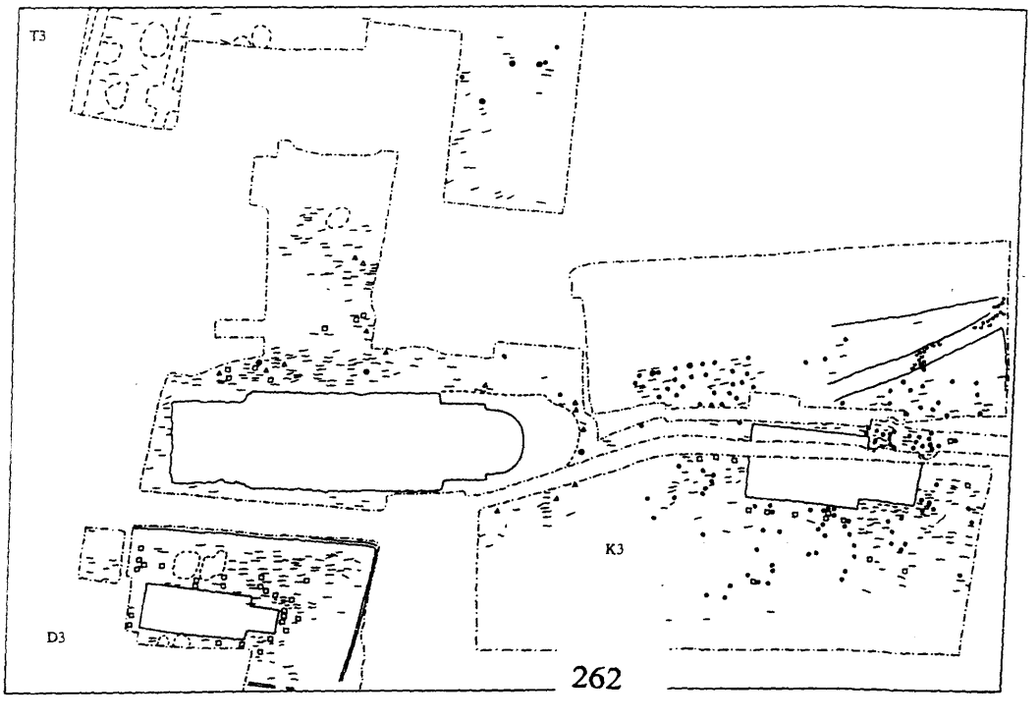
The skeletons were very fragmented and eroded, but artefacts recovered from the site suggest suggest that a cross-section of society was buried there, with evidence of wide-ranging trade or social contact.



j) **Ketton**, Rutland, courtesy of Northamptonshire Archaeology.
The site has been interpreted as a manorial complex, including a single-cell church and cemetery. The churchyard layout would suggest two burial groups, one to the north and the other to the south, but radiocarbon dating has revealed that they are contemporary.



k) **Lund** (Sweden), from Arcini 1999.
The Lund assemblage is composed of three cemeteries: T1-3, K3 and D3, all neighbouring . They represent the very first parishes of the new town in the 12th – 12th centuries.



0. The graves and the burial customs, T1, T2.

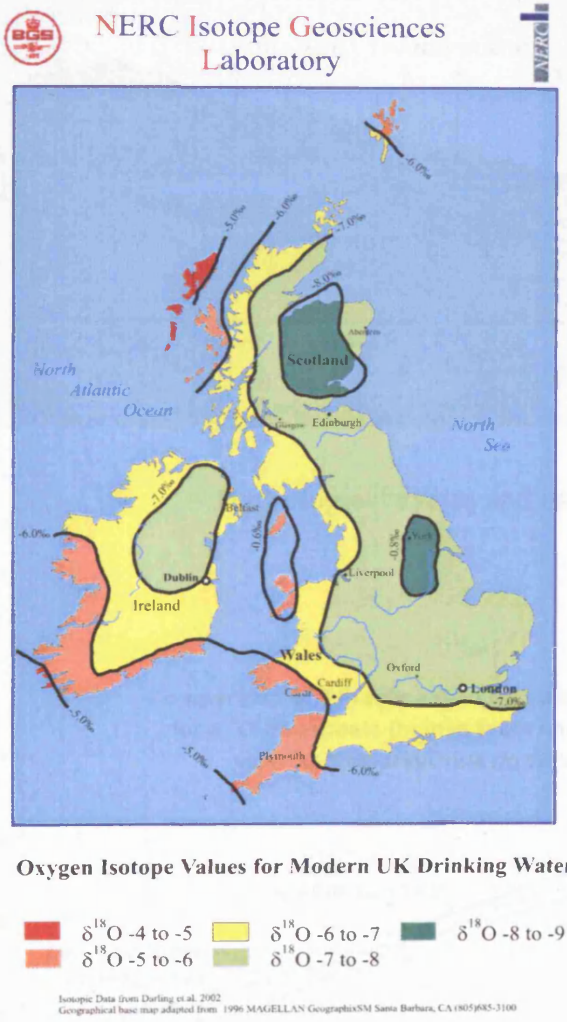
Graves with:
- charcoal
- lime
- sticks
- log coffin
- other graves
- limit of excavation

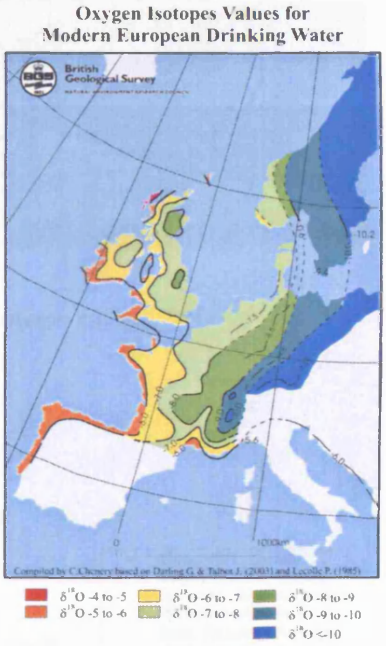
Fig 2:8 The Trinitatis Church, the two wooden churches and their cemeteries c.1050-1100. The graves and the burial customs, T3, D3, K3.

