The impact of the Roman-early medieval transition on childhood health in northern England

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PhD

University of York

Archaeology

June 2025

Abstract

The withdrawal of Roman control from Britain in 410 AD caused massive societal upheaval such that daily life was unrecognisable within a generation. Society looked different on every level, from the loss of central government, the coin-based economy and the military, to the collapse of towns and a return to subsistence farming. A downturn in climate also occurred, with colder, wetter weather impacting food production and disease transmission. Despite these transformations, the effect on the population's health, particularly in northern England, is unknown. This PhD research examines 656 individuals from northern England dating to the 3rd-7th centuries, analysing populations from Roman (n=4) and Early Medieval (n=8) cemeteries, and others that span the transition (n=7), for skeletal indicators of stress. It aggregates data from previous analyses of age and sex, stature, cribra orbitalia, dental enamel hypoplasia and rickets for comparison between the two time periods. In addition to the creation of this large dataset, some populations are reanalysed to collect vertebral neural canal measurements, a novel technique to uncover growth delay that may have been masked in stature by adolescent catch-up growth. Contrary to expectations, the dataset reveals broadly poorer health in the Roman period, with the early medieval individuals suffering fewer instances of pathology and less growth delay in stature comparatively. The vertebral neural canal did not present any change in size over time, indicating that the additional stress experienced by the Roman population was chronic, not severe acute episodes. This new evidence counters the picture of health worsening with the withdrawal of Roman control, seen in southern England and on the continent, and therefore indicates the unique position of northern England over the 3rd to 7th centuries.

Contents

List of tables

List of figures

Acknowledgements

A thesis like this cannot be produced without the assistance of many people, and I am grateful for the support I have received from all sources.

Firstly, the greatest thanks are due to my supervisors, Paola Ponce and Dawn Hadley, for their essential guidance, suggestions and comments on many successive drafts of this work. Their help has been integral to the success of this project.

Many people from a variety of institutions are also due thanks for helping me identify suitable case study sites, sending me reports which were often unpublished and unavailable through the standard routes, and allowing me access to skeletal assemblages for recording. I thank Malin Holst and Anwen Caffell of York Osteoarchaeology, Emily North from York Museums Trust, Ellie Drew, Christine McDonnell and Giulia Gallio of York Archaeological Trust, Charlotte Roberts and Sarah Semple from Durham University, Dominic Powlesland of the Landscape Research Centre, Lauren McIntyre of Oxford Archaeology, Paula Ware and Kelly Hunter from MAP Archaeological Practice, Katherine Baxter of Leeds Museum, David Marchant of East Riding Museums, Graeme Young from the Bamburgh Research Project, Robin Daniels of Tees Archaeology, Greg Speed from Northern Archaeological Associates and Stephen Sherlock, for sharing their knowledge and work with me.

I also owe gratitude to several people at the University of York, namely the Library Help desk and Kings Manor student services for their assistance in tracking down many publications, the Maths Skills Centre for their support in my statistical analyses, James Browne from Disability Services, the donors to the Palmer-Scott award for enabling me to attend fieldwork and the Archaeology departmental funding for allowing me to attend conferences. I am also thankful to Becky Knight for assistance in the lab, Jordi Ruiz Ventura for teaching me the correct method to measure vertebral neural canals, Malin Holst and Maureen Carroll for allowing me to attend their lectures, and Helen Goodchild for helping me learn to use ArcGIS.

Of course, I am also incredibly grateful to those who have supported me in a non-academic context throughout this project, including my parents and wider family, Cathy Platts, Elana, and the UoY Archery Club. I would also like to acknowledge the invaluable four-legged support offered by Leo, Eliza, Belinda, David, Galahad, Fuzzy Nerys, Snowy, Artie, Bliss, Walter, Buddy, Merlin and Georgiana.

Finally, this thesis is dedicated to the 656 people who formed the case study population, about whom there will always be more questions than answers.

Author's declaration

I declare that this thesis is a presentation of original work and I am the sole author. This work has not previously been presented for a degree or other qualification at this University or elsewhere. All sources are acknowledged as references.

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June 2025

Chapter 1: Introduction

This thesis presents a study of health in the population of northern England across the Roman to early medieval transition. The assessment of the health status of the population is based on the presence of key skeletal indicators of stress in 656 adult individuals from 19 cemeteries, spanning the early 3rd to late 7th centuries. The indicators of stress include cribra orbitalia, dental enamel hypoplasia, rickets and growth delay. Growth delay is measured in two ways; estimated stature and the dimensions of the vertebral neural canal. This technique for assessing levels of childhood growth delay has been the focus of several studies of health in recent years, but is not commonly used despite the anticipated benefits of combining two measures of growth delay which occur at different stages of an individual's development. Archaeological and historical evidence shows that the collapse of Roman rule in Britain impacted life in many ways, including the move away from urbanism back to small village settlements, the loss of the military, continental trade routes, and the coin based economy, and the concurrent climate downturn leading to colder, wetter weather year-round. This work aims to reveal the consequences of this societal upheaval on the health of populations from northern England.

1.1 Studies of transition

Transitionary periods and their impact on health are an increasingly popular focus of osteoarchaeological research. Some transitions have been seen worldwide, and therefore have a greater collection of work, such as the move from nomadic hunter-gatherer societies towards agriculture in the Neolithic period, and the increasing urbanisation and industrialisation of more recent centuries. The development of agriculture and the adoption of more sedentary lifestyles caused a general deterioration in health in studies across the globe due to the increasing reliance on more limited sources of food, and increasing population density, though there were regional differences in the changes seen in specific conditions or indicators of stress (Cohen and Crane-Kramer, 2007; Cohen and Armelagos, 1984). Many studies of the effects of urbanisation and industrialisation in historic communities (for example Valme, 2019; Schats, 2016; Lewis, 1999), have found a deterioration in population health status over time due to the increasing health hazards associated with urban living and industry.

A similar transition, with changes in food acquisition, living environment and daily activity changing for all levels of society, occurred during the decline of Roman rule across the Empire's former territory. For almost four centuries from 43-410 AD, Britain was under the control of the Roman Empire, during which time monumental infrastructure was developed, and cultural influences introduced new ways of living. Yet within just a few decades of the official withdrawal around 410 AD, daily life was almost unrecognisable as the loss of central government led to a return to subsistence farming, the collapse of towns, and the end of the coin-based economy. This massive upheaval is a much-debated chapter of history, with plenty of scholarship on the political manoeuvrings, nominated "causes" for the collapse of the Roman Empire, and questions of migration, invasion and identity. However, there has been little work on the experiences of the people living through these times. This thesis explores the health of populations in northern England from before and after the loss of Roman rule, and in comparing skeletal indicators of health presents new insight into the quality of life experienced by people living in northern England in the 3rd to 7th centuries.

Previous work on population health during this dynamic period has been conducted in areas of the continental reaches of the Roman Empire. Studies of comparing each region's respective Roman and early medieval periods have been carried out in Italy (Belcastro et al., 2007; Salvadei et al., 2001; Manzi et al., 1999) and Croatia (Šlaus et al., 2011; Šlaus, 2008), which generally found a deterioration in health over the transition from the Roman to early medieval period. However, studies of one region of Italy (Belcastro et al., 2007) and one region of Croatia (Šlaus et al., 2011), found no change, sparking questions about the potential nuance to be found. Work on the Roman-early medieval transition is less frequent in Britain. This is due to the scarcity of 5th-century inhumation burials (Brownlee and Klevnäs, 2024), and the difficulties of confidently dating 5th-century deposits due to the dearth of coinage, distinctive pottery, and metalwork (Gerrard, 2013, 156-207), as well as the plateau in the radiocarbon calibration curve which produces broad margins for error (Bayliss et al., 2013, 35). Some comparative studies have, nonetheless, been undertaken for southern England, where Griffin (2017) found improved oral health in the early medieval populations, and Walther (2017) found a decrease in indicators of stress. In Cambridgeshire specifically, Klingle (2012) found that changes in health were complex, leaving neither period conclusively better-off. However, none of these studies venture north of the Humber. The variation in changing health status within Britain and across the continent shows distinct regionality in the changes to population health, and therefore this neglect of northern England leaves a void in our understanding of the complexities of this dynamic period. This thesis aims to contribute to the field by bridging the scholarly divide between northern and southern England, and bring to light the experiences of the more often neglected populations north of the Humber.

1.2 Terminology

1.2.1 Northern England

For the purposes of this thesis, northern England is defined as the area between approximately the mouths of the Humber estuary and River Ribble, and the border with Scotland. The case study sites are from the modern counties of East, West and North Yorkshire, Durham and Northumberland. The reasoning behind the division of England in this way is twofold. Firstly the study area was defined approximately by considering the 3rd- and 4th-century divisions of *Britannia* into smaller provinces: with northern England

and the midlands becoming *Britannia Inferior* in the 3rd century, and northern England being separated again in the 4th century, becoming *Britannia Secunda* (Mattingly, 2007, 227-229). This northern province, regardless of name, was different in character to southern England in the later centuries of Roman rule, as the military retained a strong presence throughout the region in response to the continued conflict with the Picts living in what is now Scotland (Mattingly, 2007; Sargent, 2002). Therefore in limiting the study area to the region north of the Humber, this thesis focuses on populations who may have had a very different experience of Roman control and its subsequent loss, to those populations in southern England which are more often the focus of osteological work. The River Humber remained an important boundary in the early medieval period, while social hierarchy was redeveloping and territories were in flux, separating the kingdoms of Bernicia and Deira, later to merge and become Northumbria, from the kingdoms of Mercia, East Anglia, Essex, Sussex and Wessex (Fleming, 2011, 149). The exact northern and southern limits of the study area were refined by using the modern county boundaries, which simplified the process of searching for case study sites. Each county keeps its own Heritage Environment Record, so it was more prudent to search the whole record for a county than to divide a county – Greater Manchester for example – and attempt to only identify sites within the desired area.

1.2.2 Early Medieval

The term "early medieval" is used in many ways by scholars, broadly referring to a stretch of time somewhere between 410 AD and 1066 AD, with the earliest and latest dates shifting sometimes by centuries depending on the publication (for example Fleming, 2011; Roberts and Cox, 2003; Hamerow, 2002. There are also a range of terms to describe more specific eras within the broad early medieval period, including the Migration period, the Anglian period, the Anglo-Saxon period, the Saxon period, the early, middle and late Saxon periods (approximately 4th-7th century, 7th-9th century, and 9th-11th century), and more (for example Mainman, 2019; Mahoney Swales, 2013; Hamerow et al., 2011; Craig, 2010). This thesis uses "early medieval" to describe the 5th to 7th centuries, similar to the typical use of "early Saxon period". In this way the time period is constrained to the immediately post-Roman centuries which form the comparative focus for this thesis. Additionally, the term "early medieval" does not contain any references to ethnicity or origin, so can be applied to all populations of the 5th to 7th centuries without concern for misrepresenting a group or applying terms they themselves may not have identified with or understood.

1.2.3 Health

The World Health Organisation defines health for living people as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (World Health Organisation, 1948, 100). This has inspired much criticism due to its broad, qualitative and unachievable nature (Leonardi, 2018), though attempts to change the definition have not been fruitful. This definition is not appropriate for use in an osteoarchaeological study, because skeletal remains cannot provide evidence of an individual's mental well-being, and while the skeleton and funerary ritual can be interpreted to understand their physical and social well-being, any such interpretation will be largely conjecture based on small clues. Additionally, the osteological paradox must be considered when studying a skeletal population, as a skeleton which presents few lesions could either be a person who did not experience severe illness or trauma, i.e. "healthy", or a person who was very susceptible to illness, and so died before any impact was made on the skeleton, i.e. "unhealthy" (Wood et al., 1992). This can also be framed in terms of survivorship when considering juvenile individuals and indicators of childhood stress in adult skeletons, with juveniles being non-survivors who succumbed to an episode of stress, and adults survivors who were resilient enough to live through such a vulnerable life stage. This thesis does not seek to redefine health, or to ascribe a status of wellbeing to any particular individual from the case study populations. The word health is simply used to summarise the concept of an individual or a population's physical condition.

1.3 Aims and Objectives

1.3.1 Aims

This thesis broadly aims to reveal the effects of the fall of the Roman Empire on the people of Britain by assessing the childhood health, stature and mortality of Roman and Early Medieval adult human remains. More specifically, this thesis aims to:

- Determine whether the health of populations declined, improved, or stayed the same after the transition from the Roman to the Early Medieval Period.
- Test whether one sex was more resilient to this change.
- Ascertain whether the vertebral neural canal size will be indicative of childhood health and therefore correlate with other indicators.

1.3.2 Objectives

These aims will be met by pursuing several objectives:

- To compare the osteological evidence for childhood stress indicators between Roman and Early Medieval adult individuals (including cribra orbitalia, dental enamel hypoplasia, rickets, stature and the vertebral neural canal dimensions), uncovering the impact of the societal transition.
- To determine whether male and female adults from the same time period experienced different levels of childhood stress.
- To compare the effect of the transition on males and females and determine whether one group was more resilient than the other.
- To supplement current literature using the vertebral neural canal as an indicator of growth delay during development.

- To compile a large dataset for statistical analysis, thereby augmenting the value of past studies of small assemblages.

1.4 Structure of the thesis

This thesis first explores the typical daily living conditions of the people of northern England during the Roman and early medieval periods in Chapter 2: Living experience and health in Roman and early medieval Britain. This chapter examines the current scholarship on the archaeological, palaeopathological and historic evidence to determine the factors and identify societal changes which may have influenced health over the transition. Chapter 3: Skeletal manifestations of stress, contains an exploration of the aetiologies of each pathology chosen for the study of health among the case study populations. The physiological drivers and the characteristic skeletal changes of cribra orbitalia, dental enamel hypoplasia, rickets, stature and the vertebral neural canal dimensions are discussed in turn, in order to understand what their presence in the case study populations might indicate about the lives of the individuals.

The methods employed in this thesis are laid out in Chapter 4: Methods. The chapter initially describes the process used for study site selection, followed by the standard osteological techniques for the assessment of age, sex, stature and the identification of cribra orbitalia, dental enamel hypoplasia and rickets. These were performed by the osteologists who conducted the original examination of each skeletal assemblage, and any methods of standardisation applied to the existing data by myself are also described. The standard techniques for the measurement of vertebral dimensions are described and illustrated, and finally the statistical analysis and production of figures are discussed. The archaeological background, as well as the circumstances of the excavation and osteological analysis are detailed for each of the case study sites in Chapter 5: Materials. Each site is discussed in turn, first the Roman, then those with burials of both periods, and finally the early medieval sites, so as to provide context for the origin of the skeletal assemblages, and of the demographic and pathological information which is compiled from the literature into the dataset for this thesis.

The results are presented in two chapters. Chapter 6: Results from the compilation of literature lays out the results of the statistical analysis of the demographic and pathological information compiled from existing reports. This chapter shows a distinct improvement in health over time in northern England, with the prevalence of cribra orbitalia and dental enamel hypoplasia decreasing, and stature increasing between the Roman and early medieval periods. Secondly, Chapter 7: Results from the study of the vertebral neural canal presents the statistical analysis of the vertebral neural canal measurements. These two chapters present a surprising contrast in results, with the compiled data in chapter 6 showing clear differences between the two periods, but the vertebral neural canal measurements in chapter 7 showing consistency over time. In Chapter 8: Discussion, the results are discussed in their historical and pathological context, to determine how the skeletal evidence was able to contribute to the picture of life and health over the tumultuous transition. Finally, Chapter 9: Conclusion summarises the major factors affecting the health of the case study populations, and identifies areas which would benefit from further study.

1.5 Summary

Periods of transition present a particularly ripe opportunity for osteological research, as the changes in societal organisation and the typical life experience of a population will influence their health, allowing comparative studies to examine the intersection of palaeopathology and the archaeological and historical evidence for living conditions. The rapid loss of Roman control in Britain, and the accompanying profound changes to the economy, governance and subsistence is one such transition, for which the impacts on population health have not been studied in the detail required to understand the complexity of the regional differences. Northern England is often neglected in osteoarchaeological studies, and has thus far been left out of the discussion of the Roman-early medieval transition too. This thesis is designed to target this understudied area, and discover how the population of this remote province was affected by Imperial governance and its subsequent withdrawal.

Chapter 2: Living experience and health in Roman and early medieval Britain

Archaeologically speaking, it would be difficult to find another two consecutive periods so dramatically different than the era of Roman occupation in Britain, 43-410 AD, and the early medieval period, loosely dated to 410-700 AD. Monumental Roman architecture is visible in many locales around Britain today, most famously Hadrian's Wall, in stark contrast to the centuries immediately following where people seemingly disappear from the archaeological record leaving only the enigmatic "dark earth" (Fleming, 2011; MacPhail et al. 2003). Before this, Britain had been home to one eighth of the entire Roman army, necessitating a strong trade network to facilitate the movement of people and provisions, and stimulating the economy. Unrest in the continental empire during the 3rd century AD destabilised the economy, with a significant proportion of the army removed from Britain and trade routes becoming less secure (Fleming, 2011). However, a resurgence in the late 3rd and 4th centuries saw villa complexes emerging around the province and craft and trade booming (Esmonde Cleary, 1989). Roman control in this remote province faltered for decades before the official withdrawal due to further conflict in the continental empire necessitating the removal of more legions and harsh taxation (Fleming, 2011). By the late 4th century the Romano-British way of life was vanishing rapidly as even essential industries like metalworking collapsed and towns were abandoned as outdated venues for trade that no longer came. Ties were cut with the administrative control of the empire around 400 AD, when the supply of coinage from the imperial mint seems to have stopped (Esmonde Cleary, 1989), and in 410 AD the *civitates* were told by the emperor that they must defend themselves against the ongoing Germanic invasions as aid would not be sent, the final severance of the province (Hunter Blair, 1975).

In this chapter, the previous scholarship covering life and health in Roman and early medieval Britain is discussed, with the aim of painting a broad picture of the environment people lived in, and assessing the differences between the periods. The osteoarchaeological literature will also be covered, discussing the pathologies commonly seen in each period and their likely causes given the environmental conditions present at the time, anticipating possible changes in health status between Roman and early medieval populations.

2.1 Roman Britain

2.1.1 Settlements in Roman Britain

Romano-British settlements were different in character to those of the Iron Age, being shaped by the strict system of governance and taxation, the privileges afforded to those considered Roman citizens, and the new connection to a network of movement spanning the modern regions of Europe, the Middle East and North Africa. Towns were introduced for the first time immediately after the conquest, frequently being built over the preceding native settlement, such as at Silchester and Leicester (Hunter-Blair, 1975, 105-6). Villa complexes were established in rural areas in the later centuries of Roman rule (Birley, 1976, 85). The urban settlements were created amongst a hierarchy, from the highest status *coloniae,* to *vici*, the roadside communities which sprung up outside forts (Bennett, 1984). The first *coloniae* in Britain, Colchester, Lincoln and Gloucester, were created deliberately to house veteran soldiers, required to be Roman citizens (Birley, 1976, 79). They were built to a regimented plan common across the empire, with a forum, basilica, grid system, water supply and drainage, and amenities such as baths and theatres (Fleming, 2011; Birley, 1976). Slightly lower status settlements, *municipia*, were inhabited by a mixture of Roman citizens and native Britons who were allied with the empire (Bennett, 1984). *Civitates* were self governing towns controlled by native leaders, though monitored closely by the imperially appointed governor (Birley, 1976). *Vici* had more spontaneous origins, as they were created by tradespeople settling outside a fort in order to take advantage of the large group of soldiers with wages to spare and desires for better provisions. York is believed to have initially been a simple community accompanying the fort, and its rapid growth led to it gaining the status of *colonia* in 237AD (Crabtree, 2018). These towns and their characteristically Roman blueprint were deliberately created in an effort to Romanise the new province. Construction from stone, and investment in public buildings was encouraged by emperors such as Hadrian (117-138 AD) and Septimius Severus (193-211 AD), and in northern England especially, thousands of soldiers were stationed in new forts, so the urban landscape and population grew rapidly during the period (Birley, 1976).

Figure 2.1.1: Illustration of Roman Colchester showing the *colonia* in the centre, and associated extramural settlements. (Visit Colchester, 2024).

In practicalities, there was little difference between *coloniae* such as London or York, and *civitates* such as Brough (East Riding of Yorkshire) or Aldborough (North Yorkshire), which were all equipped with similar facilities despite their differing social status, and even the distinction between statuses dwindled over time (Jones, 2004). Their most important functions were as commercial centres, where the sale of goods was conducted and taxes were collected. Many inhabitants would have had specialised craft skills, and townhouses generally had a workshop and shop front on the street to facilitate the owner's profession (Perring, 2002). Some of the smaller towns revolved entirely around one industry, many focused on pottery production like Chesterton (Cambridgeshire) and Mancetter (Warwickshire) (Todd, 1970), but other industries also flourished. At Healam Bridge (North Yorkshire), an unusual preponderance of horse and mule bones suggests the settlement specialised in breeding these animals (Ambrey et al. 2017). Inherent hazards came with urban living and its attractive economic opportunities. The aforementioned industries, whether large scale or in the household of individual traders, would have been polluting, filling the air with smoke from furnaces and exposing many people to heavy metals such as lead, mercury and arsenic (Roberts and Cox, 2004). The concentration of a large population into an enclosed area created ideal conditions for the spread of disease and parasites, and the same applied to the storage of provisions for such an amount of people; vermin such as grain pests and rats have been identified from Roman warehouses in different locations around York (Kenward et al. 1986; Hall et al. 1980; Hall and Kenward, 1976). Regardless, the urban lifestyle persisted until the very end of provincial Britain, when the shattered economy could no longer support large groups of specialised tradespeople.

Outside of the new towns, rural life carried on in a similar manner to the Iron Age. This is demonstrated by environmental evidence showing continuation in land clearing practices through steady decline in the frequency of tree pollens and increasing frequency of grass and cereal pollens (Dark, 1999; Branigan, 1984). The character of rural settlements was far more varied across the province than that of urban settlements, as seen in farmsteads defined by Smith and Fulford (2016, 385) as "small rural farming settlements without villa architecture". These remained the most common style of settlement throughout the period in all regions, though with significant stylistic regional distinctions in shape, complexity and construction technique. Farmsteads have been split into sub categories based on these differences in complexity and form of external enclosures by Taylor (2007), and Allen and Smith (2016), but in general constituted a small cluster of domestic buildings and structures related to agricultural activity such as livestock enclosures, field systems and corn dryers. Villages as defined by Allen and Smith (2016) were not analogues of modern villages but rather a cluster of farmsteads, recognisable by the presence of multiple domestic foci. Settlements of this type are predominantly known from the south of England, though a few are seen in Yorkshire, such as Wattle Syke and Wheldrake (Allen et al. 2018). It is unclear whether they are absent from the west and north of the country or simply are yet to be discovered. While towns were deliberately created on the site of conquered Iron Age settlements to establish Roman colonisation and power across the south-east in the 1st century AD (Hunter Blair, 1975), villages are generally considered to have developed organically, though often in the vicinity of Iron Age predecessors as in the case of Mucking, Essex, (Allen and Smith, 2016; Evans et al. 2015). In Wales and the south-west some Iron Age hillforts remained occupied as rural settlements throughout the Roman period, reusing older earthworks in a style very similar to the enclosed farmsteads seen across the province (Brindle, 2016a; 2016b; Smith, 2016).