Appendix B

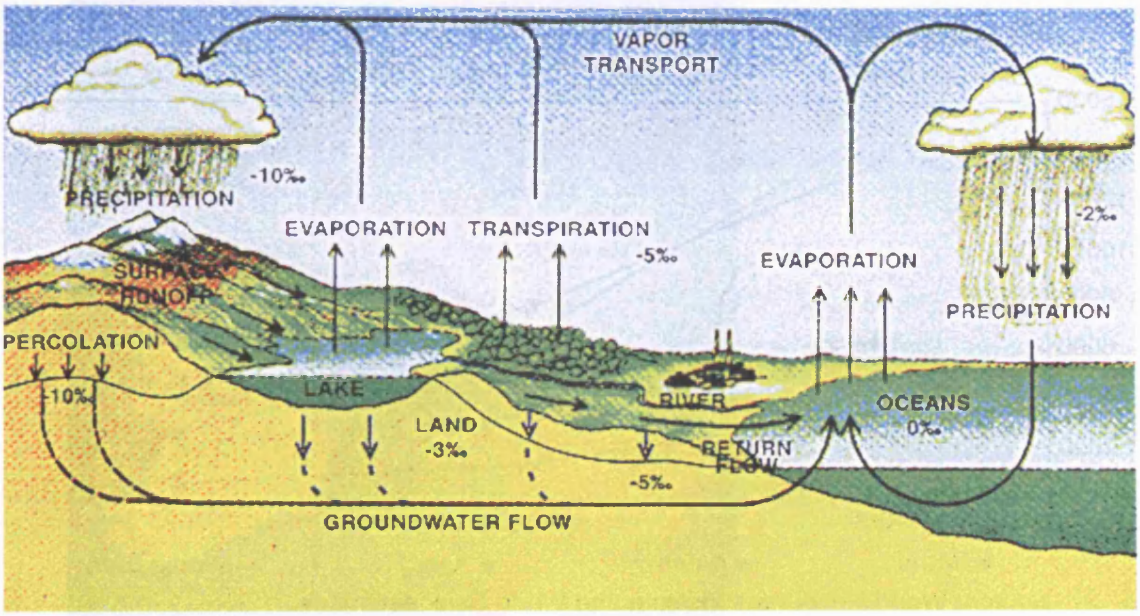
Illustrations

Oxygen isotope analysis

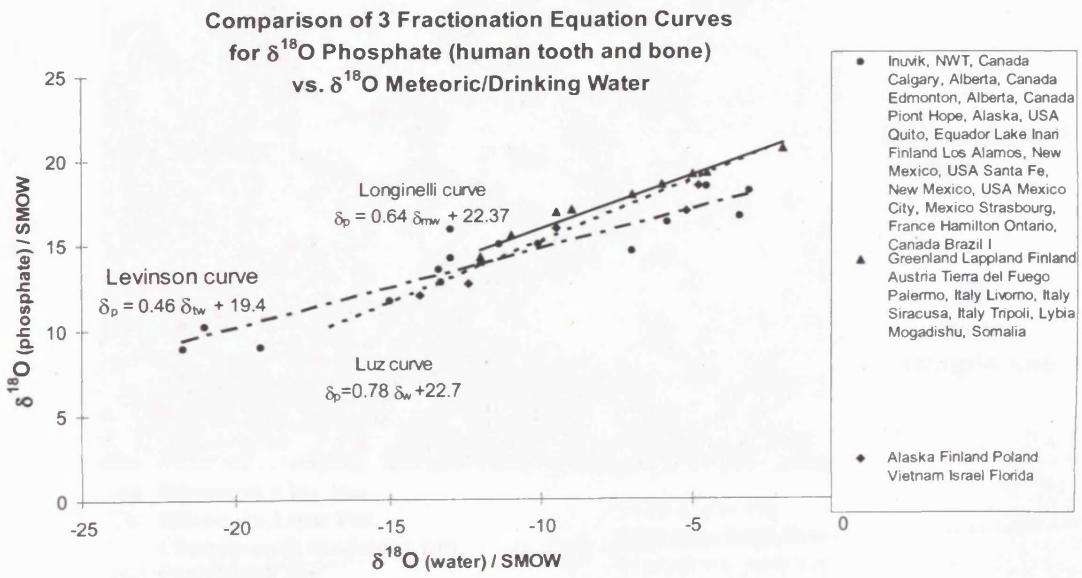




Drinking water maps for oxygen isotope analysis: the UK and Europe



Hydrological cycles and oxygen isotope ratios



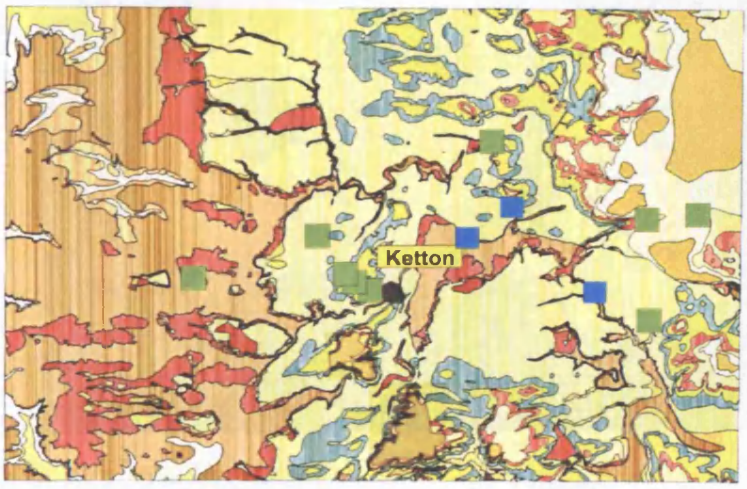
NERC Isotope Geosciences Laboratory

Strontium isotope analysis.