Figure 2.1.2: Illustrative reconstruction of a Roman farmstead excavated in Great Glen, Leicestershire. Illustrated by Cecily Marshall for Luke et al. 2015.

The more isolated nature of farmsteads, and smaller populations of villages would have been less conducive to the spread of infectious human diseases than the population-dense towns of Roman Britain. This is difficult to see in the skeletal record, however, as these illnesses rarely manifest in bone. Respiratory infections, on the other hand, can be inferred from lesions on the inner surface of the ribs. Rural housing, while not in close proximity to the smoke of industry, still contained the smoke typical of household cooking fires and therefore would have made the inhabitants vulnerable to respiratory and sinus infections. An additional risk on farms was the close contact with animals, as zoonotic diseases such as anthrax, rabies, brucellosis and bovine tuberculosis are transferable to humans with prolonged contact (Roberts and Cox, 2004). Most zoonotic conditions do not affect the skeleton, so their effect on the people of Roman Britain cannot be quantified, and the lesions distinctive of tuberculosis cannot be ascribed to either bovine or human tuberculosis in individual cases (Upex and Dobney, 2011). Overall, the osteoarchaeological evidence from the Roman period exhibits a gradient in health. Skeletal populations from town environments present a lower prevalence of stress or infection related conditions and those from rural locations show more skeletal evidence of stress the more remote the settlement (Griffin, 2017; Pitts and Griffin, 2012).

Larger rural settlements included roadside settlements, which bore many similarities to *vici* in that they developed in linear form alongside major roads, or encompassed crossroads, but lacked the military presence that was the lifeblood of the *vici*. Roadside settlements were generally accompanied by field systems attached to each domestic plot of land, and did not have defensive structures even though some, such as Great Walsingham (Norfolk) and Old Sarum (Wiltshire), grew large enough to rival the defended towns (Allen and Smith, 2016; James, 2010; Dennis, 2006). In the later centuries of Roman control, villa complexes emerged, particularly in the south where the land was more suitable for the characteristic intensive farming and production of surplus wealth (Jones, 1984). While some are known in Yorkshire, such as Rudston, villas are absent from the archaeological record in County Durham, Cumbria and Northumberland, despite pollen evidence proving the land was heavily farmed (Evans, 1984). By the fourth century these industrial Romanised farms exhibited the owner's higher status, and the remains are known for their luxuries including private baths, hypocaust systems and beautiful mosaics and wall paintings such as those seen near Ketton (Rutland), Lullingstone (Kent) and Dalton Parlours (West Yorkshire) (Peterborough Archaeology, 2022; Mackenzie, 2019; Wrathmell, 1990). The inhabitants of these complexes, however, were mostly slaves and poor workers, so did not have the comfortable and privileged life enjoyed by the owner.

Figure 2.1.3: Part of the Medusa mosaic from the Roman villa at Dalton Parlours. Image courtesy of York Museums Trust. https://yorkmuseums trust.org.uk CC BY-SA 4.0

2.1.2 Lifestyle in Roman Britain

The typical daily lives of the inhabitants of Britannia were determined by the strict social hierarchy of the period. Status was based on a complex combination of sex, age, family and forebears, citizenship of the Roman Empire, freedom, and of course wealth (Allason-Jones, 2004). Those able to afford it would have owned slaves to take care of household tasks, with the richest families having enough to run the family business as well. A 3rd-century inscription found at Halton Chesters (Northumberland), the site of a fort on Hadrian's Wall, was dedicated by the local guild of slaves (Collingwood and Wright, 1995, 464), demonstrating that many families in the area of the fort and *vicus* had enough money to purchase slaves. In terms of osteological evidence for enslavement, there is little direct proof of an individual's enslaved status, besides a handful of burials discovered with shackles (Chinnock and Marshall, 2021; Harward et al. 2015; Thompson, 1993). Slavery is instead one of a variety of potential explanations for skeletal remains of an individual exhibiting lifelong poor health and strenuous activity (Redfern, 2018). Many such cases could also be free individuals who worked either in specific crafts, or on farms. In northern England, the threat of rebellion from the local tribes, or invasion from Scotland, Ireland and Scandinavia led to the permanent stationing of up to one-eighth of the entire Imperial army at any one time (Mattingley, 2007, 149). This huge increase in population, estimated to be around 40,000 men at its height (Fleming, 2011, 2) boosted the economy, driving demand for goods, circulating coinage and acting as protection for perilous trade routes, but also presented a significant burden to the area as more resources were required, and expected to be produced by the conquered local population.. As mentioned above, urban craftspeople were regularly exposed to smoke and toxins such as heavy metals, while rural labourers were at risk of zoonotic diseases and musculoskeletal stress. These risks were increased in comparison to those experienced by the Iron Age or early medieval populations, because of the extreme pressure to produce surplus, either to sell and be able to pay the taxes levied by the Empire in coin, or to pay the tax directly in grain, which would then be distributed to the military (Mattingley, 2007, 511).

By the end of the 1st century AD, and before the advent of villa complexes, anyone in Roman Britain who had accumulated at least a little wealth lived in an urban environment, where there was regular access to society, entertainment and markets selling a wide variety of goods. The populations of towns enjoyed varied diets, based on the classic staples of grains and olive oil, but supplemented with goods both from the local region and the far reaches of the empire's trading network. Zooarchaeological assemblages show many types of fish, birds and livestock were regularly consumed in the towns of Roman Britain (Locker, 2007; Grant, 2004; King, 1999), though of course, the access to some of these foodstuffs was limited by wealth, with the urban poor likely eating very little meat (Erdkamp and Holleran, 2018). It is particularly noted by King (1999) that the proportion of cattle and pig among the animal bone assemblage was higher in towns and particularly in military sites. This indicates a higher status, more "romanised" diet in contrast to the native Iron Age British diet which contained a higher proportion of sheep. Isotopic studies show a general increase in $\delta_{13}C$ and $\delta_{15}N$ in Roman skeletal remains compared to those of the Iron Age, where greater numbers are indicative of more food of higher trophic levels being consumed (Mülder, 2013). In this case the high isotopic values demonstrated that fish, in addition to meat, played a greater role in people's diets after the introduction of the Roman way of life (Mülder, 2013). Across England, the isotopic results indicating greater fish consumption are in accordance with King's observations of animal species distribution, with the skeletal populations of Roman villages and small towns including Catterick presenting lower $\delta_{13}C$ and $\delta_{15}N$ values than those of large towns including York (Chenery et al. 2011; Müldner and Richards, 2007). As could be expected, isotopic studies also reveal variation in diet within towns indicating food availability was restricted by wealth or social custom. A notable study of this was conducted on the remains from the rural settlement site of Poundbury Camp (Dorset), where the greater isotopic values were strongly associated with individuals buried in lead coffins or mausolea, the most expensive modes of burial (Richards et al. 1998). The influence of sex on diet seems to vary by site, with Poundbury showing no differences between males and females (Richards et al. 1998) in contrast to both Catterick and London where males clearly indicated a more varied and rich diet (Powell et al. 2014; Chenery et al. 2011). Within

York there is much variation to be found in isotopic values, and these cannot be decisively linked to the individual's sex or status as inferred from funerary practices (Müldner, 2013), but may instead be indicative of migrants.

A contributor to the Romano-British diet not seen in previous periods were C4 plants, which are a group of plant species that utilise a different system of photosynthesis to survive hotter and drier environments than the C3 plants native to Britain (Müldner, 2013). Those found in Roman excavation contexts include millet and legumes, which were surprisingly less common in the continental empire. This difference is theorised to be due to migration patterns seeing many North Africans entering Britain as part of the Roman army, willing to spend their money on importing their native foods (Bourbou, 2018). The presence of both native and imported pulses in the diet would have been nutritionally beneficial, as they are protein sources known to be abundant in the amino acids which are rarer in grain proteins, and were much cheaper than animal proteins (Heinrich and Hansen, 2018). Grain based dishes have also been determined to be more nutritionally dense than modern equivalents. This is due to the common practice of mixing different types of grain within a meal, the inevitable harvest of weeds among the crop, and the lower yield of crops allowing each individual grain to hold more minerals from the soil (Heinrich, 2018). Those individuals who lived in towns, where the diversity of food has been shown to be greater, and could also afford a variety of grains, pulses, vegetables and animal products would have had a much more nutritionally complete diet, and therefore have been less at risk from conditions like rickets, cribra orbitalia and scurvy.

2.1.3 Climate in the Roman period

In palaeoclimatic studies there is a period commonly referred to as the "Roman Warm Period", which lasted from approximately 300 BC to 350 AD, when the climate over much of Europe, the Middle East, and North Africa was warmer and drier than standard (Lamb, 1995). Various climatic proxies, including dendrochronology, the presence or absence of plant species, chemical analysis of ice and rock cores, and sediment and peat formation have been used to develop this picture of the climate before records began, and the changes that occurred. Tree ring sequences show the new growth of the tree in each year of its life, with the width of the ring indicating the success of growth. Northern and Western European chronologies generally consist of wider rings during the Roman period, evidence of favourable growing conditions across the region including warmer summer temperatures, which would have benefited agriculture (Esper et al. 2014; Leuschner et al. 2002). In Britain, evidence of viticulture (Brown et al. 2001) implies that average temperatures were increased during the Roman period; temperature is the most limiting factor in determining the range in which grapes are able to grow (Malheiro et al. 2010), and even in the modern climate with its increasing warmth, viticulture is unusual in Britain (Van Limbergen et al. 2021). Sediment analysis in the North Sea demonstrates a clear decrease in winter deposits during the Roman period, indicating that the winters were warmer and less prone to storms (Hass, 1996). This would have been a benefit to vegetables such as cabbages and leeks which grow over the winter, and also to the human population, who would have benefitted from the vitamin C in these vegetables, staving off scurvy, and been able to spend more time in the sun decreasing their chances of developing rickets.

Warmer temperatures are not always of benefit, however. Malaria has been the focus of much research in recent years due to climate change introducing the possibility of it once again becoming endemic to Britain as it was in the past. The strain *Plasmodium vivax* requires temperatures above 15°C to survive in its mosquito hosts, and is known from the historical records of health complaints and causes of death to have been endemic in Britain from at least the 16th century in wetland areas (Dobson, 1989). While not known from either the historical or skeletal record of the Roman period, malaria was likely widely present in Britain due to the constant movement of people and goods from the continent where it was common (Sallares, 2002), and the warmer weather being conducive to survival of the parasite. The distribution, if it followed the pattern seen in medieval and early modern populations, would have mostly covered the south of England and the Humber Estuary, though the low lying valleys and marshes of northern England could well have suffered infections too. Malaria is known to be linked to anaemia, both in that chronic infections increase iron deficiency (Madu and Ughasoro, 2017), and that inherited anaemias such as sickle cell and thalassaemia provide some resistance to the pathogen thereby increasing their own frequency as a beneficial gene (Ayi et al. 2004). Studies of cribra orbitalia as an indicator of anaemia have found that rates in Britain were lower than those on the continent, potentially indicating either the influence of thalassaemia, a hereditary anaemia common in the Mediterranean region (Waldron, 2021), or a much greater frequency of malaria in Italy where conditions were warm enough to sustain *Plasmodium falciparum*, a different malaria strain (Sallares, 2002).

2.1.4 Disease in Roman Britain

The majority of health problems, regardless of cause, are not visible in the skeleton, so the impact of disease in a period before recording cause of death was standard is difficult to assess. In Roberts and Cox's (2003) notable summary of disease in human remains from Britain, it was found that cribra orbitalia and dental enamel hypoplasia, both discussed in detail in Chapter 3 of this thesis, were fairly common across England in the Roman period, occurring in 8.05% and 6.7% of individuals respectively. While dental enamel hypoplasia cannot be ascribed a specific cause, cribra orbitalia is most often linked to iron deficiency anaemia (Cole and Waldron, 2019), and thereby hints at several environmental stressors present in the period, such as malaria as previously discussed. An increased pathogenic load from any infectious disease also increases an individual's likelihood of being anaemic (Grauer, 2019). Aside from transmissible illnesses, the lead pipes used to carry fresh water in towns would have contaminated the water, giving lead poisoning and therefore susceptibility to anaemia to large swathes of the population, especially children (WHO, 2010). Lead poisoning via the water supply depends on the water hardness; much of northern England has soft water which contaminates easily (Drinking Water Inspectorate, 2021). People living in hard water areas were still at risk though, due to lead glazes on cookery and tableware, and lead cooking pots (Retief and

Cilliers, 2006). Roman skeletons from London were found to have elevated lead concentrations consistent with anthropogenic exposure, though none of the 20 individuals sampled had lead concentrations higher than commonly found in modern populations (Shaw et al. 2016). From the skeletal population of Cirencester, the lead concentration was found to be well above the modern maximum in all individuals, and in many was ten times as high (McWhirr et al. 1982). The skeletal concentration of lead in children's remains has been found to be strongly associated with younger age at death and skeletal indicators of metabolic stress in populations from the continental Roman provinces (Moore et al. 2021). In addition to anaemia, gout has been linked to higher blood lead concentrations because the lead poisoning damages the kidneys and leads to a build-up of uric acid (Nriagu, 1983). However, this factor was not considered by Roberts and Cox (2003) when they noted a high prevalence of gout among the Roman period skeletons, which they attributed to wealthy individuals consuming a rich diet with much meat and wine.

Rickets, to be discussed further in Chapter 3 of this thesis, was noted in 14 individuals by Roberts and Cox (2003), though only in the populations from southern England. Though this geographic discrepancy was not addressed by Roberts and Cox, it could be interpreted as evidence of differences in diet, time spent outside, or cultural dress between populations residing in the north and south of England. However, it is more likely to simply be an indicator of better preservation of skeletal remains due to the geology of the south, as long bones need to be largely whole in order to diagnose the condition. Mean stature, a very broad indicator of a population's health due to the variety of stressors which can induce and contribute to growth delay in children (Bogin, 2020), was found to be 168 cm for males and 162 cm for females in the Roman period (Roberts and Cox, 2003). The modern European mean stature ranges from 170-179 cm for males and from 160-167 cm for females (Cavelaars et al. 2000), so we may infer that Roman males experienced a proportionally greater degree of stress than females when compared to modern populations, or conversely, that modern females have not experienced the same degree of reduction in stress when compared to Roman populations. The typical life expectancy of Romano-British populations is more difficult to determine, as methods to determine age at death are imprecise and the categories assigned are not standardised across reports. There was no attempt by Roberts and Cox (2003) to compile mortality data for the whole country, but several regional studies exist that we may consult. Klingle (2012), in his study of Bedfordshire and Cambridgeshire, found that 10% of individuals died before the age of 5, though this is of course likely to be distorted by biases in burial practices and preservation. Of those who lived to adulthood, 27% were found to be older than 45 at death. Roman York was found to have less than 5% of individuals under 5, with more than 60% dying between 35 and 50 (McIntyre, 2014), again subject to bias from the lack of infants in the archaeological record. In rural settlements across central and southern England, about 65% of burials were determined to be of adults, with the majority dying between 26 and 45, and the majority of non-adult burials being of perinates (Rohnbogner, 2018). From these studies, while infant mortality is difficult to understand, we can see that those who survived childhood in Roman Britain could reasonably expect to live into their 30s and perhaps 40s.

Infectious diseases such as pneumonia, tuberculosis, leprosy and Paget's disease were found by Roberts and Cox (2003) to be increasingly prevalent during the Roman period, implying that the population was living in environments conducive to the spread of disease, or coming into contact with new pathogens more frequently. They suggest that Paget's disease, leprosy and tuberculosis in particular were introduced for the first time by migration from the continental empire, though more recently, cases of tuberculosis have been identified or questioned in several prehistoric individuals (McCarrison, 2012; Taylor et al. 2005). Within the study area for this thesis, evidence of tuberculosis and Paget's disease was seen in Roman cemetery populations from York (McIntyre, 2014), suggesting the town saw enough migration and people living in close quarters for the transmission of these conditions. Parasites also appeared to spread easily in the period; evidence of many species of intestinal worms, fleas and lice has been found in excavations of urban Roman areas including in York itself (summarised in Mitchell, 2017), in addition to the infestations of storage facilities discussed above. York, in particular, was noted to have especially high numbers of fleas in Roman deposits (Hall and Kenward, 2015); while not a danger to the people affected, they are certainly an indication of poor hygiene. Further evidence of the unsanitary nature of Roman towns are the whipworm eggs found in a Roman well from York, the number present representing human faecal contamination of the water supply (Kenward et al. 1986). Skeletal and environmental evidence therefore suggests that on the whole, the public provision of fresh water, baths and sewer systems in urban areas were not sufficient to mitigate the effects of housing many people in a small area, an issue which persists to this day (Kuddus et al. 2020; Moore et al. 2003).

2.2 Early medieval Britain

2.2.1 Settlements in early medieval Britain

One of the key differences between life in Roman Britain 43-410 AD, and life in Early Medieval Britain 410-700 AD, was the complete collapse of the towns that had thrived in the Roman period, and the creation of small, self sufficient villages and farmsteads that lasted until the emergence of *wics* in the 7th century, the trading settlements of the Middle Saxon period (Fleming, 2011). The average population of these villages was calculated to be around 30-50 people (Hamerow, 2012), with rare exceptions for larger villages such as Mucking (Essex) thought to be inhabited by around 80 people (Hamerow, 2013). In the 5th to early 7th centuries, these villages were very simple, with no defensive structures, enclosures or internal boundaries to separate different families' land (Higham, 2010). Buildings were made of timber and organic materials, and came in two styles: the *grubenhäuser*, or sunken-featured building, and small rectangular, single room constructs (Figures 2.2.1 and 2.2.2). *Grubenhäuser* (singular *grubenhaus*, which can be translated from the German as 'pit-house'), consisted of sub rectangular pits dug into the earth, with gable roofs built over them (Darvill, 2009). The sunken style of building was widespread in the early medieval period, with examples seen in excavations from East Yorkshire, Hampshire, Lincolnshire and Essex (Albone, 2000;

Haughton and Powlesland, 1999; Drury et al. 1982; Davies, 1980). Such structures were used for a variety of purposes, including storage, activities such as spinning, and as domestic living spaces. The second style of construction was post-built rectangular houses, typically around 40 square metres with no internal subdivision (Hamerow, 2012). Both construction styles seem to have been used throughout lowland Britain for the duration of the period, though excavation efforts have been strongly focused towards the south and east of England. The two building types have often been discovered mingled together on the same site, for example, those at Mucking and West Stow (Suffolk) (Hamerow, 2013; Higham, 2010; West, 1985). West Heslerton is a rare exception to this as the majority of *Grubenhäuser* were clustered in one area of the site, with post-built structures at a distance (Powlesland, 1997).

Figure 2.2.1: A *grubenhaus* at the West Stow visitor centre. (St Edmundsbury Chronicle, 2009).

Figure 2.2.2: A post built house at the West Stow visitor centre. (St Edmundsbury Chronicle, 2009).

These small villages inhabited in the Early Medieval period were incredibly rudimentary, with few even having wells or latrines to manage fresh and wastewater. Other 'service features' that are noticeably absent from the archaeological record are ovens, fire pits, and rubbish or storage pits (Hamerow, 2012). While it is acknowledged that excavations rarely uncover enough of a settlement to come to a satisfactory understanding of its inner workings, the lack of simple facilities is striking. The relatively scarce excavations of 5th-7th century settlements hinder our understanding of the environmental conditions present in the communities. Minimal evidence of intestinal parasites has been recovered: at West Stow intestinal worm eggs were extracted from faecal matter, though this was not confidently identified as human (West, 1985). Eggs were also reported from soil samples at Lyminge (Kent) (Maslin, 2018). The samples were taken from an area which had been the bank of a stream in the early medieval period, and the concentration of parasitic worm eggs led to the conclusion that faecal matter had been dumped there. If this stream was the main water source for the settlement, any collection downstream of this dumping site would have been contaminated and easily facilitated the spread of these parasites and diseases of faecal-oral transmission such as cholera, hepatitis or dysentery (Byers et al. 2001).

2.2.2 Lifestyle in early medieval Britain

Very little evidence of 5th-century life has been found in Britain, the early phases of occupation excavated at West Stow being a rare exception (West, 1985). In York, beyond cremation cemeteries at Heworth and The Mount and deposits of animal bone around the remains of the Roman fort, evidence from the 5th century remains elusive (Mainman, 2019; Crabtree, 2018). Instead, clues about life in the very early decades after Roman withdrawal must be gleaned from the cemetery populations like those at Wasperton (Warwickshire) (Carver, 2009), or Berinsfield (Oxfordshire) (Boyle, 1995), which are more often discovered than their dwellings. While farming and keeping a household were strenuous physical work, it is noted by Roberts and Cox (2003) in their compilation of skeletal evidence from the period that the signs of musculoskeletal stress were less prevalent than in the Roman period. This is theorised to be due to the less intensive farming practised as communities only needed to support themselves, in contrast to the production of surplus necessary in the Roman period (Gerrard, 2013). The faunal assemblages from small sites such as Quarrington (Lincolnshire) and Kilham (East Yorkshire) as well as larger sites such as West Stow, indicate through the animals' older ages and representation of all skeletal elements, that there was no specialised production of any goods for trade. Instead all animals raised in the village were used for multiple purposes by the people of the village (Archer, 2003; Taylor et al. 2003; Crabtree, 1989).

In the 6th century, social stratification was redeveloping, as evidenced in differing funerary practices for some individuals, with markedly elite graves starting to be noted such as those at Loftus (North Yorkshire) and Buckland (Kent) (Parfitt and Anderson, 2012; Sherlock and Allen, 2012). The 6th century also saw building styles differentiated, indicating some households had more importance and greater accumulated wealth than others. Examples include the extraordinarily large halls at Cowdery's Down (Hampshire) and Yeavering (Northumberland), which are thought to have been created as higher-status settlements in the 6th century (Hope-Taylor, 2014; Millett and Simon, 1983). Other villages retained their smaller huts in the most part, with much larger buildings being added and inhabited concurrently such as the great hall at Lyminge (Thomas, 2013). During this time settlements grew and connected more with each other (Fleming, 2011). As a result of this, trade in goods became more important, pottery at the 6th-8th century settlement at Heslington (York) was determined to come from the East Midlands (Spall and Toop, 2008), and animal remains including marine fish and beaver from West Stow are evidence of contact with the coast and the fens (Crabtree, 1989). There are even indications of trade with Europe at this time; glass beads from the Netherlands were found in Heslington (Spall and Toop, 2008), and a great quantity of lava querns from Germany at West Heslerton (Powlesland, 1998), both of which likely arrived via the River Humber. Movement of people between Britain and Europe was also common at this time, leading to the term "Migration Period". It has previously been theorised that the incoming Angles, Saxons, Jutes, Frisians and other groups, had violently conquered the local people and completely replaced the population (Lennard, 1933; Stubbs, 1874). However, more recent theories have promoted the idea of a more peaceful integration between the newcomers from continental Europe and the local Britons. These are supported by ancient DNA and strontium and oxygen isotope analysis, which identified women and children as migrants in addition to men, who would be expected to be predominant if part of an invading force, and found that many settlements were populated by a mixture of Britons and Germanic migrants (Gretzinger et al., 2022; Hills, 2017; Montgomery et al., 2005).