Map of expected values for Britain

$^{87}Sr/^{86}Sr$ <0.7073
$^{87}Sr/^{86}Sr$ 0.7073-0.7084
$^{87}Sr/^{86}Sr$ 0.7084-0.7100
$^{87}Sr/^{86}Sr$ >0.7100

Map of Ketton geology

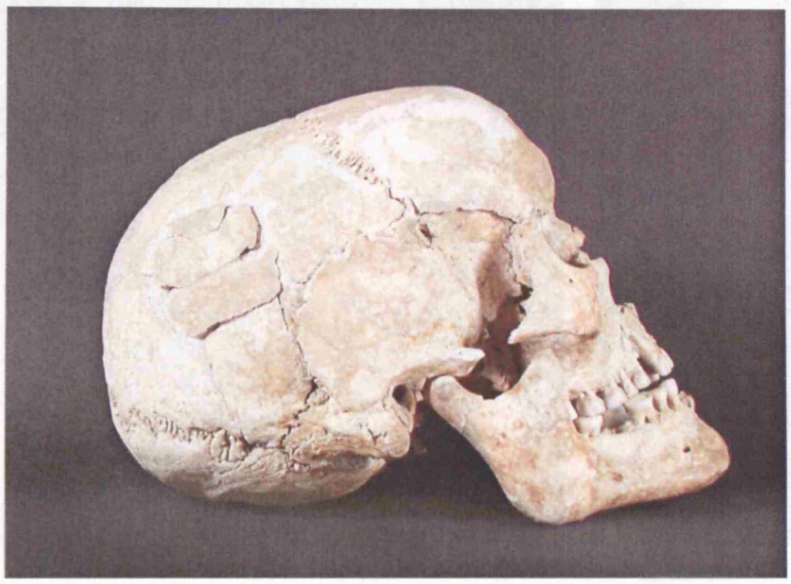


Soil and plant sample site

Water sample site

Blisworth Clay Fm
Blisworth Lmst Fm
Charnmouth mudstone Fm
Cornbrash Fm
Dyrham Fm
Grantham Fm
Kellaways Fm
Lincs. Lmst Fm
Marlstone Rock Fm
Northhants sand Fm
Oxford Clay Fm
Rutland Fm
Whitby Mudstone Fm

Evidence of inter-personal violence in an urban environment (Rouen)



Young male from Rouen with sword cuts to the head

Evidence of long-term physical disability (Rouen)

Two young females with congenital hip dislocations

Dislocated shoulder joint (scapula) in a young male with new joint formed anteriorly

Shortened humerus as a result of trauma to the proximal half during childhood

Appendix C

Paleopathology plates and notes

Plate A

Tuberculous spine lesions in individuals from Rouen

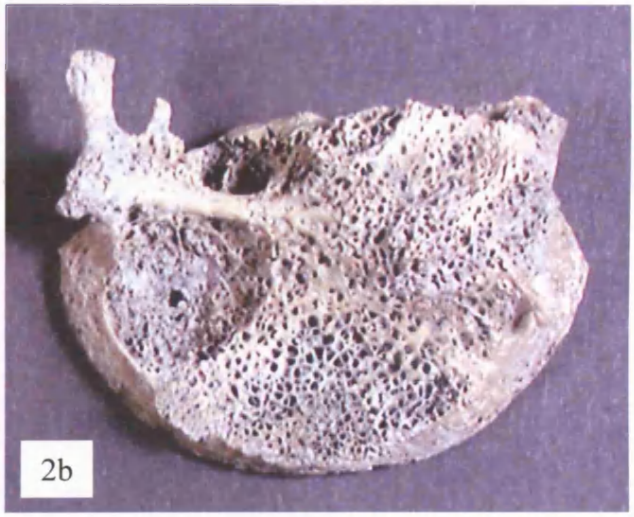


Plate B

Possible tuberculous lesions from Rouen

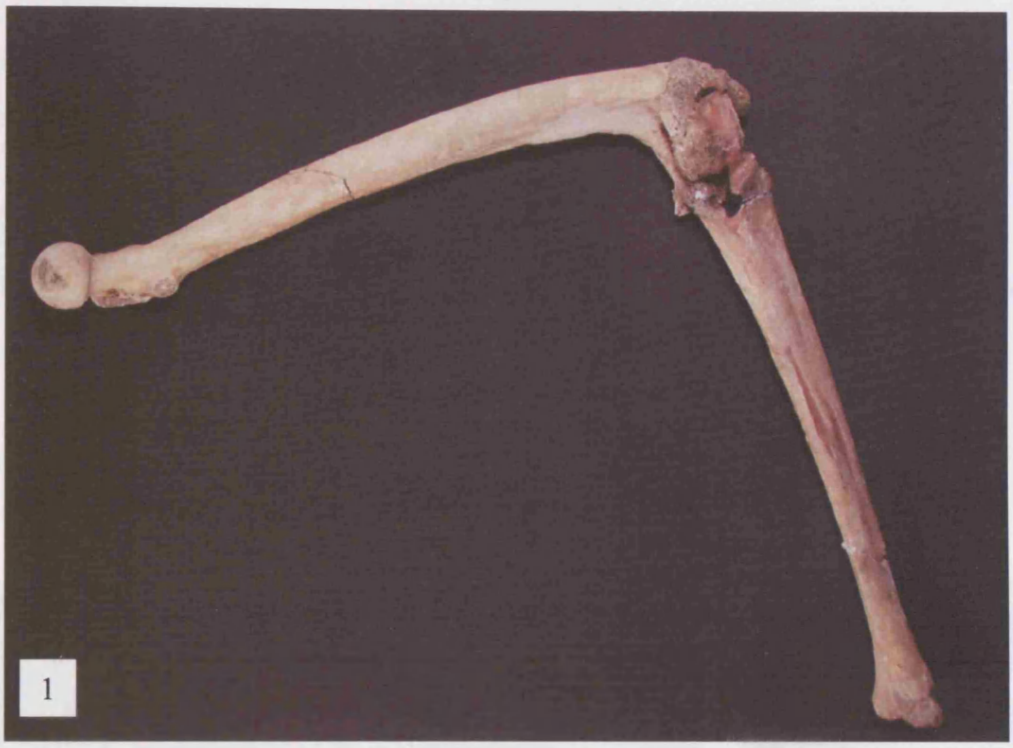
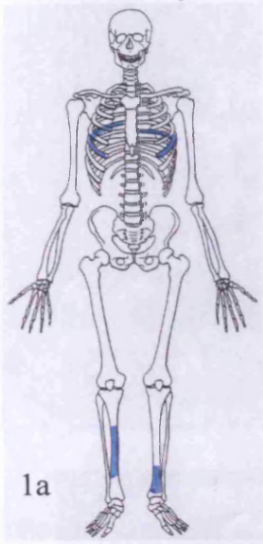
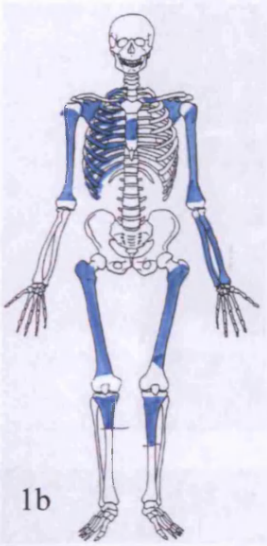
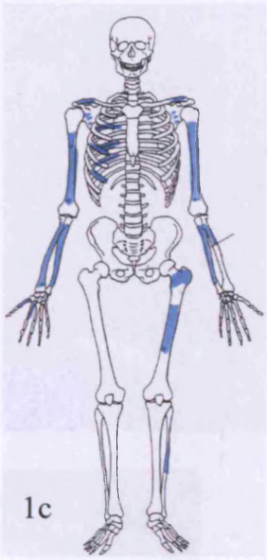