The early medieval diet varied little from meal to meal during a day, but would have been highly seasonal depending on the types of fresh fruit and vegetables available to harvest, and the traditional slaughtering times of different livestock. The majority of people would have had regular access to meat, dairy and eggs, and fresh produce regardless of financial status, as family groups tended their own vegetable gardens and livestock (Hagen, 2010). The staple crop varied by region and date; wheat was preferred for making bread due to its high gluten content, though it would be supplemented with other crops such as oats and barley, especially in northern England where the soil composition was more favourable to those species. Emmer and spelt wheats, both common in Roman Britain, were slowly replaced by bread wheat, which does not require threshing after harvest so would need less manual labour to produce. Animal bone assemblages such as those from Heslington (Spall and Toop, 2008) and West Stow (Crabtree, 1989) demonstrate a marked preference for beef, though pork was also common as were both fresh- and saltwater fish and molluscs depending on their local availability (Hamerow, 2013). However the physical remains of foodstuffs as excavated are subject to preservation biases, and it is not simple to tell whether there was any cultural separation in the types of food different groups of people ate. Therefore, isotopic analyses of human remains are used to complement the archaeological evidence. In the skeletal population from Berinsfield, a varied diet including meat and freshwater fish was standard with no sex based differences. When compared to funerary practices it was shown that the wealthier people had more access to beef and dairy products and the poorer mostly ate fish and pork. These meats require less time and fewer resources to produce; fish could be obtained from local water sources and pigs fed on scraps, whereas cows, sheep and goats needed pasture set aside and crops grown to feed them. For males however, wealth only afforded the privilege of consuming beef and dairy until the age of 30, when their diet seemed to revert to fish and pork regardless of grave richness (Privat et al. 2002).

2.2.3 Climate in the early medieval period

During the decline of Roman control in Britain in the 4th century, there was also a significant downturn in the climate. Evidence from peat bogs across the British Isles shows an increase in surface moisture and decrease in air temperature between the 5th and 8th centuries; the magnitude of the change had affected the formation of the peat itself, and the species of vegetation which were able to grow (Blackford and Chambers, 1991; Blackford, 1990). Analysis of the tree ring sequence developed from Northern Irish bog oak also revealed a significant peak in the number of trees with narrow rings around the mid-sixth century (Baillie and Munro, 1988). Narrow tree rings indicate a poorer growing climate, which can be ascribed to any of a list of factors in much the same way as human stature, including widespread colder and wetter conditions, but also local environmental disturbances like a flood. However, while the study assessed trees from across Northern Ireland, other tree ring studies in Europe show similar results (Luterbacher et al. 2016; Esper et al. 2014), so it is likely that the poor climatic conditions were not limited to the region of study; instead, the deterioration impacted Britain as a whole and also extended over Europe. This would have seriously impacted the growth of crops by shortening the growing season, likely leading to famines in years with particularly cold summers.

The peak seen in poor tree ring growth in the mid-6th century by Baillie and Munro corresponds to a peak in acidity in a Greenland ice core sequence examined by Hammer and colleagues (1980). The acidity of the ice is affected by volcanic eruptions, which eject massive amounts of sulfuric acid into the atmosphere, to later fall in snow and be compacted into the ice sheet. The atmospheric pollution caused by volcanic eruptions obscures the sun, decreasing average temperatures and blocking necessary light from reaching plants, an effect which can last months if not years. The 6th-century volcanic events in 536, 540 and 547 AD impacted the climate of Europe, and much of the Northern Hemisphere. This occurred to such an extent that the period from 536 AD to 660 AD is commonly known as the Late Antique Little Ice Age, and is theorised to be the inspiration for the *Fimbulvinter* of Norse mythology (Oinonen et al. 2020; Büntgen et al. 2016). With the general decline in climatic favourability and in particular the volcanic winter seen in the mid 6th to 7th centuries, the people of the early medieval period would have experienced more frequent food shortages, increasing the risk of malnutrition and vitamin deficiencies, and susceptibility to infectious disease. The inclement weather would also have decreased the amount of sun exposure people could expect, and therefore potentially increase the risk of rickets from vitamin D deficiency.

Contrary to expectations, evidence of malaria in early medieval populations has been identified despite the drop in temperature reducing the suitability of the environment for the parasite. Gowland and Western (2012) compiled skeletal analyses of 5th- to 11th-century populations from eastern England, comparing the rates of cribra orbitalia as an indicator of chronic anaemia, with dental enamel hypoplasia to represent systemic stress. They found a much higher prevalence of cribra orbitalia than dental enamel hypoplasia in the East Anglian Fens and interpreted this as evidence of malaria. They noted that the distribution of higher rates of cribra orbitalia closely matched the pattern seen in 19th-century reports of 'ague'. It is possible that, while the average temperature was less suitable, the increased wetness enlarged the area of wetlands such as marshes and bogs, and potentially created new ones where mosquitoes could thrive. The climatic downturn has also been linked to the first known epidemic of the bubonic plague, *Yersinia pestis*, also known as the Justinianic Plague. First recorded in Egypt around 540 AD, it was able to spread rapidly through North Africa, theoretically due to cooler summer temperatures making the region more hospitable to the bacterium's rodent flea host, *Xenopsylla cheopis*, and encouraging its rapid breeding (Harper, 2017). From Africa, *Yersinia pestis* made its way across continental Europe over the next three years (Sarris, 2002), also making its way to Ireland which had maintained strong trading links with the continent (Maddicott, 1997). It was previously considered to have only entered Britain in the latter half of the 7th century as no written account describes it before Bede, writing in the early 8th century, recorded its arrival in 664 AD.

However, recent analysis of ancient DNA has identified traces of *Yersinia pestis* in late 5th- and 6th-century burials from the Edix Hill cemetery in Cambridgeshire (Keller et al. 2019). Writing by those who experienced outbreaks, both in Britain and around the Mediterranean describes entire villages being decimated, powerful religious and political figures succumbing, and confidence in the institutions they represented declining (Sarris, 2002; Maddicott, 1997). The archaeological evidence suggests support for this catastrophic picture; around 40% of the Edix Hill burials subject to aDNA analysis showed evidence of *Yersinia pestis* (Sarris, 2022). The 7th century decline or abandonment of sites such as Mucking, West Stow, and Yeavering, has been proposed to relate to outbreaks of the disease (Maddicott, 1997).

There have been arguments that the climatic decline was itself responsible for the fall of the Roman Empire (e.g. Harper, 2017a; McCormick et al. 2012; Baillie, 1999), which have made it into popular news reporting (e.g. Harper, 2017b; Sohn, 2011). There is also contention about the level of interaction and causation there can be between human and natural history (e.g. Erdkamp, 2019; Sessa, 2019). The scope of this work does not include untangling the web of socio-political manoeuvrings, changing beliefs and economic decline that led to the collapse of the Empire, but regardless of cause and effect, both climate and governance changed for the people in northern England around the dawn of the 5th century.

2.2.4 Disease in the early medieval period

The problems caused by the lack of written accounts recording cause of death in the Roman period continue into the early medieval period. Instead we must still rely on the physical evidence of ill health in the form of the skeletal remains of the people who experienced it. In their summary of skeletal pathologies seen across Britain from the period, Roberts and Cox (2003) define the early medieval period as 410 AD to 1066 AD, covering many more centuries than this thesis, though they also discuss the period of 450 AD to 650 AD within the chapter.

In the period overall Roberts and Cox (2003) found a particular decrease in the frequency of cribra orbitalia from 8.05% in the Roman period to 5.7%. They also note an increase in the frequency of dental enamel hypoplasia from 6.7% to 8.9%. When combined with the decreases in frequency of dental disease, rickets, and bladder and kidney stones from the Roman to the early medieval periods, there are interesting implications about potential dietary changes. The lower rates of cribra orbitalia, which is generally linked to iron deficiency anaemia (Cole and Waldron, 2019), may imply that more people had sufficient meat in their diet than in the Roman period, where access to meat was limited to those with plenty of money as evidenced by the isotopic studies discussed in section 2.1.2. The lower incidence of cribra orbitalia may also indicate a decrease in infectious disease or lead poisoning, whose influences on blood iron levels have already been discussed in sections 2.1.4 and 2.2.3. It seems likely that a decrease in average blood lead concentration would have been somewhat responsible for the lower rates of cribra orbitalia as many sources of exposure from the Roman period, including water pipes and coinage, were not present in the early medieval period. The prominent presence of gout in the Roman period and its absence in the early medieval, with the exception of a late Saxon individual from Trowbridge (Wiltshire) (Roberts and Cox, 2003; Rogers et al. 1981), also implies lower lead exposure as previously discussed, but may also be related to a general reduction in richness of diet. In the cemetery population from West Heslerton, lead concentrations were low and consistent with natural background exposure (Montgomery et al. 2005), and in a study investigating changing lead concentrations over time, the early medieval individuals from Bamburgh and Stonehenge had similarly low results (Budd et al. 2004), thereby supporting the view that anthropogenic lead exposure was much reduced after the transition. In addition to the low prevalence of cribra orbitalia, Roberts and Cox (2003) suggest that the reduced presence of bladder and kidney stones is also evidence of greater meat consumption. They state that bladder stones are common "especially for vegetarian people", though this is not supported by the more recent clinical literature which finds vegetarians with relatively balanced diets are less likely to develop urinary stones than meat eaters (Ferraro et al. 2020; Turney et al. 2014). The lower prevalence of urinary stones in early medieval people could therefore indicate a nutritionally beneficial diet including the consumption of dairy products, but without a great amount of meat, as recommended to modern patients with recurring urinary stones (Ferraro and Bargagli, 2021; York and Scarborough Teaching Hospitals, 2021).

Potential dietary changes were also suggested by the sharp decrease in the frequency of rickets from 0.2% in Roman populations to 0.02% of individuals from the early medieval populations seen in Roberts and Cox's assessment (2003). Rickets is caused by deficiencies in vitamin D and calcium (Shore and Chesney, 2013a), so the much lower occurrence implies dietary sources of calcium were more readily available to the early medieval population, supporting the inference of more dairy in the diet from the lower rates of urinary stones. The decrease in the frequency of rickets may also be due to changes in lifestyle requiring more time working outside to tend livestock and crops rather than in craft workshops, therefore increasing the average exposure to sunlight, a necessity in the production of vitamin D and prevention of rickets (Shore and Chesney, 2013a). It is likely that poor preservation of skeletal remains also had a significant effect on the diagnosis of rickets, as it did in the Roman period, though this would not account for the difference between the two periods, implying some level of change occurred in the living conditions of the two periods. Scurvy existed at a similarly low frequency to rickets in the early medieval populations, potentially indicating the access to fresh fruits and vegetables and therefore provision of vitamin C was adequate, but also likely to be related to the rigorous diagnostic criteria and poor preservation of the necessary skeletal elements hindering its diagnosis (Klaus, 2017). The reduction in dental disease seen overall in the early medieval populations studied by Roberts and Cox (2003) suggests the standard diet contained much less sugar in the form of honey, as simple sugars encourage the destruction of the tooth surface by bacteria, leading to caries, periodontal disease and abscesses (Roberts and Manchester, 2010). It is unlikely that the diminished presence of these conditions can be attributed to improvements in dental hygiene as the frequency of calculus was noted to be much increased from the Roman period (Roberts and Cox, 2003). The increase in calculus may be indicative of a more protein rich diet as this is known to promote mineralisation of plaque (Roberts and Manchester, 2010). Overall, palaeopathology points to a sufficiently varied, but less rich or sweet diet, with the increased frequency of dental enamel hypoplasias perhaps indicating frequent periods when the amount of food itself was lacking due to poor harvests and famine.

One of the most notable differences between the two periods in the work of Roberts and Cox (2003) is the greater mean stature of both males and females in the early medieval period. The mean male stature of the early medieval populations was 172 cm, an increase of 3 cm from the Roman mean, and female mean was 161 cm, an increase of 2 cm. These values fall within the modern European mean stature range, albeit at the lower end, implying the total impact of stress factors on growth is roughly equal in modern and early medieval populations (Cavelaars et al. 2000). Average life expectancy in the early medieval period was, as may be assumed, much lower than that of modern British populations, and also lower than that seen in Roman Britain. In his study of Cambridgeshire and Bedfordshire, Klingle (2012) found about 17% of early medieval individuals died before the age of 5, a much greater percentage than in the Roman period, though this may of course be affected by differential burial practises for infants, and poor preservation. Among those who survived childhood, around 10% lived past 45, much lower than in the Roman period. There was also a striking increase in both males and females dying as young adults, from 10% in the Roman period to 26% in the early medieval. A similar pattern was found by Craig (2010) among 7th- to 9th-century populations from northern England, where 18% of individuals were under 6 at death, and only 6% were over 45.

Considering pathologies not included for analysis in this thesis, infectious disease was spread within households in the early medieval period as in the Roman. Roberts and Cox (2003) reveal slightly increased frequencies of infectious diseases like tuberculosis, and respiratory conditions including rib lesions and sinusitis which imply the ventilation in houses was poor. However, their collation of data from all cemeteries in use between 410 AD and 1066 AD makes it impossible to theorise on the living conditions for people of the 5th to late 7th centuries focused on in this thesis. Instead, it is likely the developing towns of the mid to late Anglo-Saxon period were responsible for a significant majority of the individuals presenting with infectious and respiratory diseases. Increases were also seen from the Roman period for congenital conditions and neoplastic diseases. More variety was seen in these conditions, with many new types of malignant tumours seen in the skeletal record of Britain for the first time, and conditions such Down’s Syndrome, cleft palate and osteogenesis imperfecta also recorded for the first time, though their absence before the early medieval period could be a hazard of poor preservation or less thorough analyses. This is evidenced by the case of Down’s Syndrome discovered in a Roman individual from Healam Bridge (Ambrey et al., 2017), suggesting that earlier cases of other conditions may come to light with continuing excavation and analysis of human remains. Another possible explanation for the increased variety seen by Roberts and Cox in the early medieval period is that new genetic material from continental migrants brought these conditions to Britain. However this does not take into account the greater variation and distance of incoming migrants in the Roman period and the relatively smaller variety in conditions.

For the most part, we can see that skeletal evidence indicates that life was perhaps less hard for early medieval people than their Romano-British predecessors, as overall there were lower frequencies of many indicators of both specific and non-specific stress. Growth delay was decreased, along with signs of nutritional deficiencies, and rates of accidental trauma and joint disease were also lower, being observed in 5.9% and 8.8% of individuals respectively. This may be related to the changes in occupation and employment, with fewer specialised craftspeople and trade, and more farming for subsistence without the pressure of taxation to demand the production of vast surplus.

2.3 Summary

From the archaeological, historical, biomolecular and palaeopathological literature, it is clear that there were vast differences in the experiences of people living in northern Britain during the Roman and early medieval periods. The changes in living environment, work, and accessibility of nutrition may have impacted the population's health in myriad ways, so with no prior studies focusing on northern England, it remains unclear what impact the collapse of Roman power had on this distant province. The evidence surveyed in this chapter strongly suggests that the outcome of this thesis will not be a healthy Roman population contrasted against a very stressed early medieval population. However, it remains to be seen whether there will be no difference in overall population health over time, or whether health improved as sources of stress decreased in the early medieval period.

Chapter 3: Skeletal manifestations of stress

Skeletal manifestations, or indicators, of stress can be loosely defined as "the biobehavioral response to environmental conditions" (Goodman et al., 1988, 171). These are changes to the typical structure or appearance of bones and the dentition brought about by the body's physiological response to the environment. There are countless environmental variables and their interactions which can have a detrimental effect on health, including nutrient provision, climate, amount and type of physical activity, infection and disease, psychological factors and war (Osipov et al., 2020; Steckel et al., 2002; Blackwell et al., 2001). When discussed in palaeopathological terms, stress is divided into two broad categories: specific stress where a skeletal change is known to have a specific cause, and non-specific stress where the change could have been driven by any of a range of factors. It must be remembered that the presence of skeletal manifestations of stress indicates a failure of the individual to adapt to the environmental stress, and absence can either indicate high resilience or high susceptibility resulting in a quick death. This is known as the osteological paradox (Wood et al., 1992) and can be neatly illustrated by supposing that an otherwise healthy person experiences a long term illness which eventually takes their life. Bone is resistant to remodelling and so will not be affected by acute illness leading to death, or by mild illness which is recovered from in a matter of days or weeks (Ortner, 2003, 153). The presence of lesions on bone is therefore indicative that a person was healthy enough to survive with the condition for a long enough period of time that it reached the bone, and could therefore be seen as more resilient than a person who succumbed faster with no indicators of stress in their bone. This chapter discusses the five skeletal manifestations of stress which are examined in this thesis, summarising the current understanding of their formation and appearance to assist in their interpretation in the case study populations.

In general, juveniles are found to be most susceptible to stress (Goodman and Armelagos, 1989), and so are often used to indicate the worst of what a population experienced. Females are usually most resilient in both child- and adulthood (Stinson, 1985). However, juvenile individuals in a skeletal assemblage are considered non-survivors, in that they were so highly stressed that they did not live to adulthood, and so their inclusion in the dataset would indicate a far greater stress prevalence than realistic. Additionally, there is a bias in skeletal preservation towards adults, with generally few remains surviving from juvenile individuals in any given cemetery excavation (Caruso et al., 2021; Walker et al., 1988). This is true of the case study sites chosen for inclusion in this thesis, which are discussed in more detail in Chapter 5. Therefore male and female adult remains will be studied for indicators of stress which occurred during childhood, in order to build a sufficiently large dataset for statistical analyses with as little bias as possible, while maintaining focus on the most vulnerable period of life. The skeletal manifestations of stress examined in this work will be:

- Cribra orbitalia, which can form until the age of fifteen from nutritional stress or disease
- Dental enamel hypoplasia, which forms up to the age of six from non-specific stress
- Rickets, which forms between the ages of four months and four years from nutritional stress or behavioural differences
- Stature, which develops until late adolescence and is affected by non-specific stress
- Vertebral neural canal dimensions, which – depending on the specific dimension – develop until the age of five or until the age of fifteen, and are affected by non-specific stress.

The combination of indicators of stress which act at different times during growth and development with different causes can help to reduce the effects of the osteological paradox by creating a broader picture of a population's health (DeWitte and Stojanowski, 2015). Rather than studying a specific disease or stressor, this will allow a more nuanced understanding of both individual and population level health throughout life, the possible environmental variables at play, and the subsequent effects on mortality, reproduction and work.

3.1 Cribra orbitalia

3.1.1 Manifestation

Porosity of the cranium can take two forms: cribra orbitalia affecting the roof of the eye orbit, and porotic hyperostosis affecting the cranial vault. These conditions are among the most commonly recorded lesions in archaeological populations, though they are not often co-occurring (Brickley, 2018). Cribra orbitalia was first described, and the name coined, by Welcker in 1888 (as cited in Cole and Waldron, 2019). Macroscopically, cribra orbitalia presents as clusters of tiny pits in the orbital roof (Grauer, 2019, 515), though microscopically these clusters have been seen to resemble vascular grooves (Rothschild et al., 2020). The area covered by the lesion can vary from a strip a few millimetres wide, to over half of the orbital roof (Welcker, 1888, as cited in Cole and Waldron, 2019), and can also vary between the two orbits of the same cranium. It was suggested by Cole and Waldron in their review of palaeopathological studies of cribra orbitalia (2019) that lesions identified as cribra orbitalia can in fact be divided into three groups, and that these groups potentially represent three different conditions or aetiologies. The standard lesion described is an area of porosity which does not affect the morphology of the orbit (for example Figure 3.1.1), and the authors suggest this is the only form that should be recorded as cribra orbitalia. The second is a variation where the lesion is created by deposits of new bone, making the orbital roof more convex (for example Figure 3.1.2). The third group contains variants where the morphology of the orbit is made more convex by inflammation in the cortical bone. As of yet, this system has not been adopted for use in osteological analysis, instead the typical presence/absence scoring system is still most often used. However, given that the appearance and area covered by cribrotic lesions are not known to be associated with the severity of the health insult in life (Grauer, 2019, 517), recording presence or absence of the lesions remains a valid and practical method.

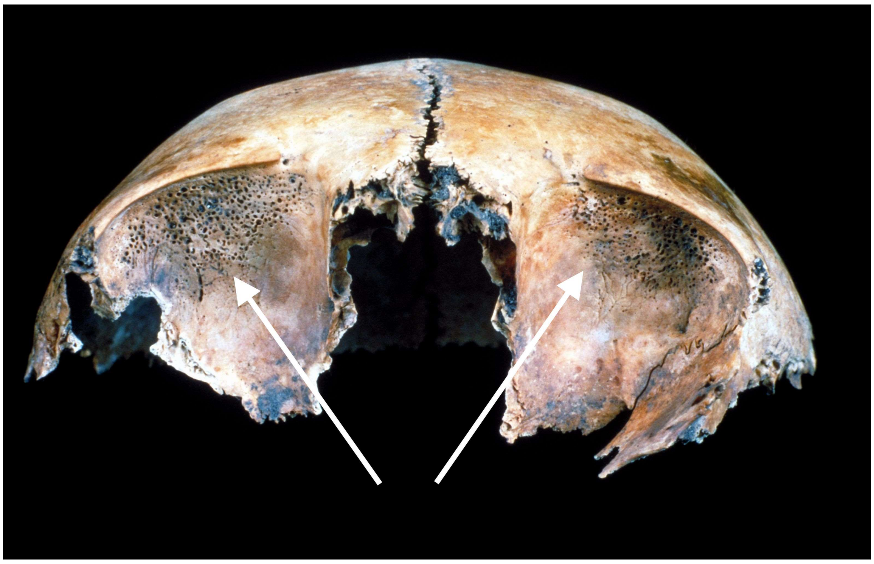


Figure 3.1.1: An example of cribra orbitalia in both orbits of a juvenile from Aberdeen's Carmelite Friary. Photo from Cameron et al., 2019, arrows added by author.

Figure 3.1.2 Cribra orbitalia affecting the morphology of the orbit in an individual from a Neolithic Hungarian site (Spekker, 2012).