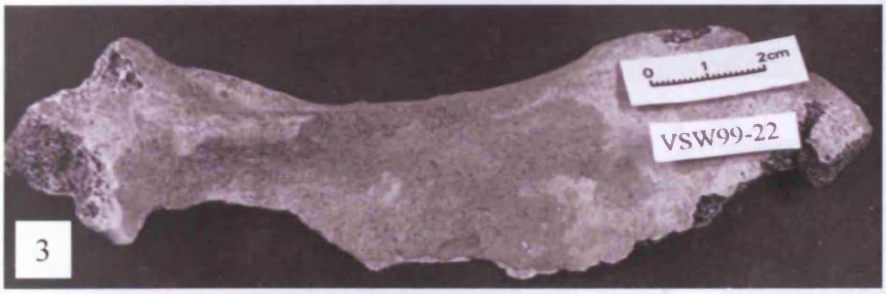
Plate C

Hypertrophic Osteoarthropathy (HO) in three individuals from Wing









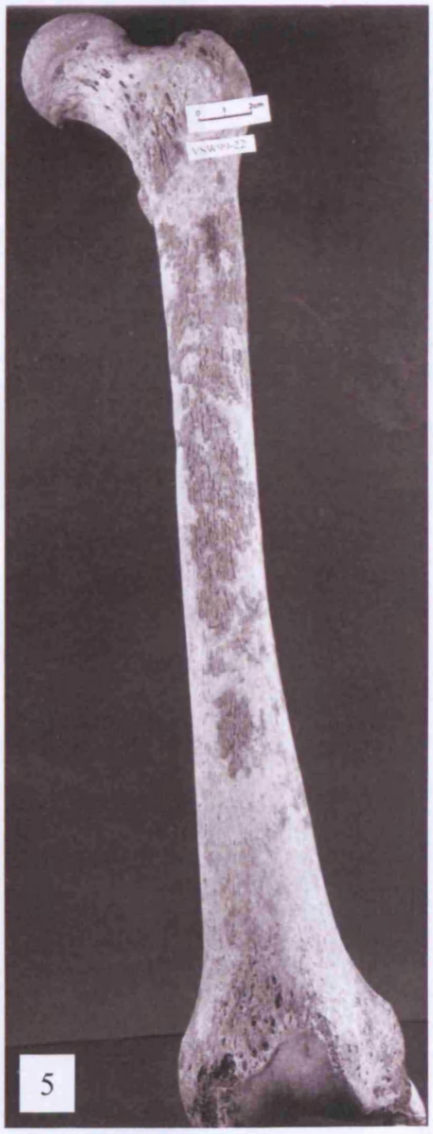
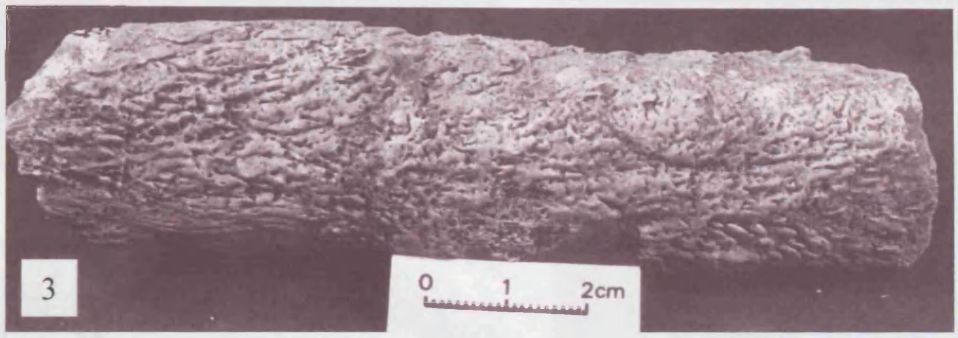
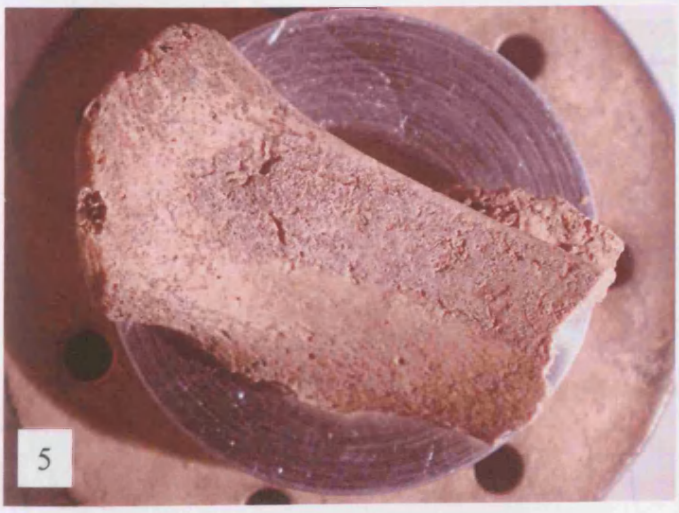


Plate D

SEM samples (rib and femur) from individuals with HO (Wing)





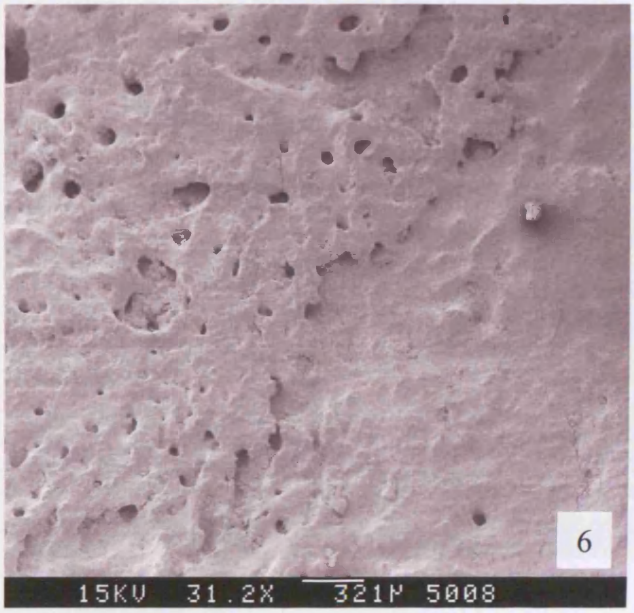
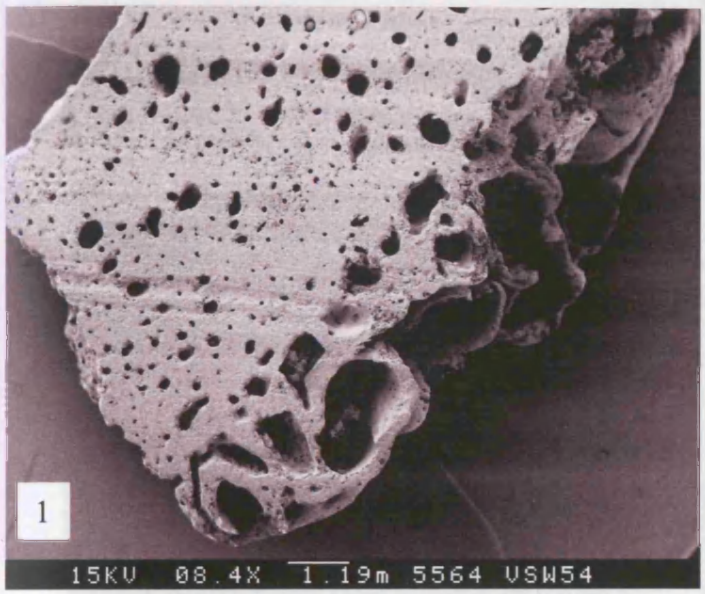
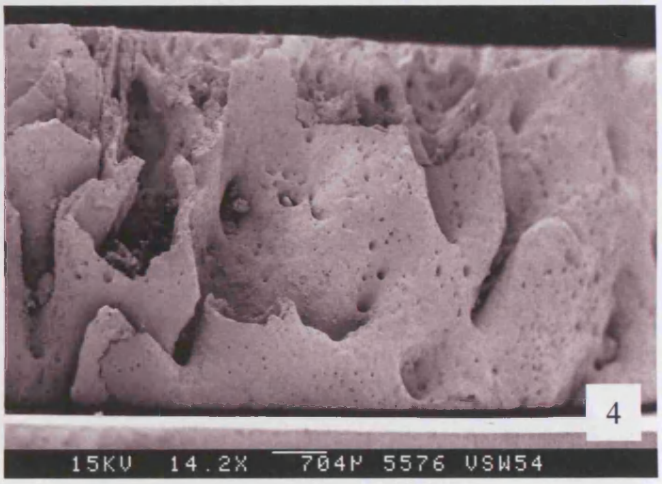
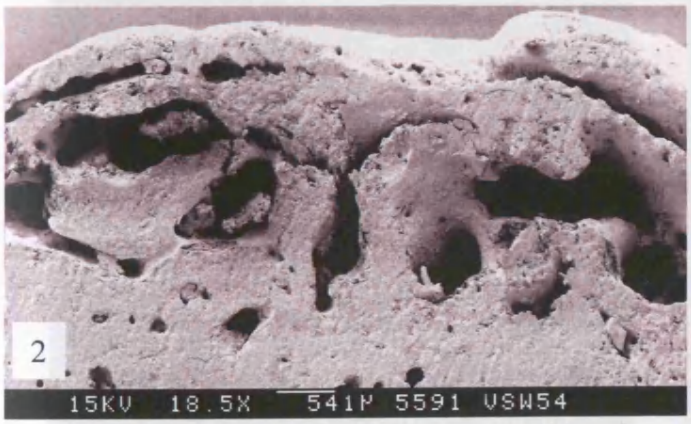


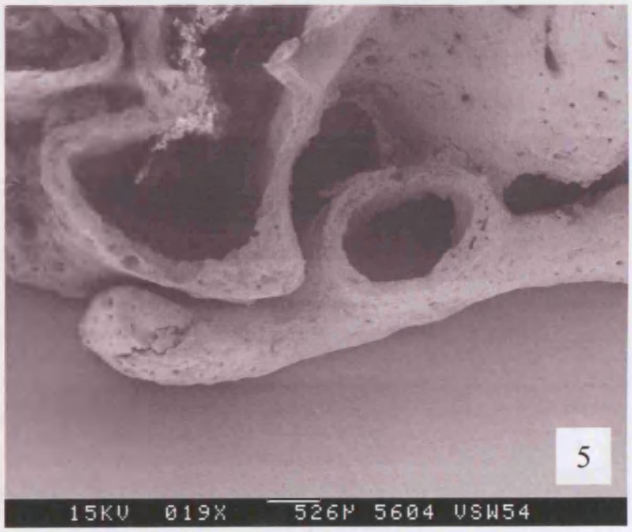
Plate E

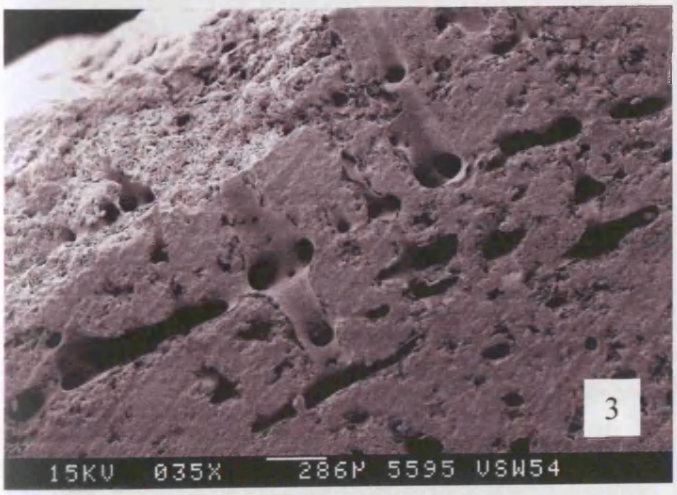
SEM of the femur with HO (Wing)