Palaeopathologically, cribra orbitalia is found in archaeological populations worldwide (e.g. O'Donnell, 2019; Suby, 2014; Jatautis et al., 2011; Oxenham and Matsumura, 2008; Facchini et al., 2004; Carlson et al., 1974). The distribution of the condition between sexes varies between populations. Some find a higher frequency of lesions in males (for example Mangas-Carrasco and López-Costas 2021; Liebe-Harkort, 2012;), some in females (for example Wapler et al, 2004; Piontek et al., 2001; Lubocka, 2000), and some find no significant difference between the frequency of cribra orbitalia appearing in males and females (for example Beňuš et al., 2010; Jatautis et al., 2011; Kozak and Krenz-Niedbała, 2002). Active lesions are only seen in skeletal remains of those under twelve, with those in adolescents and adults showing signs of healing (Mittler and Van Gerven, 1994). One study drawing comparisons between age groups found a much lower frequency of healing lesions in older adult males compared to females, despite the much higher lesion frequency in younger adult males (Mittler and Van Gerven, 1994), suggesting that males have a greater ability to repair the lesions. Nonetheless, despite the ability of bone to remodel itself, the signs of disturbance remain because the cranium has a low remodelling rate, and repairing the lesions is not necessary for function (McFadden and Oxenham, 2020). This makes cribra orbitalia a persistent indicator of childhood stress in the better preserved adult skeletal remains of a population.

Some papers theorise that modern populations are much healthier and therefore experience negligible levels of cribra orbitalia (for example Exner et al., 2004), though this is not supported by what little work has been done in this area. Clinically, cribra orbitalia is rarely seen in live patients as it has no impact on the functionality of the eye orbits, and can only be discovered through radiographic imaging. Instead, it is studied in modern skeletal assemblages such as forensic collections. One such study examined forensic remains from South Africa and North America, finding that the frequency of cribra orbitalia was greater in the modern skeletal assemblages from both South Africa and North America, seen in up to 40% of individuals, in comparison to archaeological assemblages of the same regions (Steyn et al., 2016). The exact provenance of the individuals in the forensic collections was unclear, though as unidentified victims of crime they were expected to have come from deprived backgrounds, and therefore were likely to have experienced unusually high levels of stress in comparison to their peers. A study of post-mortem CT scans of American children also identified cribra orbitalia in almost a quarter of the individuals, seen more frequently in those who died of natural causes but also appearing in healthy children who died by accident or murder (O'Donnell et al., 2020).

3.1.2 Aetiology

The aetiology of cribra orbitalia has been long debated. On a cursory level, the biological cause of cranial porosity is the expansion of the diploë, or cancellous bone, in response to marrow hypertrophy, and the resulting pressure atrophy on the thin outer table of the bone. This is particularly likely to develop in the orbital roof because the bone is very thin, so less marrow expansion and pressure is required to perforate the outer table (Brickley, 2018).

Anaemia is generally accepted as the cause of cribra orbitalia, and has been since the 1960s (for example Zaino and Zaino, 1975; Nathan and Haas, 1966; Angel, 1964). The World Health Organisation defines anaemia as a haemoglobin concentration below a certain level, which differs for individuals based on sex and age (WHO, 2004). There are, however, many causes of clinical anaemia, including hereditary anaemias such as thalassaemia and sickle cell anaemia, infection and dietary deficiencies (Brickley and Mays, 2019). All of these are capable of causing diploic expansion because the low concentration of haemoglobin triggers overproduction of red blood cells in bone marrow. Palaeopathological studies have a tendency to interpret cribra orbitalia as an indicator of iron deficiency anaemia (e.g. Vyner and Wall, 2011; Powers et al., 2009; Vincent and Mays, 2009). The reason for this is twofold. Iron deficiency anaemia stimulates red blood cell production because of the insufficient oxygen supply in the blood. However, the lack of iron means many of the new cells never become functional and are instead destroyed in the bone marrow, causing hyperplasia (Oxenham and Cavill, 2010). Secondly, hereditary anaemias are restricted to certain genetic backgrounds and geographic areas: thalassaemia in the Mediterranean, Middle East, Southern Asia and Africa, and sickle cell anaemia in Africa (Brickley and Mays, 2019). However cribra orbitalia has been found in archaeological populations worldwide, including Native American populations who would have had no contact with those carrying the genes for hereditary anaemias (Blom et al., 2005; Palkovitch, 1987; Zaino and Zaino, 1975). The distribution of iron deficiency anaemia – a widespread condition both historically and in modern populations – therefore more closely corresponds with the distribution of cribra orbitalia (Bothwell, 1995).

Regardless of the specific aetiology, the lesions characteristic of cribra orbitalia form in childhood. Red blood cell production, and therefore remodelling in response to anaemia, only takes place in red marrow. The distribution of red marrow changes over time as it is converted to yellow marrow in a broadly consistent pattern of development. In subadults, red marrow is distributed across the whole skeleton, including the cranial vault and orbits. Conversion begins with the facial region and eye orbits, which become composed of either mixed or fully yellow marrow by the age of 15. In adults red marrow is restricted to the torso, mostly the vertebrae (Brickley, 2018) so anaemic marrow expansion is restricted to the same area. In addition to this, adult bone has been found to accommodate marrow expansion without a corresponding change in the appearance of the outer table (Al-Adhadh and Cavill, 1983), so cribrotic lesions can be assumed to represent an environmental stressor causing anaemia before mid-adolescence.

A variety of other conditions have been suggested to either cause, or contribute to the development of cribra orbitalia. Scurvy is known to create porotic lesions of the orbit, but also affects other skeletal elements such as the mandible, maxilla and long bone epiphyses so would not be recorded as cribra orbitalia if the skeleton is examined thoroughly (Brickley and Mays, 2019). Walker et al., (2009) suggest a deficiency of vitamin B12, combined with disease and parasitic infection, can provoke haemolytic anaemia, though this paper is hotly contested (see McIlvaine, 2015; Oxenham and Cavill, 2010). Chronic disease alone is often discussed, as some parasites and pathogens can cause heavy bleeding, leading to iron deficiency (Grauer, 2019). Iron deficiency anaemia has also been linked to respiratory infections as each can exacerbate the other; iron deficiency can decrease the immune response and exacerbate hypoxia, and infection can cause iron deficiency thereby increasing the likelihood of cribra orbitalia forming (O'Donnell et al., 2020). Work has also focused on malaria, which can cause haemolytic anaemia in those infected due to both the parasite and the immune system directly destroying red blood cells, and reduced red blood cell production as the infection damages bone marrow (Phillips and Pasvol, 1992). In areas where malaria is endemic, the population experiences recurrent bouts of anaemia, most notably in childhood where the severity of the anaemia has been seen to cycle with the seasons (White, 2018). While not seen in Britain today, malaria is believed to have been introduced by the Romans and became endemic in marshy and low lying areas in the post medieval period (Hutchinson and Lindsay, 2006; Sallares, 2002). Differences in the frequency of cribra orbitalia have therefore been seen between archaeological inland and marshland populations where life conditions were otherwise very similar (Gowland and Western, 2012).

Environmentally, cribra orbitalia was historically connected to food supply, with increasing prevalence in each region after the adoption of agriculture. In Native American populations, cribra orbitalia was found to be significantly more frequent among groups engaging in agriculture in comparison to earlier hunting and gathering groups, theorised to be due to the low iron content of maize (Lallo et al., 1977). Differing frequencies are also observed between coastal and inland areas of the same period, in southern Patagonia during the mid-late Holocene skeletal remains were found to exhibit a greater frequency of cribra orbitalia and porotic hyperostosis in the marine hunter-gatherer group (Suby, 2014). This pattern is not universal however; a study of medieval remains from northern Spain showed no differences between any coastal and inland populations (Mangas-Carrasco and López-Costas, 2021), and a study of prehistoric Indonesian remains found a higher prevalence of cribra orbitalia amongst populations with a higher reliance on marine foods, though the sample size was very small (Koesbardiati et al., 2018). Discussion is ongoing as to the relationship between weaning and the formation of cribra orbitalia, with the hypothesis being that weaning at a young age exposes infants to new pathogens and poorer quality food, easily creating iron deficiency by any of the aforementioned mechanisms. Studies that have emphasised weaning as a potential include Fairgrieve and Molto's (2000) examination of pre-Roman and Roman Egyptian populations where pathogen loaded goat's milk would have been fed to infants, and a study of differences between Neolithic groups of Europe in which the authors theorise the higher prevalence of cribra orbitalia in one group is due to lower agricultural productivity reducing the range of weaning foods available (Ash et al., 2016).

3.2 Dental enamel hypoplasia

3.2.1 Manifestation

Hypoplasias are the most common enamel change seen in archaeological populations, of which teeth are the most common survivors, so they are frequently discussed in osteoarchaeological work focusing on population or individual health (Hillson, 2005). The basic characteristics are generally reported to be alterations to the profile of the tooth crown where less enamel has been deposited, which can be seen macroscopically or felt with a fingernail. The alteration is generally clearly delimited and appears in a ring around the whole crown, following the layering of the perikymata (Hillson, 1992). Enamel hypoplasias can take slightly different forms within this general framework. The smallest defects are pits, resembling pinpricks in the enamel surface (Figure 3.2.1). These can be seen alone or in a line of pits forming a ring around the tooth crown. Recorded most often are lines, defined as a thin groove less than 0.5 millimetres wide running all the way around the crown (Figure 3.2.2). The most severe defects are in the form of grooves, which are much wider linear changes in the enamel (Figure 3.2.2) and can be much deeper than pits or lines as well (Ensor and Irish, 1995). Other enamel defects include changes to the opacity of the enamel, resulting in darker or lighter patches or lines on the tooth crown (Robles et al., 2013). These visible defects can be seen on multiple teeth from the same individual, with each matching set representing a period of disruption in the enamel formation (Hillson, 1992). Anterior teeth are most commonly affected, with canines most strongly so as they take longer to develop and therefore may have more opportunity to be affected by a disruption (Lewis, 2007; Goodman and Armelagos, 1985). For this reason data often only exists for the canines and incisors of a population.

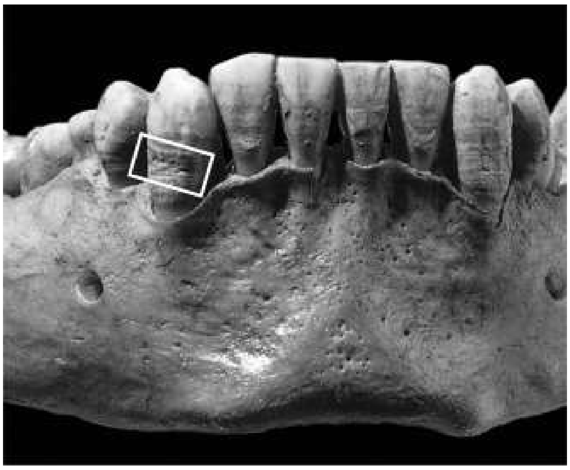


Figure 3.2.1: Linear and pit (boxed) forms of enamel hypoplasia in the dentition of a juvenile individual from prehistoric California. Photo from White et al. (2011), box added by author.

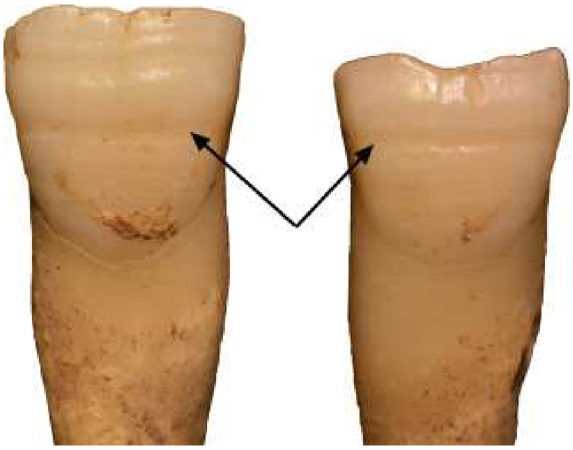


Figure 3.2.2: Linear and groove (arrowed) forms of enamel hypoplasia on the incisors of an adult from medieval Leicester (Nikita, 2017).

The timing of the formation of each hypoplastic defect can be estimated from its position on the crown, the tooth type and position, and the known developmental stages through which teeth go in early childhood (Hillson, 2005). The most common pattern seen in studies of archaeological populations is of a peak in the number of defects formed between the ages of two and four years old (Goodman and Rose, 1991). This is of course variable, and differs by population. For example, a Neolithic population from Liguria in Italy had an earlier mean age of formation of 1.7 years (Orellana-González et al., 2020), whereas, in contrast, a population in 19th-century Florence was seen to have more groove defects forming between 2 to 2.5 years, and more line defects forming after that point (Moggi-Cecchi et al., 1994). Among remains from medieval Canterbury in England, there was a mean formation time of 2.5 years of age for a priory population compared to 3.2 years for the neighbouring lay cemetery (Miszkiewicz, 2015). Populations of 18th- to 19th-century enslaved Africans from the north east United States showed great variation with hypoplasias forming anywhere between 1.5 and 4.5 years old (Blakey et al., 1994). The commonality to these results is that enamel hypoplasias can only form when the tooth crowns are actively developing in early childhood, and so provide a record of physiological stress events which occurred when an individual was younger than around six years of age.

3.2.2 Aetiology

Enamel formation, or amelogenesis, is one of the processes involved in crown formation, before the tooth erupts. For the permanent dentition, this begins with the first incisors at around six months of age, and ends with the third molars at around twelve years of age (Ubelaker, 2008). The enamel matrix is secreted by ameloblasts after the formation of dentine, and this matrix is subsequently mineralised (Nanci, 2017). Secretion begins at the tip of the crown, with the ameloblasts circling the tooth, and proceeds down towards the cementoenamel junction; a process which happens at a known rate (Hillson, 2005, 172). The success of this requires sufficient calcium, vitamin A and vitamin D, as shown in a series of experiments on puppies who developed enamel hypoplasias when deprived of one of those nutrients (Mellanby, 1931). If the process is disrupted, the ameloblasts will fail to secrete enamel matrix until the disruption is ended, but still proceed towards the cementoenamel junction. This results in a thinner area of enamel encircling the crown, forming the characteristic indentation (Hillson, 2005).

Dental enamel hypoplasia is incredibly rare as a hereditary trait, and would be found alongside other indicators of abnormal calcium deposition like rickets if it were so (Kinaston et al., 2019). Therefore it is considered as another manifestation of disruption during growth and development in palaeopathological studies (Goodman and Rose, 1991). Like many growth abnormalities, there are multiple potential causes and factors in its formation which are indistinguishable in any one specific case, so it is generally interpreted as a marker of non-specific systemic stress (Boldsen, 2007). A variety of factors have been investigated in both clinical and palaeopathological studies. Clinically, dental enamel hypoplasia has been linked to malnutrition in a study of modern populations in Mexico, where even mild malnutrition could significantly increase the frequency of enamel defects (Goodman et al., 1987). Maternal malnutrition has also been seen to manifest in enamel hypoplasia of the deciduous dentition in severe cases of vitamin D deficiency during pregnancy (Purvis et al., 1973). One particular enamel defect, the neonatal ring, is noted in all deciduous teeth which are undergoing amelogenesis around the time of birth, and has been seen to be particularly pronounced in those individuals who suffered a stressful birth or birth injury (Eli et al., 1989). Enamel hypoplasia has been noted, alongside other dental defects, to be particularly present in those who survive childhood cancer treatment because the high levels of radiation the body is exposed to can alter the activity of the dental stem cells (Kaste et al., 2009). When considering changes to the opacity of the enamel, these are generally thought to result from hypomineralisation, generally due to a deficiency of calcium, and therefore represent a stress response in a similar manner to hypoplasias. However colour changes can also be caused by trauma directly impacting the tooth crown, so are not often considered alongside hypoplasias in the examination of archaeological populations (Blakey et al., 1994).

One commonly examined source of stress in palaeopathological populations is weaning, as the change in diet and exposure to new pathogens can cause a great deal of stress in an infant, and the mean time of hypoplasia formation between two and four years aligns roughly with the typical weaning age of many populations (Blakey et al., 1994; Goodman and Rose, 1991). Attempts to prove a link between weaning and the formation of enamel hypoplasias have met with variable success, with many studies finding defects formed at very different times to the culturally expected age of weaning. An example of this is the study by Blakey and colleagues (1994) on enslaved African populations, where the frequency of hypoplasia formation only increases approximately nine months after the standard weaning age, so was unlikely to be related. A 19th-century Canadian sample also observed a peak in formation between two and four years, but weaning took place generally between five months and 1.5 years old (Saunders and Keenleyside, 1999). A third study involving medieval European populations found a peak in formation around four years, when weaning was unlikely to have continued past three years (Palubeckaitė et al., 2002). Studies which have found a link between weaning age and the peak frequency of hypoplastic defect formation include one of various Neolithic LBK populations (Ash et al., 2016), a Colonial New Zealand population (Kind et al., 2022), populations from the Japanese Edo period (Nakayama, 2016), and a 19th-century Italian population (Moggi-Cecchi, 1994). These consistently note a peak in the formation of hypoplasias between the ages of two and four, with the cultural weaning age falling at various points within that time frame. It has been suggested that the development of tooth crowns is most susceptible to disruption from stress in the stages which occur between two and four years of age, and that the association with weaning age is not causal in nature (Goodman and Armelagos, 1985). This makes the inference of weaning age from frequency of enamel hypoplasia (such as Lanphear, 1990) somewhat problematic. Overall, some groups may have experienced stressful weaning practices, but this cannot be said to be the sole cause of dental enamel hypoplasia.

Due to the effects of malnutrition on the dental development, enamel hypoplasias are a useful component of research into dietary isotopes. The combination of isotopic analysis and enamel hypoplasia frequency enabled the discovery that social bias in a population from medieval Portugal determined the type of food individuals tended to eat, but that no difference existed in the amount of stress experienced by different sexes or age groups (Toso et al., 2019). In a study of a cemetery population from Machu Picchu known to represent immigrant individuals from many areas, the prevalence of enamel hypoplasia in individuals was significantly linked to both dietary isotopes (carbon and nitrogen) as well as environmental isotopes (oxygen, strontium and lead). The results showed that the individuals with lower quality proteins in their diet had greater frequency of dental enamel hypoplasia, and may have lived at higher altitudes, where the body suffers from hypoxia (Turner and Armelagos, 2012).

Other sources of stress examined in historic assemblages include social status, which can be seen within a group, as in a study of large Roman cemeteries where higher frequency of enamel hypoplasia was related to a poorer standard of grave furnishing (Minozzi et al., 2020), and also between groups, such as a medieval English priory cemetery and neighbouring lay population, where the frequency of enamel hypoplasia was much higher in the lay people (Miszkiewicz, 2015). Status would have controlled a person's access to a varied diet and clean environment, and therefore controlled the amount of stressors experienced by the children. Enamel hypoplasia is also often studied in relation to mortality, as severe childhood stress is thought to create problems for an individual throughout life, resulting in a shorter life expectancy. Medieval European populations demonstrate this relationship, with the most highly stressed groups – as according to the frequency of enamel hypoplasias – having a lower life expectancy (Palubeckaitė et al., 2002), as does a prehistoric Maya population where the combination of number of defects and age at death showed the individuals with more defects per tooth were much less likely to survive early childhood (Cucina, 2011).

3.3 Rickets

3.3.1 Manifestation

Rickets, as a more obviously manifesting disease than cribra orbitalia or dental enamel hypoplasia, has been described and studied for centuries. In Britain it was first described in the 17th century by Whistler, and this was closely followed by several other medical texts on the subject across Europe (O'Riordan and Bijvoet, 2014). The pathological definition of rickets is that it represents a failure to mineralise newly formed bone, and this manifests in the body in several characteristic ways (Shore and Chesney, 2013a). From clinical observation, patients with rickets are seen to have widened wrists and knees, projecting sternal rib ends often referred to as the 'rachitic rosary', and bowing in the long bones of the legs and, occasionally, arms (Brickley and Mays, 2019). The condition can also cause deformities in the spine and pelvis, impeded growth, muscle weakness, spasms and limb pain (Holick, 2006; Narchi et al., 2001). Radiographically (Figure 3.3.1), or in palaeopathological studies, rickets can be seen in changes to the distal epiphyses of the leg and arm bones, namely widening, fraying and cupping of the profile (Brickley and Mays, 2019; Nield et al., 2006). If an individual died while the condition was actively healing, signs of remodelling and smoothing of porosity are visible on their skeletal remains (Brickley and Mays, 2019).

Figure 3.3.1: A wrist X-ray from a three year old presenting clinically with rickets. The distal epiphysis of the radius demonstrates widening, cupping and fraying of the outline. (Shore and Chesney, 2013b).

The bones most affected by these changes are those which grow fastest and therefore accumulate greater changes during an episode of stress. These elements are the distal ulna, radius and femur, and the proximal tibia (Pettifor and Prentice, 2011). The deformation is also affected by the mechanical stresses placed on the body. For example, a toddler would present with bowing in the legs (Figures 3.3.2 and 3.3.3), and possibly deformities in the spine, but an infant still in the crawling stage would also have bowing in the arms (Brickley and Mays, 2019). These changes can all be masked by severe growth delay, however, as the epiphyses will not undergo changes if they are not growing (Shore and Chesney, 2013b).

Figure 3.3.2 [left]: Lateral view of right femur showing anterior bowing in a case of residual rickets in an adult from Roman Italy. (Mays et al., 2018).

Figure 3.3.3 [right]: Posterior view of tibiae showing lateral bowing from active rickets in a seven year old juvenile from Roman England. (Mays et al., 2018).

Rickets is a disorder of growth, localised in the growth plates, and as such is only seen in the active stages in juveniles (Shore and Chesney, 2013a). Studies on the timing of development have found slightly varied results, but most agree rickets rarely develops outside of the ages of four months to four years. It most commonly begins development between 3 and 18 months, but can be as late as 24 months (Brickley and Mays, 2019; Prentice, 2013). It does not usually present in younger infants as they are protected by the placental transfer of 25-hydroxy-vitamin D, one of the key compounds required for normal bone growth (Shore and Chesney, 2013b). In newborn infants the condition appears slightly differently. If the mother is deficient in Vitamin D, the baby will be born deficient as well, with its vitamin D levels correlated with the mother's for the first two months of life (Özkan, 2010). Despite this, infants generally have normal bone mineral content and no indicators of rickets for the first few months of life (Pettifor and Prentice, 2011). In adults, only residual rickets is seen because the bones are no longer growing. Generally, this takes the form of bowing in the long bones, with the porosity and fraying seen in the epiphyses in the active condition having since healed during continued growth with sufficient vitamin D (Brickley et al., 2010). Vitamin D deficiency in an adult results in osteomalacia, a different condition characterised more by pseudofractures and their accompanying deformation of bone than bowing and epiphyseal widening, and is therefore distinguishable in palaeopathological studies (Brickley and Mays, 2019).

While the active stages of rickets are only observed in juveniles, the effects of residual rickets persist in causing difficulties into adulthood. These can include higher incidence of dental enamel hypoplasia (Cohen and Becket, 1976) and dental caries, a painful condition which can result in abscesses or tooth loss (Schroth et al., 2016; Rabbani et al., 2012). It is also a known risk factor for bone fractures and the development of osteoporosis later in life (Cooper et al., 2005; Docio et al., 1998), as well as the development of autoimmune conditions such as multiple sclerosis, type 1 diabetes and Crohn's disease (Cantorna et al., 2004; Ponsonby et al., 2002; Hyppönen et al., 2001; Hernán et al., 1999). One of the more severe lasting effects of childhood rickets is pelvic deformity, which in females is known to cause complications in childbirth and commonly results in the death of the infant, mother or both (Paterson and Ayoub, 2015; Stone, 2009; Mauriello, 2008). Rickets and vitamin D deficiency has also been shown to be associated with the development of several common cancers, though the relationship is not yet clearly understood (NCI, 2013; Holick, 2004; Grant, 2002).

In modern clinical studies, rickets is most commonly seen in black and Asian populations of Europe and North America, the Middle East, Southern Asia and North Africa, due to cultural styles of clothing which cover the body, and darker skin both inhibiting the synthesis of vitamin D when skin is exposed to sunlight (Thacher et al., 2006). The modern distribution differs greatly to that of historic cases where rickets was most prevalent in Europe, especially in Britain, leading to the nickname "the English Disease" (Shore and Chesney, 2013; Thacher et al., 2006). In both palaeopathological and clinical studies, variation has been found in the distribution of rickets between the sexes. Some studies, such as the assessment of the 19thcentury population of a village in the Netherlands (Veselka et al., 2018), found females were more often affected. In contrast other researchers have found a higher prevalence in males, such as in modern Bangladeshi villages (Talukder et al., 2017), or no significant difference between males and females, as in a 19th-century population from Birmingham (Brickley et al., 2010), post-medieval groups from the Netherlands (Lamer, 2020) and in modern American children (Weisburg et al., 2004). Overall it seems that the distribution of rickets is population-specific and could depend on any number of cultural and environmental factors.

3.3.2 Aetiology

The underlying cause of the bony changes seen in cases of rickets is the impairment of bone mineralisation at the growth plates (Thacher et al., 2006). There are three known biochemical types of rickets. Calcipenic rickets is characterised by low blood concentration of the Ca^{2+} ion, usually caused by a vitamin D deficiency and therefore also known as nutritional rickets, the most common form. Phosphopenic rickets is caused by renal disorders or an overproduction of the hormone FGF23. The third type involves the direct inhibition of mineralisation at the growth plate of bones, with normal blood levels of calcium and phosphate (Prentice, 2013). This thesis will focus on nutritional rickets as it is caused by environmental factors and therefore contributes to the study of changes in health caused by the loss of Roman administration in Britain.

Biochemically, Vitamin D is inert; in order to be used in the body it must first be metabolised by the liver to 25(OH)D, a form in which it is able to circulate in the blood. This is then activated in the kidneys to $1,25(OH)_2D$, which in turn regulates the metabolism of calcium, phosphate and bone (Holick, 2006). When a vitamin D deficiency develops, it stops the absorption of calcium in the intestines by up to 90% (Holick, 2007). The low blood concentration of Ca^{2+} triggers the secretion of parathyroid hormone, releasing calcium and phosphate from the bone. The low levels of calcium and phosphate in the bone decrease the mineralisation rate, and cause disorganisation in the cells, affecting the morphological development of the growth plate (Özkan, 2010). Fraser et al. (1967) described the changes in nutritional rickets as having three stages: the first stage includes the initial deficiency of vitamin D, and subsequent release of calcium and phosphate from bone; the second is indicated by more normal levels of blood calcium while blood phosphate remains high; and the third occurs when the deficiency of vitamin D is more severe, lowering calcium concentration and triggering further bone release. These stages have their attendant clinical symptoms: stage one is when muscle spasms or seizures will appear; in stage two the epiphyseal changes are visible radiographically; and in stage three the changes to the bones are visible on observation.

The cause of vitamin D deficiency has long been studied. As discussed earlier, rickets has been known among the medical community for centuries, and theories about the aetiology of the condition and potential cures have been discussed just as long. In the 19th century, the association between rickets and cities started to emerge, and in 1890 a paper was published revealing the restriction of rickets to northern

Europe and deducing the link to sunlight (Chesney, 2012). Since then, biochemical studies have discovered vitamin D, and its metabolism and interactions within the body. It has become clear that there is very little vitamin D in most diets, and the most viable source is therefore synthesis within the body brought about by ultraviolet light on the skin, specifically UVB (Holick, 2006; Loomis, 1970).

Modern large-scale clinical studies have compiled a list of risk factors which increase the likelihood of a child developing rickets. These can differ between countries and cultures, but in general include diet, clothing, time spent outside and darkness of skin (Munns et al., 2016; Prentice, 2013; Nield et al., 2006; Molla et al., 2000). For example in the British Asian community the prevalence of rickets is high due to the cultural clothing style and low calcium diet, in India the high levels of fluoride in drinking water exacerbates any dietary calcium deficiency, and in the Middle East the clothing style prevents vitamin D synthesis despite ample sunlight (Thacher et al., 2006). The clinical studies can be roughly grouped into the simpler idea that in Africa and tropical Asia the main driver of the development of rickets is calcium deficiency, whereas in Europe and North America the main driver is vitamin D deficiency.

Rickets is not necessarily always an indicator of diet, cultural practice or environmental factors. Genetic issues in the kidney, liver and gut, or in the metabolic pathways of vitamin D, calcium and phosphate can act on bone in the same way as a vitamin D or calcium deficiency (Prentice, 2013). Other conditions such as renal failure, respiratory infections, cancer, parasitism and organ malfunction can have secondary rickets as a symptom (Zhang et al., 2016; Nield et al., 2006). However, these are unlikely aetiologies for rickets in archaeological populations as any issues with the major organs would not have been survivable for long without medical care, and so the condition would not have been present long enough to affect the skeleton (Brickley and Mays, 2019).

For the purposes of this thesis, it is noted that as another vitamin deficiency disorder, scurvy could also have been included in the study of skeletal indicators of stress. However the decision was taken to discount it as no cases were identified within the case study population. As will be further discussed in Chapter 5, skeletal preservation tends to be poor in northern England so it could not be determined whether the condition was truly absent, implying the population was not affected by vitamin C deficiency, or whether its identification was simply hindered by the skeletal preservation.

3.4 Stature

3.4.1 Manifestation

An individual’s adult height is strongly genetically determined, and varies greatly within a population. The stature of any offspring is predictable from their mid-parent height, the average of the mother and father’s stature, demonstrating the heredity of the trait (Bogin, 2020). Around the world, among modern populations, mean height varies from 160cm in Timor-Leste to 182cm in the Netherlands for males, and from 149 cm in Guatemala to 169 cm in Latvia for females (Roser et al., 2013). In a selection of ten modern European countries, mean stature has been recorded to vary from 170-179 cm for males and 160-167 cm for females (Cavelaars et al., 2000). A study investigating the stature of medieval European populations and modern Amazonian populations also found significant differences in the body proportions of individuals within the populations (Vercellotti, 2012). The genetic variation presented in stature has been shown to approximately cancel out between most populations, with the exception of Eastern Asian and pygmy groups, such as the Efé people, who are much shorter overall (Perry and Dominy, 2009; Martorell and Habicht, 1986; Tanner et al., 1982). Therefore any significant difference in mean height between populations is likely to have a non-genetic cause.

The variation in adult stature has been shown to not be solely genetically determined, with influence estimated to be 90% genetic and 10% attributable to the environment (Henneberg, 2001). This means the potential final height of an individual is determined by their genotype, but it may not be reached depending on many environmental factors present during growth and development. A series of studies on adopted children, their biological and adoptive siblings, and their adoptive parents demonstrated the influence environment can have on growth as significant correlations between family members were seen for stature and body size regardless of genetic relationship, and this was attributed to the common living environment (Garn, 1979). Economists have used stature to study inequality in modern populations, as it is found to correlate with income across a population (Steckel, 1995). This may be predictable, but it has also been found that stature can reveal inequality even within a richer subset of a population. This inequality comes in the form of cultural prioritisation of certain family members over others, the types of work they may do, or the amount of exposure to disease they experience (Jayachandran and Pande, 2017; Hatton and Martin, 2010; Berhman, 1988). From this it is clear stature is incredibly sensitive to seemingly minor environmental influences.

Growth delay, the result of environmental factors preventing attainment of the genetically possible stature, has been remarked on and studied for many years. One controversial theory regarding delayed growth was that individuals would be “small but healthy”. Seckler (1980) posited that growth delay was a sign individuals had adapted to their less than ideal environment by remaining small in response to childhood malnutrition and so requiring less nutrition as an adult, and that there were no implications of this on health or mortality. This has been refuted by nutritionists, psychologists, biologists and anthropologists in countless studies demonstrating consequences of childhood malnutrition (summarised in Messer, 1989; Pelto and Pelto, 1989). Indian children were found to reach puberty later and take longer to get through the adolescent growth phase when malnourished throughout childhood (Kanade et al., 1999; Satyanarayana et al., 1989). In subsistence populations such as the San living in the Kalahari desert, the “hungry season” when crop yield is lower has been associated with a reduction in fertility (Wilmsen, 1982). It has also been shown in Central and South American populations that malnourished children have impeded cognitive and emotional development, and weaker bonds with their parents (Chavez et al., 1994; Engle et al., 1992).

Palaeopathological studies use the calculation of living height from skeletal remains to identify individuals and populations affected by growth delay, and make inferences about the quality of the diet and living environment. The first calculations of stature from bone were made in the 1880s and 1890s by Etienne Rollet and Leonce Manouvrier, who worked separately but used the same series of cadavers in France. (Meiklejohn and Babb, 2011). The calculations involved have been improved many times with new mathematical formulae or less limited reference collections, resulting in the Trotter equations (1970) which are still the most commonly used today. Palaeopathological studies have found associations between short adult stature, other skeletal manifestations of stress, and periods of time when the environmental stressors acting on a population would have been greater. Measurement of human remains dating from the Palaeolithic, Mesolithic and Neolithic periods have revealed a steady decline in stature across prehistoric Europe, occurring alongside the introduction of agriculture (Meiklejohn and Babb, 2011; Ruff et al., 1997). A similar pattern has been seen in South Asian (Kennedy, 1984) and Native American populations (Mensforth, 1985; Goodman et al., 1984). An increase in stature is observed in European (compiled in Stinson, 2012), African (Martin et al., 1984) and Native American (Auerbach, 2011) populations during the shift from subsistence agriculture to more intensive cultivation. In Chile and Peru, inter-group comparisons of stature found little difference between any over a period of roughly 2300 years, with the exception being the post-colonial population who had a much shorter mean adult height (Allison, 1984). Similarly, stature decreased slightly in Britain after the Norman Conquest in 1066 (Roberts and Cox, 2007).

Short adult stature has been found to associate with other pathologies seen in skeletal remains. Steckel and colleagues (2002) found a significant correlation between stature and signs of anaemia – namely cribra orbitalia and porotic hyperostosis – in populations from across the Americas over a period of six millennia. In prehistoric populations from what is now Sudan, growth delay is associated with porotic hyperostosis and the early onset of osteoporosis, suggested to be evidence that long bones continued growth lengthwise despite the cost to cortical thickness (Martin et al., 1984). However these relationships are inconsistent between populations, likely due to the complex array of potential environmental stressors acting on each pathological indicator.

3.4.2 Aetiology

Gain in height takes place at the growth plate, the cartilaginous structure joining the metaphysis and epiphysis in unfused long bones. The process has two steps: chondrogenesis – the production of cartilage – and ossification – the conversion to bone (De Luca, 2006). The rate of chondrogenesis determines the growth of the bone, and so the stature of the individual. The genes known to have involvement in growth plate mechanics control a wide variety of hormones, proteins, paracrine factors and extracellular components, not to mention all of their possible mutations and copy number variants (Baron et al., 2015).

The genetic control of stature was believed to come from the growth hormone—insulin-like growth factor—I (GH-IGF-1) axis for many years. In this biochemical pathway, growth hormone (GH) is secreted from the pituitary gland, and stimulates production of insulin-like growth factor—I (IGF-1) in almost all tissue types. IGF-1 then promotes cell division in bone, muscle and other tissues (Bogin, 2020). Slight differences, known as polymorphisms, in the genes controlling GH and IGF-1 secretion and reception can cause variation in stature within the parameters standard for a population (Rosenfeld, 2005). Mutations in the genes involved in the GH-IGF-1 pathway have been discovered which cause both dwarfism and gigantism (Lin et al., 2018; Hannah-Shmouni et al., 2016; Laron, 2004). However many clinical patients presenting with idiopathic short stature were not found to have problems in the GH-IGF-1 mechanism after endocrinological testing, indicating that a wider array of mechanisms exert control over adult height (Sisley et al., 2013). Genome wide association studies (GWAS) have identified more than 400 loci in the genome which are associated with a person's height (Liu et al., 2014; Wood et al., 2014), and examination of copy number variants found another 49 loci with influence on stature (Van Duyvenvoorde et al., 2014). From this it is clear that stature variation within a population is of a complex aetiology, and it is difficult to pinpoint a single cause of growth delay even on a purely genetic level.

In addition to the genome, environmental influences can exert control over the rate of growth. When faced with an episode of stress, the body prioritises nutrient use for essential functions rather than growth. Bogin (2020, 418) demonstrates this relationship in his equation "Energy required = Maintenance + Immune Function + Repair + Work + Growth" where basal metabolism, cell and tissue repair and energy used in activity are non-optional processes so their requirements are met at the expense of growth. Both protein and calorie malnutrition are known to delay growth (Baron et al., 2015; Kimura, 1984; Brock and Autret, 1952), an effect which was particularly noted in Europe in the children growing up during the World Wars (Angell-Andersen et al., 2004; Wolff, 1935). Malnutrition can occur through a variety of mechanisms, including poor access to food due to famine, poverty and war, and other factors including child neglect and dietary limitations (Bogin, 2020). Malnourishment also slows growth by increasing susceptibility to infection, in a feedback loop where the illness can then increase malnourishment via poor nutrient retention and absorption. Where infections are frequent and widespread throughout a population, reduced work and food production can then bring on malnutrition (Scrimshaw et al., 1968). Risk of infection is usually greater in areas with higher population density and poor sanitation, and in certain geographic areas such as marshlands home to mosquitoes carrying malaria, so insufficient food production would be more likely in regions with these characteristics (Li et al., 2018; Steckel, 1995).

Growth can be affected by physical influences such as ionising radiation (Couto-Silva et al., 2006) or mechanical stresses (Stokes et al., 2006), which can be applied deliberately to correct unequal limb growth in clinical patients (Lykissas et al., 2013), though the effect of activity related compression on final height remains unclear (Mirtz et al., 2011). Pollution is another cause of stress, which for the last few centuries in Britain has taken the form of combustion emissions, chemical waste, and noise pollution from industrial processes, but before the industrial revolution would more likely have come in the form of smoke from wood or coal fires (Bogin, 2020). Clinical cases have demonstrated severe effects of pollution on childrens' growth (for example Klis and Wronka, 2020; Schwartz et al., 1986; Goldman et al., 1984). The location a population lives in can also affect their average stature, as seen in populations living at high altitudes and latitudes, where the cold increases the basal metabolism and therefore reduces the allocation of energy to growth (Pomeroy et al., 2021; Bogin, 2020). High altitude comes hand in hand with hypoxia, which also negatively impacts stature as the lower oxygen saturation in the blood enforces a decreased rate of cell metabolism and growth (Luft, 1972).

However, not all children who experience growth delay through episodes of stress will maintain that short stature throughout life. The phenomenon of catch up growth is well recorded, individuals being able to grow at a faster rate once the source of stress is remediated, or growing for a longer total period of time at the usual rate (Bogin, 2020, 119). In 19th century slave populations juveniles were seen to be much shorter than expected for their age, around the 1st to 3rd percentile, while adolescents and adults were closer to a normal height, theorised to be because those of working age were better cared for (Rathbun and Steckel, 2002; Pritchett and Freudenberger, 1992; Steckel, 1987). Catch up growth has also been demonstrated in juveniles of medieval English populations, where the stature had no correlation with the number of stress indicators present in the rest of the skeleton, showing that even younger children can recover quickly from growth delay once the stress is removed (Ribot and Roberts, 1996).

3.5 Vertebral neural canal

3.5.1 Manifestation

The vertebral neural canal, also known as the spinal canal, is the space between the vertebral bodies and spinous processes which houses and protects the spinal cord. The complete space of the vertebral neural canal is made up of the vertebral foramen of all cervical, thoracic, lumbar and sacral vertebrae, and as such there are variations in the morphology of the canal depending on the vertebra type (Peabody and Das, 2021; Watts, 2013a). Morphology of the vertebrae is measured in three dimensions: the height of the vertebral body, the transverse diameter of the vertebral neural canal and the anterior-posterior diameter of the vertebral neural canal (Newman and Gowland, 2015; Watts, 2011). These are shown below in Figures 3.5.1 and 3.5.2. Investigations into the variation have found a few typically prevailing patterns. Size tends to increase from the cervical to the lumbar vertebrae, though this is not strictly uniform in sequence. In the cervical spine, the transverse diameter is found to be narrowest at C2 or C3, increasing down towards C7. A similar pattern is seen in the anterior-posterior diameter, except that it is generally widest at C4 for African Americans, but widest at C6 for Caucasians (Tatarek, 2005). The thoracic transverse diameter has been shown to decrease from the first to sixth vertebrae, before increasing again, with no significant difference between white and African Americans. The anterior-posterior diameter has a more complicated pattern, increasing from the first to fifth vertebrae, decreasing from the fifth to tenth and then showing a sudden sharp increase from tenth to twelfth (Masharawi and Salame, 2011). In the lumbar spine, the transverse diameter increases sequentially with L1 the smallest and L5 the largest, whereas the anterior-posterior diameter is largest in L1 and L5 and smaller in the middle three (Watts, 2011). The fifth lumbar vertebra also commonly has a differently shaped vertebral neural canal to the rest, described as a trefoil rather than the more oval or triangular shapes seen in the other vertebrae (Eisenstein, 1980).

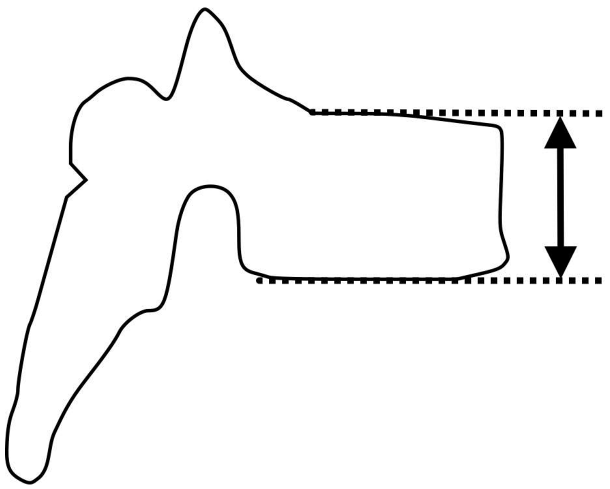


Figure 3.5.1: The location for the measurement of body height of a vertebra.

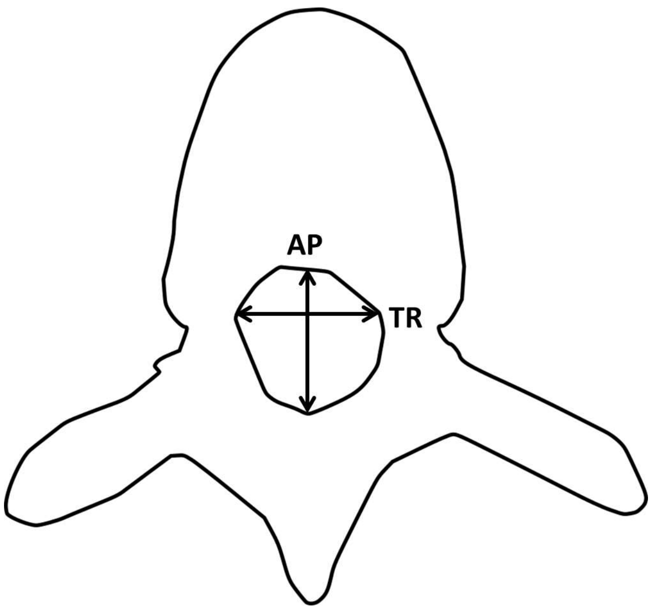


Figure 3.5.2: Locations for measurement of the anterior-posterior (AP) diameter and transverse (TR) diameter.

Sexual dimorphism in the vertebral neural canal is variable throughout the spine. In the cervical vertebrae both the transverse and anterior-posterior diameters were significantly smaller in females from both the white and African American skeletons studied by Tatarek (2005), whereas Rozendaal (2020) and colleagues found that only the transverse diameter exhibited the difference. The thoracic region has produced some varying results: one study finding that the vertebral neural canal was much smaller in males (Bastir et al., 2014), while another found no difference (Masharawi and Salame, 2011). Both had a small sample size in comparison to Tatarek. In the lumbar spine, again, Masharawi and Salame (2011) found no difference in the transverse diameter or anterior-posterior diameter between males and females. A clinical study in Chinese patients found a significantly larger anterior-posterior diameter in females but no difference in the transverse diameter, though only the first lumbar vertebrae was measured (Zheng et al., 2012). Differences in size between males and females would be expected to only appear in the transverse diameter as this continues growth through puberty whereas the anterior-posterior diameter does not (Watts, 2013a), but this has yet to be clearly and consistently demonstrated. Similar irregularity is seen in individual vertebrae; they are not found to be uniformly large or small in all dimensions. No correlation has been found between body height and vertebral neural canal size, and the transverse and anterior-posterior diameters are not necessarily correlated either (Tatarek, 2005).

While the restricted growth of the vertebral neural canal may not appear to be a serious health condition, there is modern clinical evidence that smaller canals can increase the risk of several conditions which affect the spinal cord. The narrowed canal has less room to accommodate any changes such as osteophytic growth in joint disease, injury or disk protrusion without impinging on the spinal cord itself, causing pain or even paralysis (Tatarek, 2005; Eismont et al., 1984). The implications of this have not yet been considered when pondering the quality of life for archaeological populations.

3.5.2 Aetiology

In foetuses, the development of the vertebrae in cartilaginous form begins at four weeks, and the neural processes start to form at six weeks, with closure of the vertebral arches beginning in the ninth week. This process begins with the mid-thoracic vertebrae and extends in both directions, as does the ossification of the vertebral bodies and neural processes (Mekonen et al., 2017). At birth, the vertebrae are each composed of a bony centrum and the right and left halves of the neural arch, joined with cartilaginous tissue. At this stage, the vertebral neural canal is roughly 65% of its full adult size (Hinck et al., 1966). In clinical studies of modern populations, the vertebrae are seen to fully fuse and ossify during childhood, similar to other bones. The two halves of the neural arch ossify and fuse first, starting around one year of age in the thoracic vertebrae and extending up and down the vertebral column to the cervical and lumbar vertebrae. The fusion of the neural arch to the central vertebral body takes longer, and does not occur in the typical thorax-first pattern as the other stages of development; in the cervical vertebrae it is complete between three and four years old, in the lumbar at four years old and in the thoracic at six years old (Scheuer and Black, 2000). The evidence of this can be seen in archaeological populations, where the mean anterior-posterior diameter is the same in juveniles and adults, but the transverse diameter has significant differences between each juvenile age category until 17 years, when it becomes the same as in adults (Watts, 2013a).