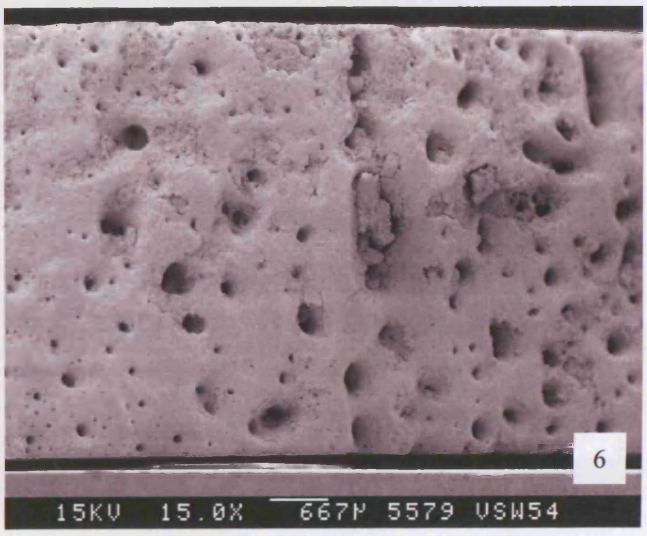
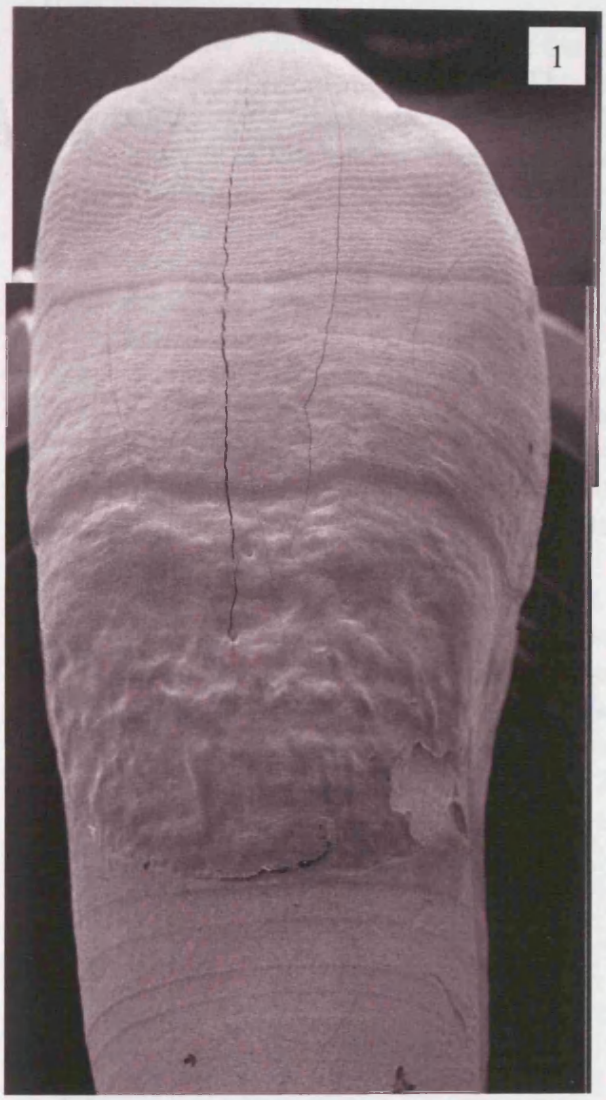
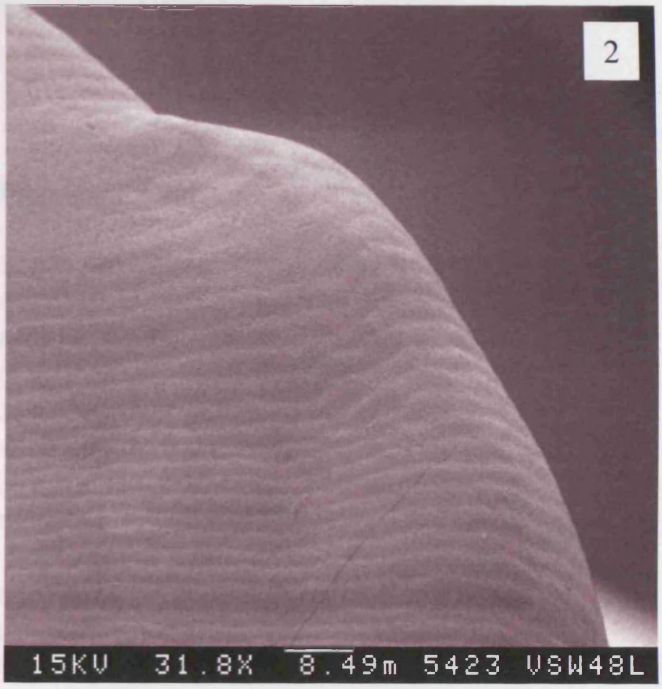
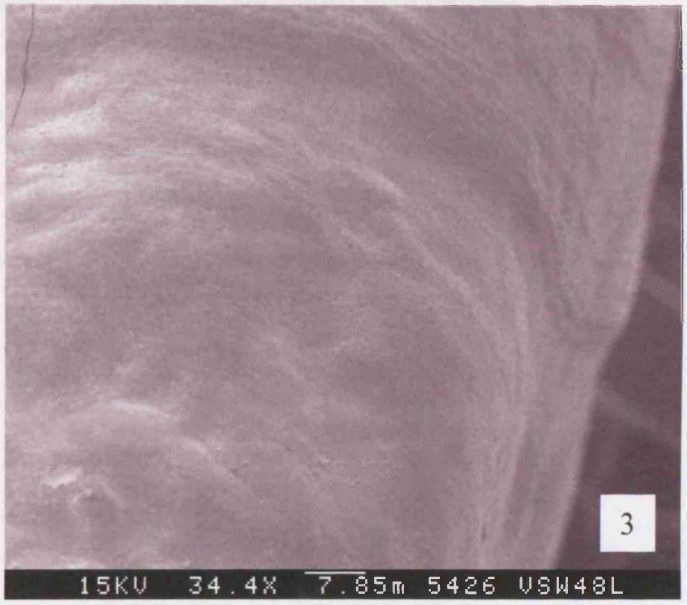