The most common bodily reaction to stress in childhood is a disruption to growth and development while the body prioritises essential function (Bogin, 2020; Martorell, 1989). As discussed previously, an individual's stature can be affected by their environment as they grow up, but it is also strongly genetic and so the individual can undergo catch-up growth in order to attain their genetic potential stature (Bogin, 2020; Tanner, 1981). In the same manner as other bodily dimensions, the growth of the vertebral neural canal can be hindered by stress, with the lumbar spine most likely to show the effects of stress as it continues growing for the longest, so has more time to be affected (Watts, 2011; Hinck, 1966). The transverse and anterior-posterior diameters have different developmental timings so can show delayed growth in isolation depending on when the stress episode occurred (Clark, 1988). The differential timings are demonstrated in a study comparing age at death with vertebral measurements, which showed associations between mortality and both stature and transverse diameter, but no relationship to the anterior-posterior diameter. This indicated that stress events occurring later in development are more likely to affect adult health and the age at which people died, and therefore that restricted anterior-posterior growth is only a sign of a stress event happening at a very young age (Watts, 2011). In contrast to stature, the neural canal does not undergo catch up growth because the size is fixed at an early age. This is demonstrated by the lack of correlation between stature and vertebral neural canal diameters (for example Amoroso and Garcia, 2018; Hunter et al., 2016; Watts, 2013b; 2011). Additionally, Newman and Gowland (2015) compared two sites where an association was found between the transverse diameter and vertebral body height in the adolescents of the poorer community, but when comparing the adults between communities, no differences in the body height were evident.

Chapter 4: Methods

This chapter presents a comprehensive account of the methods used in this thesis, covering both my own work, and the standard osteological methods employed by the osteologists who originally examined the skeletal assemblages from the case study sites. First, the process for selecting case study sites will be presented, followed by an overview of the methods for the assessment of age, sex and pathologies used in the original skeletal analysis. Then, the technique used by myself to measure the vertebral neural canal diameters will be described. Finally, the statistical analyses and methods of data presentation are given.

4.1 Selection of study sites

The sites included as case studies in this thesis were first restricted to those which fell within the early 3rd- to late 7th-century AD time frame which forms the focus of this thesis, in order to capture the experience of those living in the later Roman period, and the post-Roman period without narrowing the criteria too much and limiting the potential size of the dataset. Sites with burials from this date range were identified within the modern English counties north of the Humber Estuary from searches of the Historic Environment Records on the Heritage Gateway website (www.heritagegateway.org.uk) using filters to select the "Cemetery" option from each county's register of sites. The gazetteers of sites in relevant theses and dissertations were also consulted, including those by Lauren McIntyre (2014), who compiled a database of all Roman burials in York; Rosie-May Howard (2019), who focused on Roman cemeteries around Hadrian's Wall; and Emma Brownlee (2020), who studied 7th-century burials across Europe. Discussions with Malin Holst of York Osteoarchaeology, and an appeal to the members of the British Association for Biological Anthropology and Osteoarchaeology (BABAO) also yielded data on newly excavated sites which had not been identified through the previous methods.

From the sites identified, the list was narrowed down further based on the availability of osteological data. Only inhumation burials were chosen for study, because skeletal markers of stress are not visible in a comparable way on cremated remains. This was not expected to introduce bias into the results, as cremation burials were a consistent, if infrequent, feature in both the later Roman and early medieval periods in northern England (Esmonde Cleary, 2000; Lucy, 2000), and so their exclusion was expected to have equal impact on the case study populations from each period. Many of the reports of the discovery of human remains were registered in the 18th and 19th centuries, so had no demographic or pathological data, and in most cases it transpired that the skeletal material had not been kept for modern analyses. Excavations in the first half of the 20th century also often failed to conduct or report the results of skeletal analysis, and several in the latter half would report on age and sex but not any pathology. As this thesis focuses on changes in health over the transition from the Roman to the early medieval period, the recording of skeletal indicators of stress – including cribra orbitalia, dental enamel hypoplasia, rickets and stature – was essential. Of the sites which did have both demographic and pathological information available, those which only reported it as a summary of the whole population were discarded, as data was needed to be assigned to each individual in order to assess the association between sex, stature and the various pathologies.

Though the osteological analyses chosen were conducted by different people over a period of several decades, the majority of them referenced the standard methods used in most modern studies for each type of analysis. The potential issues therefore lay with inter-observer error; if the standard method had been interpreted in slightly different ways, the same presentation of a condition could have been reported differently. However, this was not anticipated to greatly affect the findings of this thesis, as many of the assemblages from the case study sites were assessed by teams of osteologists, many of whom worked on several of the case study sites. With the older excavations, some sites had issues with poor cleaning and storage of the remains, and long periods of time elapsing between excavation and examination when some of the more delicate features could have been lost. This was particularly an issue for Sewerby, where the remains excavated in 1959 and 1974 were only quickly cleaned of most of the soil and then packed in straw (David Marchant, personal communication 2022), remnants of which still clung to the bones when examined by myself in order to take vertebral neural canal measurements in 2022.

The case study sites used in the compilation of the demographic and pathological dataset were further narrowed to determine which assemblages would be used in the study of the vertebral neural canal. Skeletal remains found over much of northern – particularly north-western – England are commonly very fragmentary or eroded due to the shallow and acidic soil conditions (Chitty and Brennand, 2007: Petts and Gerrard, 2006). Any case study sites where the majority of individuals were very poorly preserved had to be discounted as so few vertebrae survived in a measurable state that the data collected would not have been worth the time spent. The sites used to study the vertebral neural canal were also determined by their accessibility, as some institutions were unable to facilitate access during the period of data collection for this thesis, and in the case of the Bamburgh assemblage, the skeletons had been recently reinterred (Bamburgh Research Project, 2023).

Period	**Site name**	**Osteological analysis by**	**Included in the study of the VNC?**
Roman	Catterick, Cataractonium	Malin Holst, Sophie Newman, Katie Keefe and Tessi Loeffelmann	Yes
	Pocklington,	Anwen Caffell, Lauren Kancle and	No

	Yapham Road	Tessi Loeffelmann	
	York, Hungate	Malin Holst, Katie Keefe and Roxana Gomez	No
	York, Newington Hotel	Katie Keefe and Malin Holst	No
Roman and early medieval	Catterick, Bainesse	Malin Holst, Sophie Newman, Katie Keefe and Tessi Loeffelmann	Yes
	Dalton Parlours	Keith Manchester and Helen Bush	Yes
	Ferrybridge Henge	Malin Holst	No
	Healam Bridge	Katie Keefe and Malin Holst	Yes
	Parlington Hollins	Sue Boulter	No
	Scorton	Joy Langston	No
	Wattle Syke	Anwen Caffell and Malin Holst	Yes
Early medieval	Bamburgh, Bowl Hole	Charlotte Roberts, Sarah Groves	No
	Melton	Anwen Caffell and Malin Holst	No
	Norton, Bishopsmill	Joanna Higgins	No
	Norton, East Mills	David Birkett and Sue Anderson	No
	Pocklington, Burnby Lane	Anwen Caffell and Malin Holst	Yes
	Sewerby	Don Brothwell and Justine Bayley	Yes
	West Heslerton	Jean Dawes and Margaret Cox	Yes
	York, Queen's Hotel	Katie Keefe and Malin Holst	No

Table 4.1: A list of the sites chosen for inclusion in the compilation of data and the measurement of the vertebral neural canal for this thesis, the period in which burials occurred, and the osteologists who performed the original analyses.

4.2 Assessment of age at death

The following summarises the different methods by which an individual's age at death was estimated, and the process of standardisation applied by myself when compiling previously published work into the dataset for this thesis. The age at death can be assessed in several different ways, though the most accurate estimate will be gained by performing several and combining the results (White and Folkens, 2005). The osteologists who analysed the skeletal remains from the case study sites used a variety of common methods to determine an individual's age at death. The most common was dental wear, because many individuals were so poorly preserved that only the dentition remained, therefore precluding the use of other methods. Of those studies that listed specific methods, rather than handbooks such as those by White and Folkens (2005) or Cox and Mays (2000), all of them referenced either Miles (1962), Brothwell (1981), or both, who developed charts showing typical wear patterns in British pre-industrial populations (Figures 4.2.1 and 4.2.2).

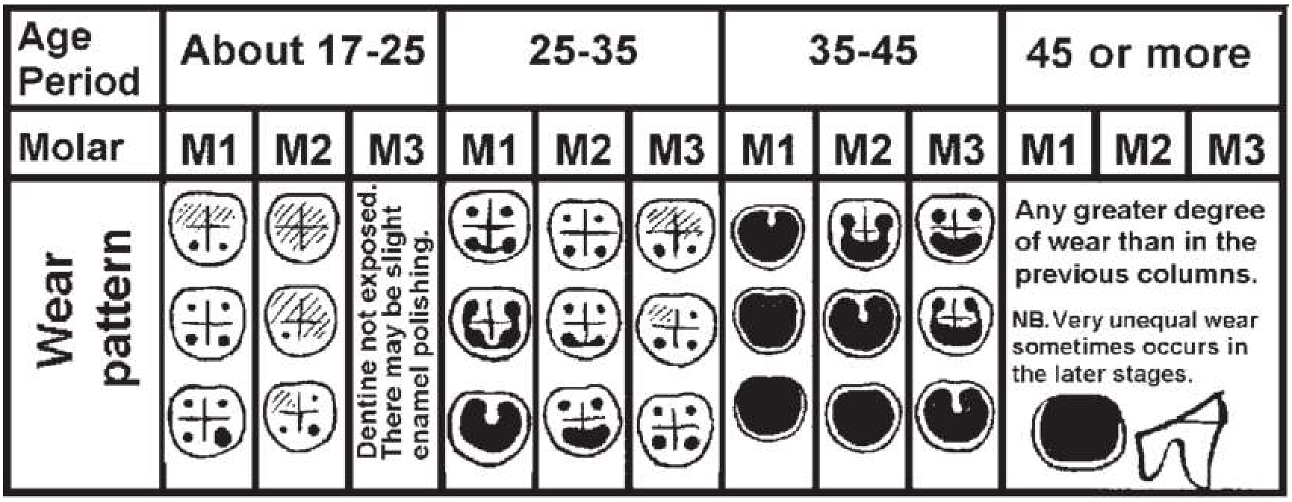


Figure 4.2.1 Patterns of molar wear in each age category (Brothwell, 1981)

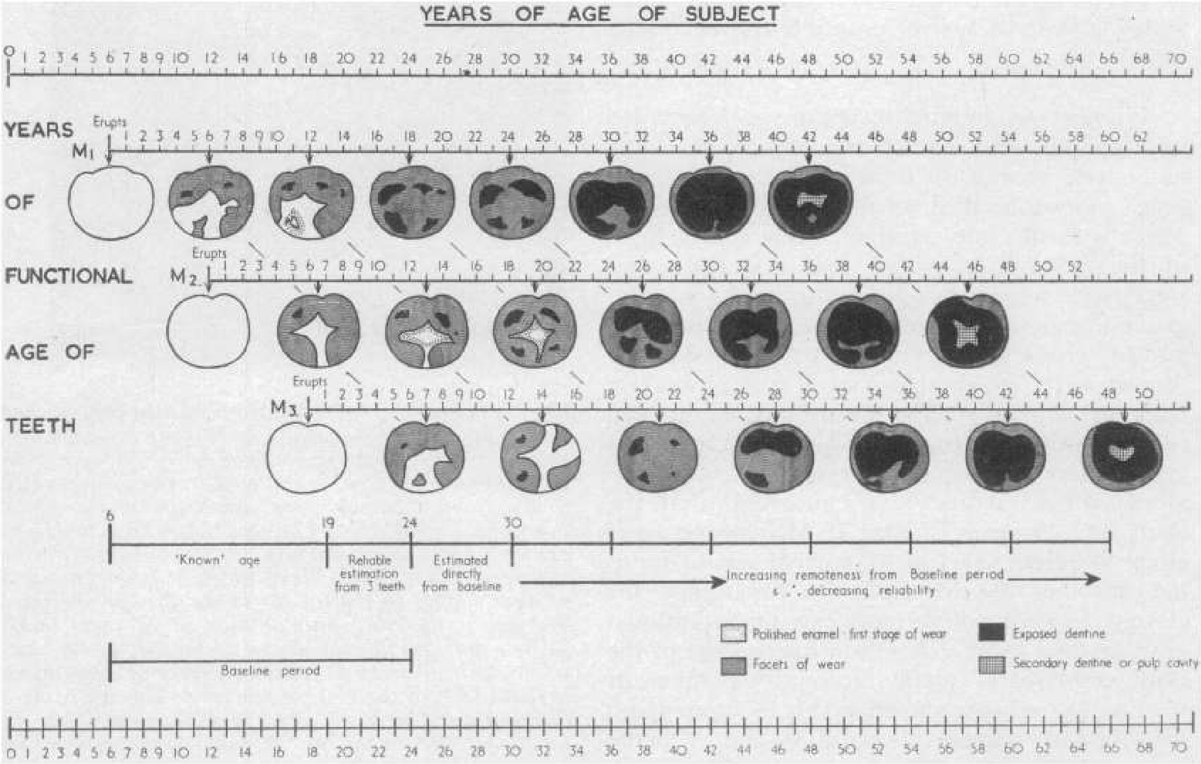


Figure 4.2.2 Typical stages of molar wear at each age (Miles, 1962)

The second most commonly used indicator of age in the analysis of the skeletal assemblages from the case study sites was degeneration in the pelvis. When methods were specified, the techniques developed by Brooks and Suchey (1990) and Lovejoy and colleagues (1985) were always referenced for assessing the pubic symphysis and auricular surface respectively. These two areas, for which degeneration can be categorised and assigned to age groups, were often used in tandem by the osteologists working on the case study sites due to fragmentation and poor preservation of the remains. In the pubic symphysis, younger ages are indicated by horizontal alternating ridges and grooves with a smooth surface, and older ages are marked by progressive flattening of the ridges and porosity of the surface (Figure 4.2.3). The auricular surface is particularly useful for more precisely ageing older adults for whom dental wear or degeneration of the pubic symphysis can be vague (White et al. 2011). In adults younger than about 30 years, the auricular surfaces have a fine grained texture and regular striations. With increasing age comes a coarser texture, increasing micro- and then macro-porosity, and increased irregularity as demonstrated in Figure 4.2.4 (Lovejoy et al. 1985).

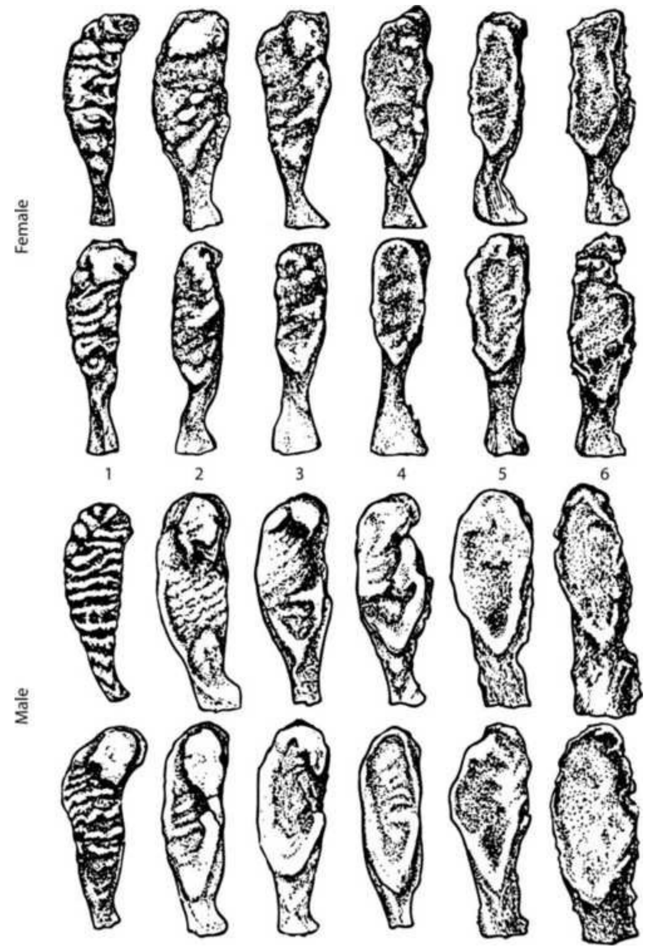


Figure 4.2.3 The stages of degeneration in the pubic symphysis of females and males as described by Brooks and Suchey (1990), illustrated in Buikstra and Ubelaker (1994).

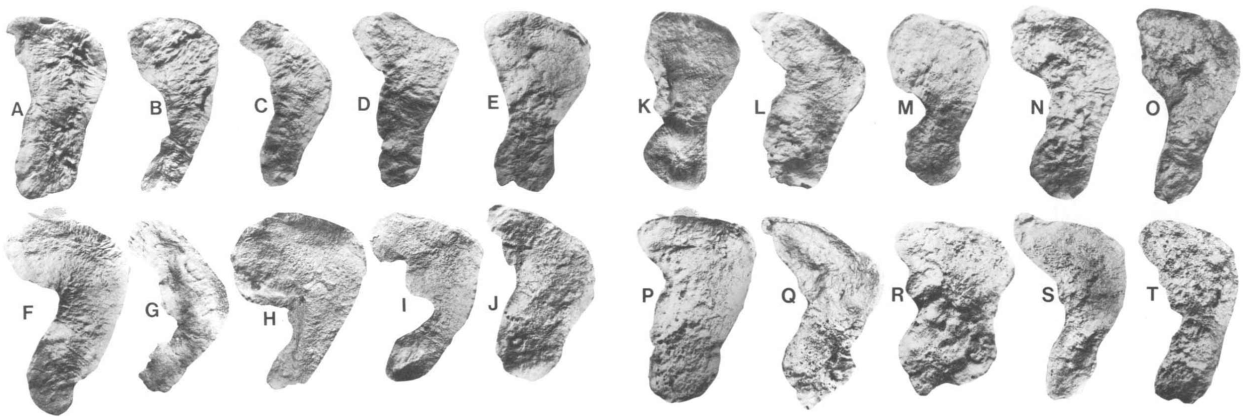


Figure 4.2.4: Age-related changes in the auricular surface of the pelvis, progressing from young adults (A) through to individuals over 60 (T). Images from Lovejoy et al. 1985.

The method least frequently used by the osteologists of the case study sites was the observation of epiphyseal fusion of various bones, as the majority of this takes place before adulthood. However the medial epiphysis of the clavicle does not completely fuse to the body until an individual is over 25 years (Scheuer and Black, 2000), and therefore is often used to very quickly visually determine whether an individual reached that age before other techniques are applied. The reports on two sites – Norton Bishopsmill (Johnson, 2005) and Pocklington Yapham Road (Archaeological Services, 2019) – mention that osteologists used the fusion of the medial clavicle to distinguish younger adults. The other less frequently used indication of age at death mentioned in the case study site reports was degeneration in the sternal rib ends (Işcan et al. 1984; 1985). Degeneration in the sternal rib end presents as increasing pit depth and irregularity of the rim of the fourth rib (Işcan et al. 1985; 1984). The poor skeletal preservation seen at the case study sites made the identification and assessment of the fourth rib difficult, so while promising as a technique, it was correctly only used in conjunction with more reliable methods by those assessing the skeletal assemblages of the case study sites.

In this thesis, the age categories originally described by Falys and Lewis (2011) were used to standardise the variety of ages listed in the sites' reports. These categories are namely:

- Young Adult (18-25)
- Young Middle Adult (26-35)
- Old Middle Adult (36-45)
- Mature Adult (46+)
- Adult (18+)

Some commonly used ages or descriptions used were sorted thus: narrow age ranges – such as Skeleton 72 from Norton Bishopsmill, listed as 40-44 years – will be sorted into the category the range falls under. More precise ageing of older adults – such as Skeleton 03 from Norton Bishopsmill, "48-64" – was ignored and the individual placed in the Mature Adult category because precise ageing becomes far more difficult with age and is therefore not generally trusted (White et al. 2011). Individuals labelled as 17-24 were included in the Young Adult group. Individuals labelled as 15-20 or similar age ranges such as 16-20 or 16-21 were discounted from the study as growth is not yet complete in 15- and 16-year-olds (Bogin, 2020; Watts, 2013a), so their stature and vertebral neural canal measurements would likely have lowered the mean stature or vertebral neural canal measurements for the population. Age ranges which spanned two categories were placed within the group which overlapped the most.

In summary, the poor preservation of bone at the case study sites necessitated the use of multiple methods of age estimation, to accommodate the absence of various skeletal elements. However, the use of multiple techniques is standard, and allows the best possible estimation of age at death by reducing the risk of age being assigned to an individual based on a skeletal element which shows atypical development. Those studies which listed methods of age determination all used dental wear and degeneration in the pelvis, and so are comparable to each other. Additionally, the case study sites chosen were worked on by many of the same osteologists, reducing inter-observer error in the application of the methods of age determination.

4.3 Assessment of sex

The methods for the assessment of sex, which were used in the original osteological studies at each of the case study sites are now presented. The sex of an individual is able to be determined through several skeletal features, most of which are found in the pelvis or cranium. The pelvis is the most sexually dimorphic so is considered the most reliable (White et al. 2011), though usually as many indicators as possible are assessed to build a solid case for an individual being a certain sex. The assessment of sex can only be conducted for adult individuals because the characteristics develop during puberty (White and Folkens, 2005). Sex must also not be conflated with gender, which is a societal concept reflecting the role a person plays in their community and does not necessarily align with their physiological characteristics. Several of the study sites, particularly Sewerby (Hirst, 1985) and West Heslerton (Haughton and Powlesland, 1999), report sex as based on both skeletal evidence and grave good assemblages. In cases where poor preservation hindered the osteological assessment of sex, so it was assigned on the basis of grave goods, this thesis treated the individual as unable to be assigned to a sex. Where the sex from the skeleton and the grave goods differ, only the skeletal sex was used.

The majority of the case study site reports on the skeletal assemblages state that the pelvis was examined to help determine sex. Those that did not referenced standard guidelines e.g. Brickley and McKinley (2004) or Cox and Mays (2000), which instruct on the methods for sexing via the pelvis. Most of these relate to the overall shape: wider and flatter in females and much narrower in males. When specific techniques were named in the case study reports, the dimorphic traits of the subpubic region determined by Phenice (1969) were described (Figure 4.3.1). The composite arch of the auricular surface (Bruzek, 2002) was also used to determine sex in the assessments of the case study site assemblages (Figure 4.3.2).

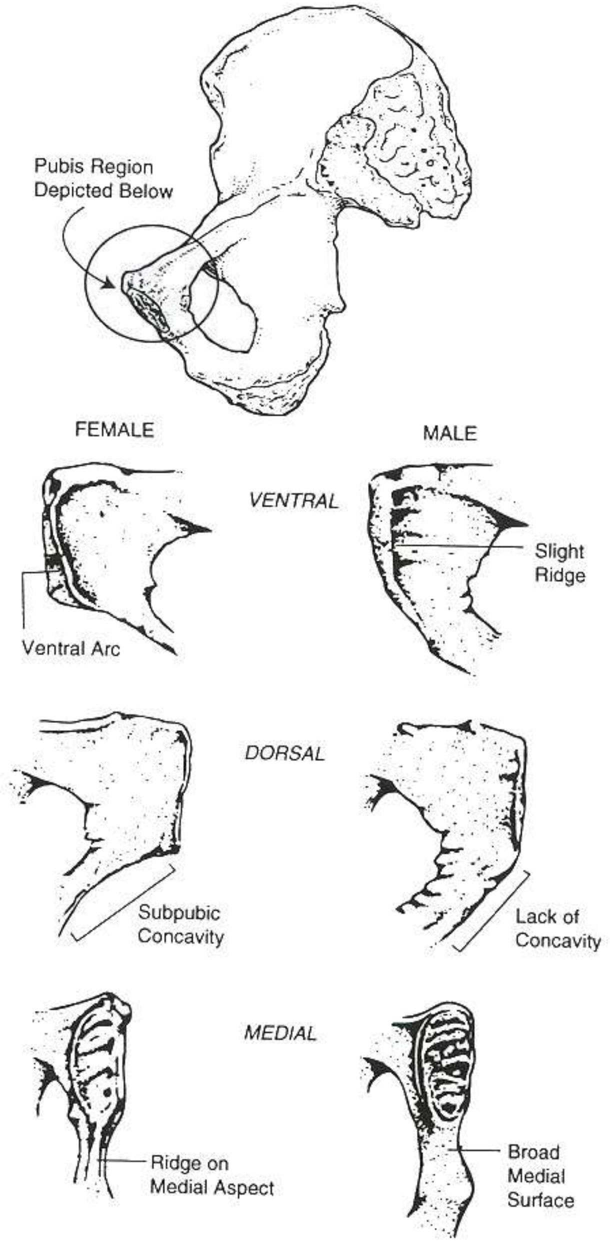
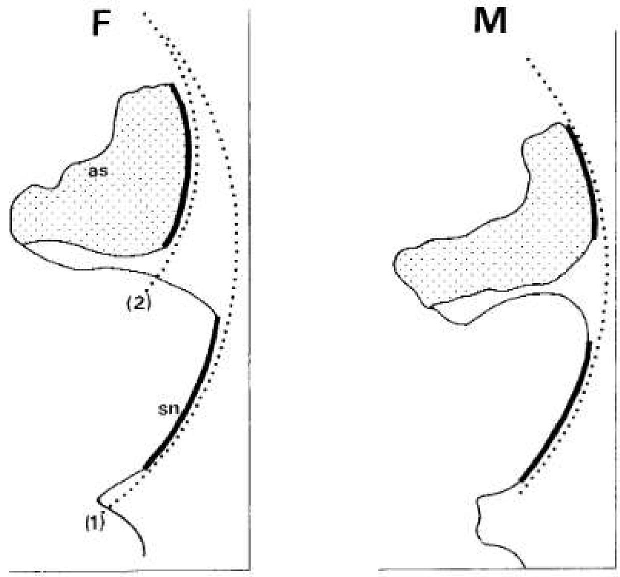


Figure 4.3.1 [left]: Indicators of sex in the pubis region as determined by Phenice (1969), illustrated in Buikstra and Ubelaker 1994.

Figure 4.3.2 [below]: The anterior edge of the auricular surface and sciatic notch form two distinct curves in females but only one in males (Bruzek, 2002).



The osteologists who examined the skeletal collections from the case study sites most frequently used the Walker method (1994) for sexing via the cranium, which scores five traits on a scale from one to five, one being hyperfeminine and five being hypermasculine (Figure 4.3.3). Brickley and McKinley (2004) note that the mental eminence of the mandible is not often of use in British populations, but it was unclear whether it was used by the teams working on the case study sites.

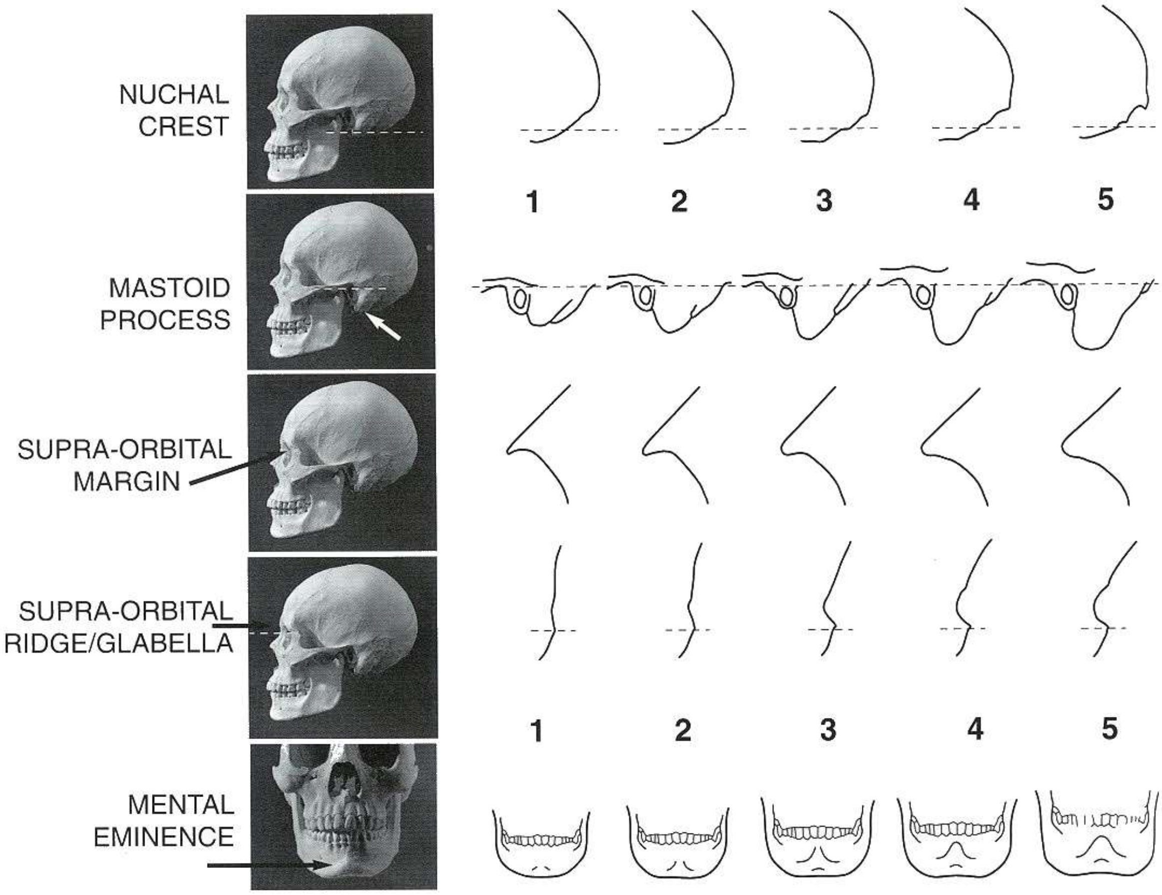


Figure 4.3.3: The determination of sex from the skull. Traits matching the appearance of 1 are hyperfeminine, and traits matching the appearance of 5 are hypermasculine. (Walker, 1994).

Determination of sex can be supplemented with measurements of certain skeletal elements as in general, males will be more robust and females will be more gracile. However, these measurements alone cannot allow confident assignment of sex as they are less dimorphic and much more variable in both sexes, so were not used by the case study sites unless in conjunction with the morphology of the pelvis and skull. The case study sites in which the osteologists utilised the long bones in determining sex used the measurement guidelines given by William Bass in various editions of his osteology manual (1995; 1987), though none of them stated which bones were used.

For the assemblages which were part of the study of the vertebral neural canal, the age of each individual was briefly assessed by myself through clavicle fusion, dental wear and pelvic degeneration, and the sex briefly assessed through pelvic and cranial characteristics to confirm the identity of the skeleton in comparison to box number, and ensure any mislabelling would not result in vertebral neural canal measurements being added to the pathological data from a different individual.

In summary, individuals from the skeletal assemblages included in the dataset for this thesis were assigned a sex using either pelvic morphology, skull morphology, or both, as necessitated by the state of preservation of each individual. These methods are commonly used, not only by the osteologists examining the skeletal assemblages from the case study sites, but also in similar studies across Britain and Europe, making the case study populations comparable to each other and to contemporary populations.

Site name	**Osteological analysis by**	**Ageing methods**	**Sexing methods**
Catterick, Cataractonium	Malin Holst, Sophie Newman, Katie Keefe and Tessi Loeffelmann	Dental wear (Miles, 1962; Brothwell, 1981), degeneration in the pelvis (Lovejoy et al. 1985; Brooks and Suchey, 1990)	Pelvis and skull morphology (Cox and Mays, 2000) and measurements of certain bones (Bass, 1987)
Pocklington, Yapham Road	Anwen Caffell, Lauren Kancle and Tessi Loeffelmann	Late-fusing epiphyses (Scheuer and Black, 2000), degeneration in the pelvis (Lovejoy et al. 1985; Brooks and Suchey, 1990), degeneration of sternal rib end (Işcan et al, 1984; 1985), dental wear (Brothwell, 1981)	Pelvis and skull morphology (Phenice, 1967; Buikstra and Ubelaker, 1994), measurements (Bass, 1987)
York, Hungate	Malin Holst, Katie Keefe and Roxana Gomez	Described in Gomez (2017): Dental wear (Miles, 1962), degeneration in the pelvis (Lovejoy et al. 1985; Brooks and Suchey, 1990)	Described in Gomez (2017): pelvis and skull morphology (White and Folkens, 2005; Buikstra and Ubelaker, 1994)
York, Newington Hotel	Katie Keefe and Malin Holst	Dental wear (Miles, 1962), degeneration in the pelvis (Lovejoy et al. 1985; Brooks and Suchey, 1990), degeneration of sternal rib end (Işcan et al, 1984; 1985)	Pelvis and skull morphology, measurements, all as described in Cox and Mays (2000)
Catterick, Bainesse	Malin Holst, Sophie Newman, Katie Keefe and Tessi Loeffelmann	Dental wear (Miles, 1962; Brothwell, 1981), degeneration in the pelvis (Lovejoy et al. 1985; Brooks and Suchey, 1990)	Pelvis and skull morphology (Cox and Mays, 2000) and measurements of certain bones (Bass, 1987)
Dalton Parlours	Keith Manchester and Helen Bush	Not mentioned	Not mentioned

Ferrybridge Henge	Malin Holst	Dental development and "standard ageing techniques" according to Cox and Mays (2000) and Scheuer and Black (2000)	Pelvis and skull morphology, measurements of certain bones. No references given.
Healam Bridge	Katie Keefe and Malin Holst	Degeneration in the pelvis, following Cox and Mays (2000)	Pelvis and skull morphology, as described in Cox and Mays (2000)
Parlington Hollins	Sue Boulter	Not mentioned	Not mentioned
Scorton	Joy Langston	Dental wear (Brothwell, 1981), degeneration of sternal rib end (Işcan and Loth, 1986), degeneration in the pelvis (Lovejoy et al. 1985; Meindl et al, 1985)	Pelvis and skull morphology (Ubelaker, 1999; Krogman, 1962)
Wattle Syke	Anwen Caffell and Malin Holst	Dental wear (Miles, 1962), degeneration in the pelvis (Lovejoy et al. 1985; Brooks and Suchey, 1990), degeneration of sternal rib end (Işcan et al, 1984; 1985)	Pelvis and skull morphology, measurements as described in Cox and Mays (2000)
Bamburgh, Bowl Hole	Charlotte Roberts, Sarah Groves	Dental wear, degeneration in the pelvis, joint fusion following Brickley and McKinley (2004)	Pelvis and skull morphology following Brickley and McKinley (2004)
Melton	Anwen Caffell and Malin Holst	"Standard osteological techniques" according to Scheuer and Black (2000) and Cox and Mays (2000)	"Standard osteological techniques" according to Cox and Mays (2000)
Norton, Bishopsmill	Joanna Higgins	Dental wear (Miles, 1962), degeneration in the pelvis (Lovejoy et al. 1985; Brooks and Suchey, 1990)	Pelvis and skull morphology (Schwartz, 1995; Buikstra and Ubelaker, 1994), measurements (Bass, 1995)
Norton, East Mills	David Birkett and Sue Anderson	Epiphyseal fusion (no reference given), pubic symphysis (no reference	Pelvis morphology (no reference given)

		given), dental wear (Brothwell, 1981)	
Pocklington, Burnby Lane	Anwen Caffell and Malin Holst	Dental wear (Miles, 1962), degeneration in the pelvis (Lovejoy et al. 1985; Brooks and Suchey, 1990)	Pelvis and skull morphology, as described by Cox and Mays (2000)
Sewerby	Don Brothwell and Justine Bayley	Not mentioned	“Amalgamation of the biological and cultural data.” (Hirst, 1985 pp. 33)
West Heslerton	Jean Dawes and Margaret Cox	Dental wear (Brothwell, 1981)	Pelvis and skull morphology (Workshop of European Anthropologists, 1980)
York, Queen’s Hotel	Katie Keefe and Malin Holst	Dental wear (Miles, 1962), degeneration in the pelvis (Lovejoy et al. 1985; Brooks and Suchey, 1990), degeneration of sternal rib end (Işcan et al, 1984; 1985)	Pelvis and skull morphology, measurements, all as described in Cox and Mays (2000)

Table 4.2: The ageing and sexing methods named in each case study site report, and which osteologists performed the skeletal analyses.

4.4 Identification of pathologies

4.4.1 Cribra orbitalia

In reporting the analyses of the skeletal remains from the case study sites, the osteologists involved most frequently simply recorded the presence of cribra orbitalia. Despite attempts by researchers such as Cole and Waldron (2019) and Stuart-Macadam (1991) to create standard gradings for the assessment of cribra orbitalia, they were not consistently used in reporting the results from the case study sites. Some reports named categories such as “slight” or “severe” but did not make it clear how these were determined. Therefore, for the purposes of this thesis it was decided to only record cribra orbitalia as present or absent when compiling the data from the study sites. Due to the fragmentary and eroded nature of many individuals included in the study, it was also decided to only record the presence or absence of cribra orbitalia in those individuals who had at least one eye orbit preserved for analysis. Therefore any individuals with the eye orbits either listed as missing or their presence was unclear on scrutinising the reports were discounted from the analysis of the frequency of the pathology so as not to conflate absence of the bone with absence of the condition.

4.4.2 Dental enamel hypoplasia

Dental enamel hypoplasia was often the only skeletal manifestation of stress recorded for a particular individual from any of the case study sites, as even the most poorly preserved burials retained the teeth. However, the recording of dental enamel hypoplasia was not standardised between the case study site reports. Some osteologists simply recorded the presence or absence of the condition, whereas others recorded the number of lesions and the number of teeth affected per individual. The grading scale of pits, lines and grooves described in section 3.2 was occasionally utilised to describe the features, but the scales were ambiguous and could not be compared between study sites. The osteologists working on the assemblages from Parlington Hollins and West Heslerton (Roberts et al. 2001; Haughton and Powlesland, 1999) calculated the age at which the disturbance occurred, as according to Reid and Dean (2000) or Smith (1991), but these were the only case study sites to report such data. Therefore, during compilation the data from all of the case study site reports was adjusted so that dental enamel hypoplasia was scored as present or absent in all individuals with at least one tooth preserved. The severity of the condition or age of occurrence were not taken into account as they could not be consistently compared between sites. This meant that the calculation of true prevalence had to be modified, as the typical calculation would be performed using data on each individual tooth. Instead, the modified true prevalence used in this thesis calculated the prevalence of dental enamel hypoplasia among dentate individuals.

4.4.3 Rickets

The identification of rickets in the skeletal assemblages of the case study sites depended heavily on the preservation of the bone, as the characteristic bowing and especially the widening of the epiphyses are difficult to identify when fragmentation and erosion hide the true profile of the bone. However, all case study sites suffered from poor preservation, so it is likely the thoroughness of the analysis conducted by the osteologists was the only hindrance to inter-site comparisons, a risk which is taken by any study of data collected by different observers. The condition was only potentially present in the skeletal reports for three sites: Bainesse (Speed and Holst, 2018), Burnby Lane (Caffell and Holst, 2022), and Hungate (Connelly and Malone, 2024). Only the Hungate report confidently ascribed the condition to one individual (SK64), and G197a was reported as having “possible residual rickets”, but most cases simply described the bowing of long bones without diagnosing the condition. In this thesis rickets was assessed as either present or absent in individuals who had at least one lower limb preserved, so the tentative assignment of the condition in the reports above was treated as presence of the condition.

4.5 Measurements of growth delay

4.5.1 Stature

In order to calculate living stature from long bone length, standard practices and equations are commonly used by the majority of osteologists. The equations calculated by Trotter and Glesser (1952) were improved upon by Trotter to account for ancestry and include a standard error calculation (1970). Trotter's 1970 equations (Table 4.3) were used in the estimation of stature for the skeletal assemblages of all the case study sites as they are the most widely used and accepted, with the exception of Sewerby, for which the Trotter and Glesser (1952) equations were used as the site was excavated before the updated equations were published.

White Males	Black Males	White Females	Black Females
3.08 × Humerus + 70.45 ± 4.05	3.26 × Humerus + 62.10 ± 4.43	3.36 × Humerus + 57.97 ± 4.45	3.08 × Humerus + 64.67 ± 4.25
3.78 × Radius + 79.01 ± 4.32	3.42 × Radius + 81.56 ± 4.30	4.74 × Radius + 54.93 ± 4.24	2.75 × Radius + 94.51 ± 5.05
3.70 × Ulna + 74.05 ± 4.32	3.26 × Ulna + 79.29 ± 4.42	4.27 × Ulna + 57.76 ± 4.30	3.31 × Ulna + 75.38 ± 4.83
2.38 × Femur + 61.41 ± 3.27	2.11 × Femur + 70.35 ± 3.94	2.47 × Femur + 54.10 ± 3.72	2.28 × Femur + 59.76 ± 3.41
2.52 × Tibia + 78.62 ± 3.37	2.19 × Tibia + 86.02 ± 3.78	2.90 × Tibia + 61.53 ± 3.66	2.45 × Tibia + 72.65 ± 3.70
2.68 × Fibula + 71.78 ± 3.29	2.19 × Fibula + 85.65 ± 4.08	2.93 × Fibula + 59.61 ± 3.57	2.49 × Fibula + 70.90 ± 3.80
1.30 × (Fem + Tib) + 63.29 ± 2.99	1.15 × (Fem + Tib) + 71.04 ± 3.53	1.39 × (Fem + Tib) + 53.20 ± 3.55	1.26 × (Fem + Tib) + 59.72 ± 3.28

Table 4.3: Stature calculations from Trotter (1970). Measurements of the long bones are taken in centimetres.

The osteologists analysing the skeletal remains from the case study sites measured the long bones on an osteometric board in the standard way described by – for example – Bass (2005). When exact methods were specified in the case study site reports, the long bones of the lower limbs had been used in preference, as they directly contributed to an individual's standing height. From all of the case study sites, the majority of individuals were not able to be given an estimation of stature due to the poor preservation and high degree of fragmentation leaving few intact long bones. Few individuals from the study sites were unable to be sexed but given an estimated stature, because a skeleton with sufficient preservation for one will usually have sufficient preservation for the other. However, those that were not assigned a sex but had stature reported were discounted from calculations of the mean because of the risk of their calculated stature being incorrect due to the wrong equation having been used.

4.5.2 Vertebral neural canal dimensions

Measurement of the vertebral neural canal was conducted on the skeletal collections from eight of the case study sites:

- *Cataractonium* (Roman)
- Bainesse (mixed period)
- Dalton Parlours (mixed period)
- Healam Bridge (mixed period)
- Wattle Syke (mixed period)
- Burnby Lane (early medieval)
- Sewerby (early medieval)
- West Heslerton (early medieval)

During data collection for this thesis, all viable vertebrae from each individual were measured in three dimensions – body height, transverse diameter of the vertebral neural canal and anterior-posterior diameter of the vertebral neural canal. This was performed with sliding digital callipers accurate to 0.1mm. Vertebrae were labelled as viable and accepted for inclusion into the study only if they could be confidently identified as, for instance, the second thoracic vertebra. With the changes in dimension dependent on vertebrae type and position, as described in section 3.5, the exclusion of unidentified vertebrae was essential to maintaining the integrity of the data. The surfaces necessary for each measurement also needed to be well preserved, and fragmentary vertebrae could only be considered if they fit exactly back together with no wear on the joining edge, otherwise the measurements would not be accurate to the 0.1mm the callipers were capable of recording. Any vertebrae which represented a border shift, supernumerary vertebrae, congenital pathologies or injury and damage were also discounted from study as the measurements were likely to be unusual and incomparable to those from morphologically typical vertebrae.

The standard methods for measuring the vertebral body height and dimensions of the neural canal were developed by Rebecca Watts, Sophie Newman and Rebecca Gowland. Body height was measured on the midline as described by Newman and Gowland (2015): “the inferior surface of the body was positioned horizontally on the sliding callipers and the mobile component moved until it touched the superior surface” (Figure 4.5.1). The transverse diameter of the vertebral neural canal (Figure 4.5.2) was measured as “the furthest distance between the medial surfaces of the left and right pedicles" (Watts, 2011), with the measuring jaws inserted superiorly into the vertebral neural canal and scale arm held parallel to the superior surface of the vertebral body. The measuring jaws were then shifted carefully until the greatest distance between the pedicles was reached. The anterior-posterior diameter of the vertebral neural canal (Figure 4.9) was measured "from the posterior wall of the vertebral body to the most anterior point on the neural arch" (Watts, 2013b). The measuring jaws were again inserted superiorly, with the scale arm positioned ventrally and the mobile component moved until it touched the neural arch. This ensured the callipers could move freely without hindrance from the superior articular facets.