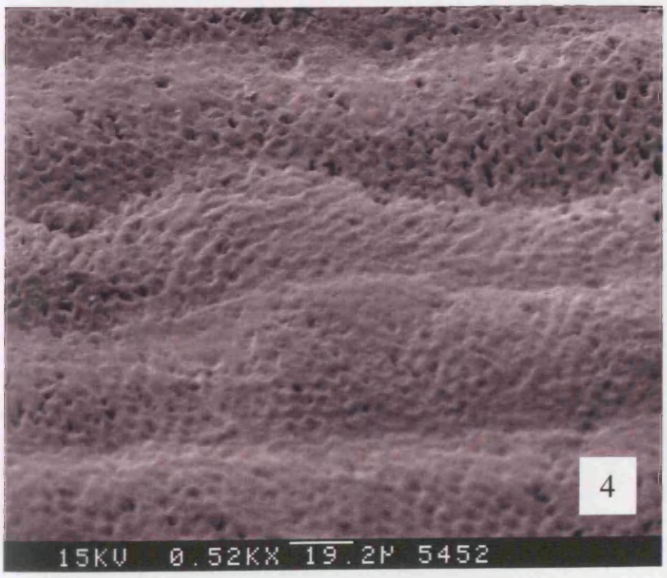
Plate F

SEM of enamel hypoplasia (Wing)









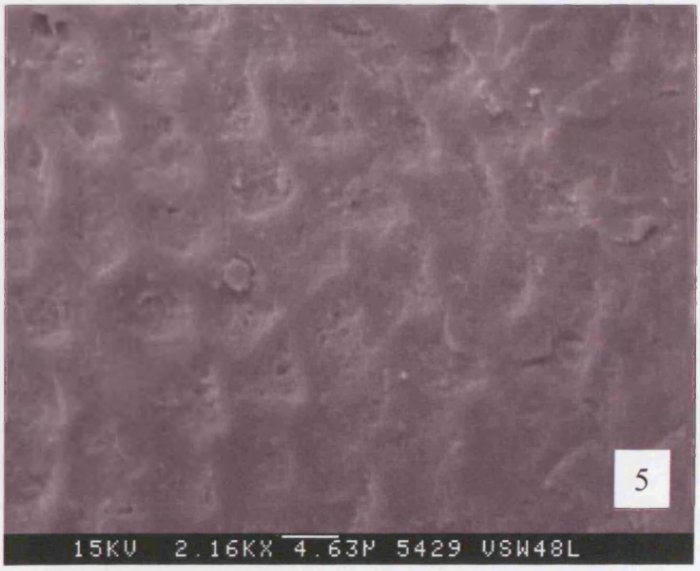


Plate A. Tuberculous spine lesions in individuals from Rouen.

1. A Pott's spine. Lateral view of the sacrum and the last three lumbar vertebrae, placed in the supine position. The sacrum is easily identifiable from the auricular surface (the shiny surface is caused by vestiges of glue). The arches and spinous process of the lumbar vertebrae are observable despite some post-mortem damage. The bodies have collapsed and ankylosed in one mass and fused to the sacrum. The resulting kyphosis is visible, especially when comparing the level of the body of the first vertebra to its spineous process. It is less common to find a Pott's spine so far down the spine as they are usually situated at the mid-thoracic level. (CA 2320: Male, 45+)
2. A and B. Same vertebral body. A is the inferior face and B the superior face. Note how normal the vertebra appears when viewed from it inferior side (2a). The superior side, however, is almost completely destroyed by a lytic process. The walls of the depressions are smooth and rounded, denoting a slow destructive process. Of the spine, only C1 to T2 vertebrae survive, and this one lumbar vertebra. (CDM 5014: Female, 45+)
3. Three mid/lower thoracic vertebrae, each with scalloping and lytic destruction of the anterior surfaces of the vertebrae. The depressions on the superior surface of the vertebrae are Schmorl's nodes and are not linked to tuberculosis. Two thoracic vertebrae (T6 and T7) were ankylosed. This is unlikely to happen at a young age, and the fact that there were rib lesions seems to support the diagnosis of tuberculosis. (CDM 4547: Female, 25-35)

Plate B. Possible tuberculous lesions from Rouen.

1. Ankylosed left femur and tibia. The pink areas are wax that was used to preserve the bones. The knee has been destroyed and ankylosed by a septic process and no longer serves its function as an articulation. The erosion on the epicondyles and the new bone formation at back of knee are clearly visible. Although the appearance of the femur remains normal apart from the distal end, the tibia feels osteoporotic and the smooth surface suggests muscle wastage caused by the ankylosis. The hip, however, was still functioning at the time of death as muscle attachments show. The upper arms were very well developed with marked muscle attachments, especially around the deltoid tuberosity, the greater and lesser tuberosity and a marked intertubercular groove. The greater tuberosity had some porosity suggesting deep sharpeys fibres. This upper arm development would concord with the use of crutches. This individual also had a Pott's spine [Plate A no.1], some traces of periosteal lesions on the ribs, all of which concur to a diagnosis of tuberculosis.
2. Endocranial periosteal lesions. This young male had periosteal lesions in the inside surface of the cranium. The lesions on the picture can be seen in the lower half of the skull, into the meningeal groove for the sigmoid venous sinuses. The brown stains on the upper half are water markings. This individual's spine also had some porosity on the anterior part of the vertebrae at the thoracic level, and the tibia had some periostitis and swelling. Altough the endocranial lesions are not specific, they could correspond to meningeal tuberculosis which is common in young people. This case though was not included in the results section. (CDM 4571: Male, 18-25)
4. Periosteal lesions on the ribs. The lesions are clear to see and cover the visceral surface of this particular rib as well as others. The periostitis in this case is very fine and lacy in its appearance, quite a contrast to that in Plate C no. 2. This individual also had vertebral lesions as shown in Plate A no. 3. (CDM 5014: Female, 45+)

Plate C. Hypertrophic Osteoarthopathy in three individuals from Wing.

1. A, b and c. Location of the periosteal lesions on the individuals. 1a: VSW 14: Male, 35-40; 1b: VSW 22: Male, 25-30; 1c: VSW 54: Male, 45-50. The distribution, centred on the long limbs and the ribs, concur with the diagnosis of hypertrophic osteoathropathy.
2. Rib lesions, notice the difference from that Rouen one [Plate B no.3]. The lesion appears to be thicker, covers a more defined space and is restricted to one area. (VSW 14: Male, 35-40)
3. Axial elements are rarely affected by HO but in this individual periosteal lesions were well spread and visible on both scapulae as well as the sternum. (VSW 22: Male, 25-30)
4. Distal right ulna. This ulna shows another type of periostitis, this one appears to be more severe and of the appliqué type. It is clearly distinctive from the underlying original cortex.
5. Left femur with patches of periosteal lesions. (VSW 22: Male, 25-30)

Plate D. SEM samples (rib and femur) from individuals with HO (Wing)

1. Section of the femur from the mid-diaphysis area. The active and remodelled lesions are on the edge of the surface and have a frilly appearance. (VSW 54: Male, 45-50)
2. Enlarged area from the section showing the extensive bone changes. The yellowish appearance of the bone is caused by the gold coating in preparation of the SEM. (VSW 54: Male, 45-50)
3. Left femur showing extensive deposits of new bone covering the surface of the diaphysis of the femur. The periostitis is particularly severe and causes the bone to appear malformed. (VSW 54: Male, 45-50)
4. The same femur showing the posterior side where there are large areas of remodelled bone as well as acute new bone formation. The healing bone has the typical porous and striated appearance of periostitis on the lower legs. (VSW 54: Male, 45-50)
5. Part of a rib with periosteal lesions on the visceral surface. The rib has already been coated with gold and mounted on a stand for SEM analysis. (VSW 22: Male, 25-30)
6. Scanning electron micrograph of the rib surface. The periostitis is distinctive on the left hand side, with the normal smooth surface of the cortex on the right hand side. The periosititis is clearly observable as an apposition of new bone. (VSW 22: Male, 25-30)

Plate E. SEM of the femur with HO (Wing)

1. The bone cortex is covered with a layer of new and active bone formation. Note the size and quantity of blood vessels. Longitudinal micrograph. (VSW 54: Male, 45-50)
2. Close up picture of periosteal lesion attached to the cortex by bony bridges. Three successive layers of reactive bone are visible. The uppermost layer shows the most recent bone-laying phase whereas the bottom one is integrating the cortex, adding thickness to the bone diaphysis. Longitudinal micrograph. (VSW 54: Male, 45-50)
3. Bone cortex. The superior part has been damaged post-mortem. It shows remodelled lesions that have been integrated to the cortex. The blood vessels separating each layer indicate a new episode of new bone forming on top of the previous one. Longitudinal micrograph. (VSW 54: Male, 45-50)
4. Bone surface showing the close-up appearance of the periostitis, where the new bone clearly encapsulates surface blood vessels, giving it an irregular appearance. (VSW 54: Male, 45-50)
5. Close up of encapsulated blood vessels. (VSW 54: Male, 45-50)
6. Cortical surface, showing the typical porosity and striation associated with the appearance of periostitis. (VSW 54: Male, 45-50)

Plate F. SEM of enamel hypoplasia (Wing)

1. Montage of a series of micrographs to recreate the appearance of the crown. Each episode of enamel hypoplasia is clearly visible. The first third of the tooth is free of defects and the perikymata (the fine horizontal lines) are very clear, showing that this individual was still young, as they were not worn away, even on the tip. In the second half the hypoplastic defects of the furrow type start to appear, showing episodes of ill health, albeit short ones. In the last third of the crown the defects become more severe and the episodes of ill-health longer as one deep hypoplastic line is followed by a long period with a mottled aspect typical of the pitted type of hypoplasia. Amongst a wide but very shallow furrow type hypoplastic defect is also visible. The formation of a line of enamel hypoplasia is viewed as an arrest of amelogenic growth during a period of stress, halting the completion of that particular implement. Because enamel cannot repair itself, when growth restarts a new increment begins leaving the previous one incomplete. Its surface has a reduced enamel thickness and is thus seen as a of sharply-defined, horizontal, linear groove extending circumferentially around the tooth crown, a permanent feature and record of a severe disruption of growth. The enamel defects are known as furrow-form defects and are the most common type of enamel hypoplasia. The pitted form is the second type of enamel hypoplasia and can be seen in 3. This individual does recover though, as her roots continue to grow and reach the age of eleven, although we cannot know if it is in better health. Left mandibular canine. (VSW48: F (DNA analysis), 11 years)
2. Close up of the top of the canine showing perikymata covering the whole tooth including the sides. Amelogenesis is an incremental phenomenon and its formation is recorded by a sequence of regularly spaced grooving which runs around the circumference, and each individual junction on the enamel, seen on the form of a groove, is called a perikyma. Each groove or perikymata has a different appearance according to its location on the crown and consists of three types of perikymata (occlusal, mid-crown and cervical). The occlusal type is shown here at the top with a mid-crown type near the bottom of the picture. Kymata in Greek means waves and it is obvious here that the broad shallow grooves give an impression of breaking waves. The perikymata are growing narrower as they progress down the tooth, which is a normal process. (VSW48: F, 11 years)
3. Enlarged area concentrating on the mottled aspect of the defective enamel. The other two forms of enamel hypoplasia are pit-form defects, where clusters of ameloblasts cease enamel matrix formation prematurely, and exposed-plane-form (not present in this tooth). The perikymata are visible on the right hand side of the picture. The linear enamel hypoplasia shows a deep indentation of the enamel, which must be very thin at that level. It doesn't seem to recover and the pitted hypoplasia is of irregular thickness. (VSW48: F, 11 years)
4. Perikymata at the mid-crown level. The lines defining the perkymata are sharper than the higher occlusal ones, which have a more rounded appearance and are starting to overlap. This will become more pronounced nearer the cervical margin. The Tomes' process pits are very distinctive and more confined to the grooves than to the wave crests.

5. A detailed view of Tomes' process pits, which mark the position of an ameloblast (enamel forming cell). Each pit corresponds to one cell.

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