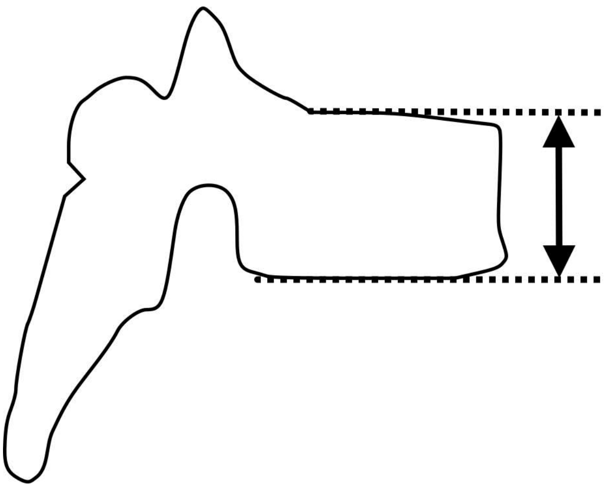


Figure 4.5.1: The location for the measurement of body height of a vertebra.

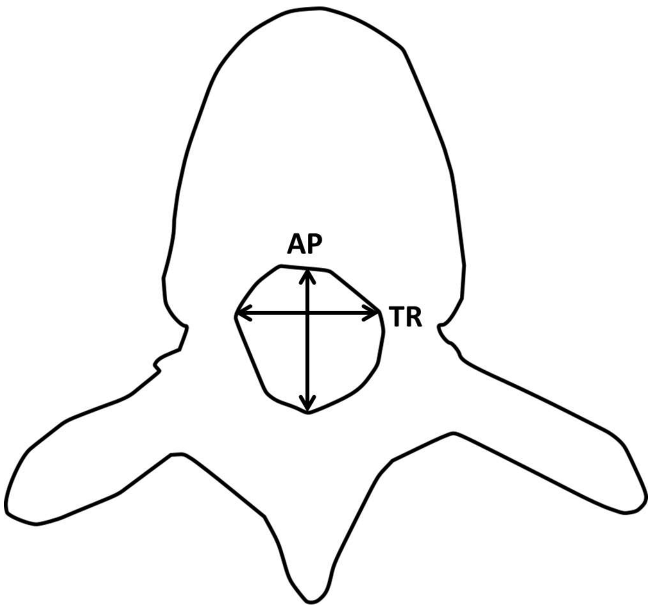


Figure 4.5.2: Locations for measurement of the anterior-posterior (AP) diameter and transverse (TR) diameter.

Figure 4.5.3: Measurement of the body height [left], anterior-posterior diameter [centre] and transverse diameter [right] conducted by the author on a thoracic vertebra from SK10 of Dalton Parlours.

4.6 Data analysis and presentation

4.6.1 Statistical analysis

The statistical analysis of the compiled dataset was performed in IBM SPSS Statistics 29.0.1.0 (171) (IBM Corp, 2023). The collected data on skeletal manifestations of stress were tested against multiple variables including time period, sex, age at death and, for the Roman period populations, settlement type, which was divided into urban and rural based on archaeological evidence for settlement size and specialised production. Several different statistical tests were performed due to the variety of data formats and the comparisons of different types of variables. When considering the relationship between two categorical variables, for example the presence of a pathology in the different time periods, Pearson's Chi-squared test was used to determine the significance of any association between categories. For significant results, adjusted standardised residuals were calculated to compare the strength of this association. To assess difference in a continuous variable between two groups as determined by a categorical variable, for example comparing stature in the different time periods, independent samples t-tests were performed, which indicated the statistical significance of any difference in the mean values of the continuous variable. In order to perform the t-tests, the data had to be checked for normality with the Shapiro-Wilk test, and for homogeneity of variance with Levene's test, to make sure the result given by the independent samples t-test was appropriate and valid. To assess difference in a continuous variable when divided into more than two groups by a categorical variable, such as comparing stature between age categories, a one-way ANOVA was used to indicate if there was significant variance in the means of the continuous variable. This again required the use of the Shapiro-Wilk test and Levene's test prior to performing the ANOVA. If the variance in the continuous variable was statistically significant, Tukey's HSD test was performed to identify the pairs of categories in which the means of the continuous variables were statistically significantly different from one another. Finally, the relationship between any pair of continuous variables, for example the transverse and anterior-posterior diameter of the same vertebra, was assessed by calculating Pearson's correlation coefficient, which indicated the strength and direction of the correlation. This also required the Shapiro-Wilk test to be performed beforehand to ensure the data for both variables was normally distributed, and scatter plots were generated and checked visually to ensure relationships were linear. Significant results were further investigated with linear regression analysis to determine how much of the variation in one variable was due to the other. For all of the above named tests, the threshold for significance was set at $p \leq 0.05$

4.6.2 Graphics production

The graphs presented in the results chapters were generated using R 4.4.0 (R Core Team, 2024) and RStudio (Posit Team, 2024), with the package dplyr (Wickham et al. 2023).

Maps were created using ArcGIS Pro 3.1.0 (Esri, 2023), using the Ordnance Survey Boundary-Line™ public sector information licensed under the Open Government Licence v3.0 to map the modern counties. Six-figure easting and northing coordinates were taken from the site reports to map the location of each site.

Chapter 5: Materials

This chapter introduces the case study sites chosen for inclusion in this thesis. The site location, including local geography and historical background, and excavation history are outlined. Previous analyses of the relevant skeletal collections, both initial reports and any subsequent studies, are also outlined. This is provided so as to present a summary of the current understanding of each of the case study sites. Sites are grouped by the date of the skeletal assemblages recovered – first the four Roman collections, then the seven sites used during both periods, and finally the eight early medieval ones. Within each sub-section these are discussed alphabetically within those categories. A total of 656 individuals from these 19 sites were selected for inclusion in the dataset for this thesis. The compilation of this large dataset allowed multiple smaller assemblages to be included, which have not previously been subject to further work due to the poor skeletal preservation generally found in northern England, and the small sample sizes at some sites.

5.1 The skeletal population of northern England from the 3rd to 7th centuries

In Roman Britain, inhumation replaced cremation as the most common funerary rite during the 2nd and 3rd centuries (Mattingly, 2007, 343), in both organised urban cemeteries and isolated rural burials (Esmonde Cleary, 2000), and so where preservation allowed, numerous inhumations of 3rd and 4th-century date have been discovered. Cremation briefly became more favoured again in the early medieval period before the conversion to Christianity, though inhumation was still common, especially north of the Humber (Lucy, 2000; Faull, 1974), so many inhumation burials of 5th to 7th-century date have been excavated. Far fewer cemeteries of both periods have been discovered in the north compared to the south, likely due to the acidic soil which is especially prevalent in the north-west of England. Those that have been discovered have rarely been studied beyond the initial evaluation of the skeletal assemblage, unless the cemetery is particularly large. Roberts and Mays (2011), in their assessment of the typical foci of osteological studies in the UK, noted that the cemeteries of the north are more neglected in further study than those of the south, especially those with fewer than 300 burials. They recommend particularly “that the ‘use load’ should be better and more evenly spread around skeletal samples in other geographic areas of the UK in order that knowledge is not limited just to a few skeletal collections”. The potential of northern assemblages, and particularly those with few individuals, is therefore being systematically neglected, and the potential of individuals from smaller sites to contribute to a regional study is typically overlooked. With the exceptions of the Norton cemeteries and West Heslerton, the majority of the following case study sites are part of that neglected wealth of skeletal assemblages, and this thesis will bring light to them, while contributing to bridging the north-south divide in osteoarchaeological studies.

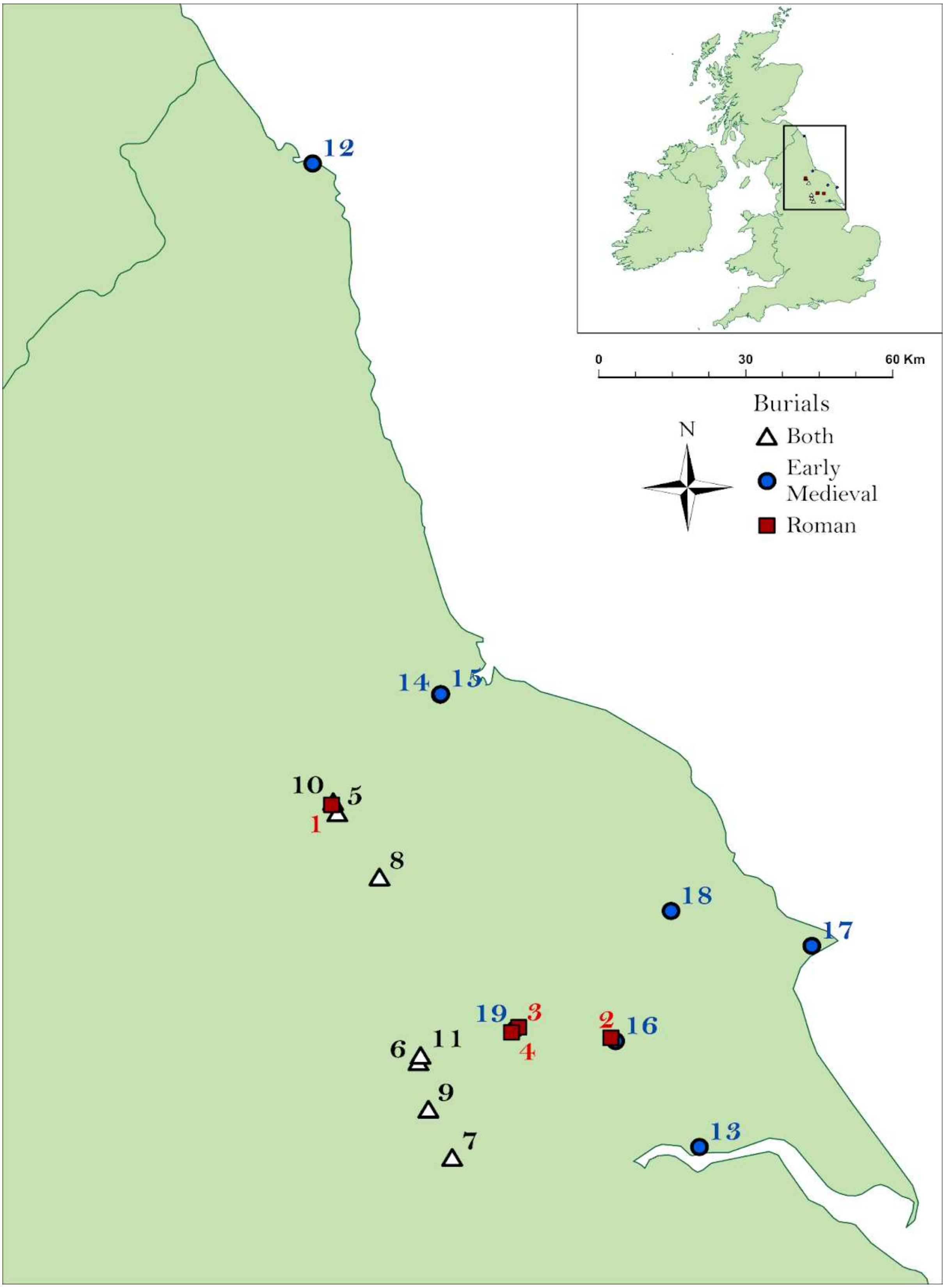


Figure 5.1: The locations of all case study sites within the study area. 1: Catterick, *Cataractonium.* 2: Pocklington, Yapham Road. 3: York, Hungate. 4: York, Newington Hotel. 5: Catterick, Bainesse. 6: Dalton Parlours. 7 Ferrybridge Henge. 8: Healam Bridge. 9: Parlington Hollins. 10: Scorton. 11: Wattle Syke. 12: Bamburgh, Bowl Hole. 13: Melton. 14:

Norton, Bishopsmill. 15: Norton, East Mills. 16: Pocklington, Burnby Lane. 17: Sewerby. 18: West Heslerton. 19: York, Queen's Hotel.

Site name	**Year of excavation**	**Excavated by**	**Osteological analysis by**	**Date and method**	**Key references**
Catterick, *Cataractonium*	2013-2017	Northern Archaeological Associates (NAA)	Malin Holst, Sophie Newman, Katie Keefe and Tessi Loeffelmann	2nd-4th century, C14	Speed and Holst, 2019
Pocklington, Yapham Road	2016	Archaeological Services Durham University	Anwen Caffell, Lauren Kancle and Tessi Loeffelmann	2nd-4th century, C14, finds	Archaeological Services Durham University, 2019
York, Hungate	2009-2011	York Archaeological Trust (YAT)	Malin Holst, Katie Keefe and Roxana Gomez	2nd-5th century, finds	Connelly and Malone, 2024
York, Newington Hotel	2017	YAT	Katie Keefe and Malin Holst	1st-3rd century, finds, stratigraphy	Keefe and Holst, 2020
Catterick, Bainesse	2013-2017	NAA	Malin Holst, Sophie Newman, Katie Keefe and Tessi Loeffelmann	1st-5th century, C14, finds and stratigraphy	Speed and Holst, 2019
Dalton Parlours	1976-1979	West Yorkshire Metropolitan County Council Archaeology Unit	Keith Manchester and Helen Bush	3rd-6th century, C14, finds	Wrathmell, 1990
Ferrybridge Henge	2001-2002	West Yorkshire Archaeological Services (WYAS)	Malin Holst	1st-7th century, C14	Roberts et al. 2005
Healam Bridge	2009-2010	NAA	Katie Keefe and	1st-7th	Ambrey et al.

			Malin Holst	century, C14	2017
Parlington Hollins	1994	WYAS	Sue Boulter	2nd-7th century, C14	Holbrey and Burgess, 2001
Scorton	1998-2000	Wessex Archaeology, NAA	Joy Langston	4th-6th century, finds	Langston, 2002; Speed 2002a; b; c
Wattle Syke	2007-2008	WYAS	Anwen Caffell and Malin Holst	2nd-7th century, C14	Martin et al. 2013
Bamburgh, Bowl Hole	1998-2007	Bamburgh Research Project	Charlotte Roberts, Sarah Groves	6th-8th century, radiocarbon dating (C14)	Bamburgh Research Project, 2023; Groves, 2010; Groves et al. 2009
Melton	2004-2005	On-Site Archaeology	Anwen Caffell and Malin Holst	6th-7th century, C14, stratigraphy	Fenton-Thomas, 2010
Norton, Bishopsmill	1994 and 2003	Cleveland County Archaeology Section (CCAS) and Tees Archaeology	Joanna Higgins	7th-10th century, C14 and grave phasing	Johnson, 2005
Norton, East Mills	1983-1985	CCAS	David Birkett and Sue Anderson	6th century, finds	Sherlock and Welch, 1992
Pocklington, Burnby Lane	2015 and 2017	MAP Archaeological Practice	Anwen Caffell and Malin Holst	5th-6th century, C14, funerary practice	Caffell and Holst, 2022
Sewerby	1959 and 1974	Directed by Philip Rahtz and Susan Hirst respectively	Don Brothwell and Justine Bayley	5th-7th century, finds	Hirst, 1985
West Heslerton	1977-1987	Humberside Archaeological Unit and The	Jean Dawes and Margaret Cox	5th-7th century, finds	Haughton and Powlesland, 1999

		Landscape Research Centre			
York, Queen's Hotel	1989	YAT	Katie Keefe and Malin Holst	7th century, C14	Keefe and Holst, 2016; Brann, 1988; 1989

Table 5.1: A summary of the companies and people involved with the excavation and osteological analysis of each case study site.

5.2 Roman sites

5.2.1 Catterick, Cataractonium

The modern village of Catterick is located in the Vale of Mowbray, between the Pennine Dales to the west and the North Yorkshire Moors to the east. It is about 13 km north-west of Northallerton. The River Swale passes to the north of the village and the A1(M) to the west, overlying the original route of Dere Street, the major Roman road connecting York to Hadrian's Wall (Road 8b, Margary, 1973, 428-9). The area around Catterick is rich in prehistoric remains, including Mesolithic flint assemblages at Scorton Quarry (Speed, 2002), a case study site discussed in section 5.2.6 of this chapter. There are also Neolithic and early Bronze Age hengiform and cursus monuments at Scorton, Bainesse and Marne Barracks (Hale et al. 2009; Speed, 2009; Moloney et al. 2003), and Iron Age field systems and settlements both around Catterick and further south in the Vale towards Leeming (Ambrey et al. 2017; Speed, 2010). It has been argued that there was a prehistoric predecessor to Dere Street (Bishop, 2005). The Romans built a fort where the route crossed the Swale, growing over time into a town, fort and associated satellite settlements (Wilson, 2002, xxiii). Occupation in the area continued throughout the Anglian period and onwards. Due to the location on a major road, and its known status as a Roman town and fort, Catterick has been subject to many archaeological investigations. Antiquarian work conducted by the landowner, Sir William Lawson, in the 19th century focused on the defensive walls of the town of *Cataractonium*, the name used to distinguish the Roman settlement from the modern village 1 km to the south (Wilson, 2002, 26). Further excavations were conducted at various times during the 20th century when construction and roadwork necessitated them, most notably the 1939 excavation by EJW Hildyard, and the 1958-1959 excavation directed by JS Wacher and supported by the Ministry of Works (Wilson, 2002, 46). Burials from both the Roman and early medieval periods were discovered in the course of many of these antiquarian and archaeological excavations, though very little information survives, and no thorough analysis of the remains was ever undertaken. Fortunately, however, there have been more modern excavations of burials that have been recorded in detail. The skeletal assemblage from *Cataractonium* included in this thesis was excavated during the 2013-2017 A1 upgrading scheme, and carried out by Northern Archaeological Associates (NAA). The

NAA excavations in the Roman town of *Cataractonium* were conducted on both sides of the River Swale and were part of a larger scheme, which also saw the excavations of the roadside settlements at Bainesse and Scurragh House.

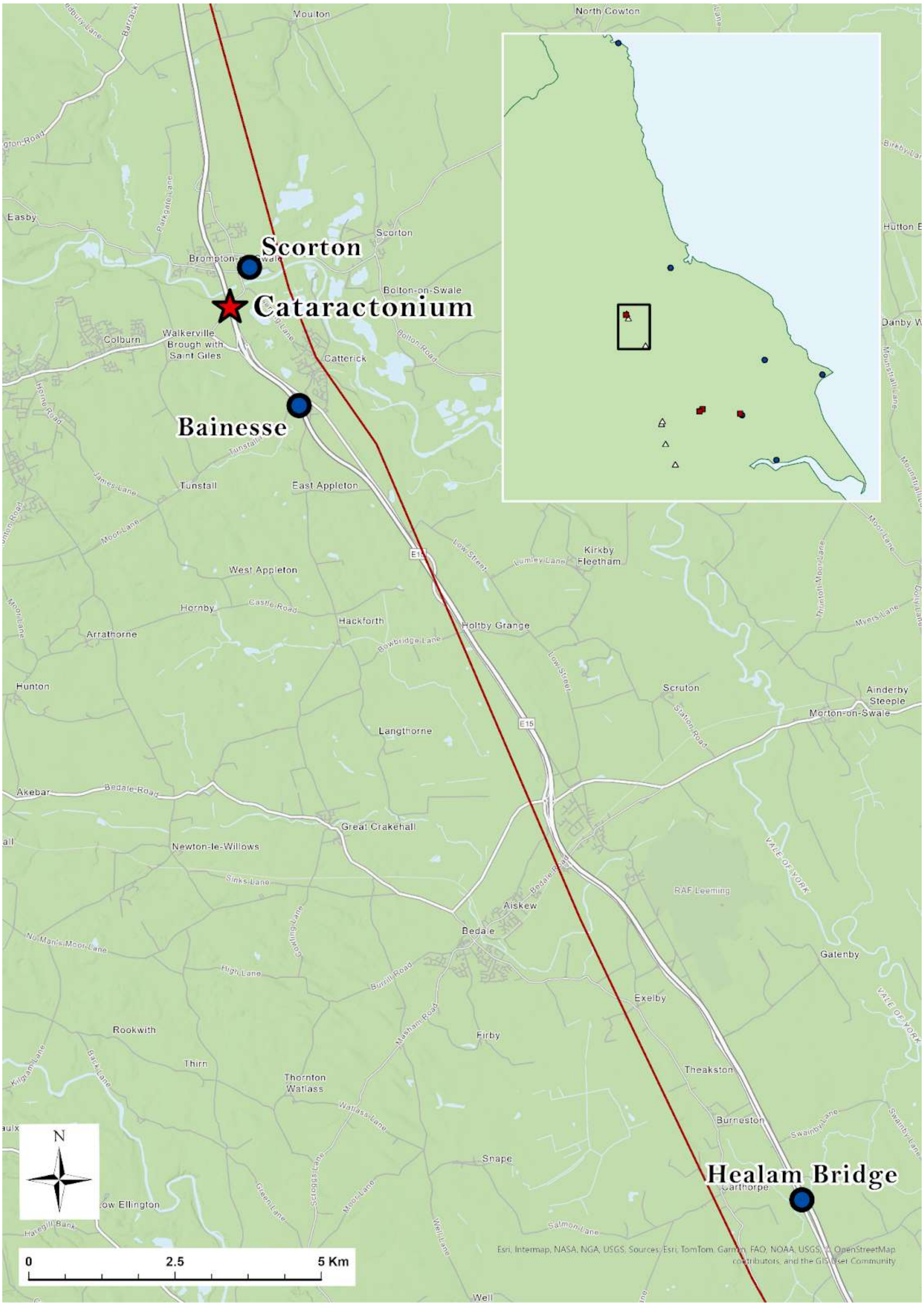


Figure 5.2.1: The location of *Cataractonium*, in relation to the modern landscape, other case study sites in this thesis, and the Roman road system (red line). Basemap Esri, 2025; Roman road data McCormick et al. 2013.

The NAA Excavations in the *Cataractonium* area uncovered 30 inhumations and 9 cremations (Figure 5.2.2), which were determined to date from the 2nd to 4th centuries through a combination of radiocarbon dating of 30 individuals, 18 of which were included in the dataset for this thesis (Table 5.2.1), stratigraphy, and grave goods including hobnailed boots (Figure 5.2.3) and copper jewellery. The analysis of the skeletal assemblage from *Cataractonium*, as well as the other assemblages found in the course of the A1 Leeming to Barton upgrading scheme, was conducted by Malin Holst, Sophie Newman, Katie Keefe and Tessi Loeffelmann of York Osteoarchaeology. It was published by NAA in a monograph specifically devoted to discussing the burials excavated in advance of the roadworks (Speed and Holst, 2019). The second monograph in the series discussed the Iron Age to Roman transition (Fell, 2020), and the third and final volume covered the evidence from the Roman and post-Roman periods (Ross and Ross, 2021). The individuals were determined to be 18 adults and eight subadults (under 18 years at the time of death). All but one of the adult burials were found in backplot – or houseplot – burials in the roadside extension of the town to the north of the river. The preservation of the remains was slightly better than that found at the other sites excavated in the scheme, because the anthropogenic soil of the town was slightly richer and less acidic. However, 10 of the adult skeletons, representing over half of the group, were assessed as having poor or very poor preservation so pathological analysis was often hindered. Regardless, the assemblage is valuable as a population from both military and civilian background, located on one of the major roads in the study region. Despite the monograph being freely available online with the Archaeology Data Service (ADS), there has not been any further work on these skeletons from *Cataractonium*.

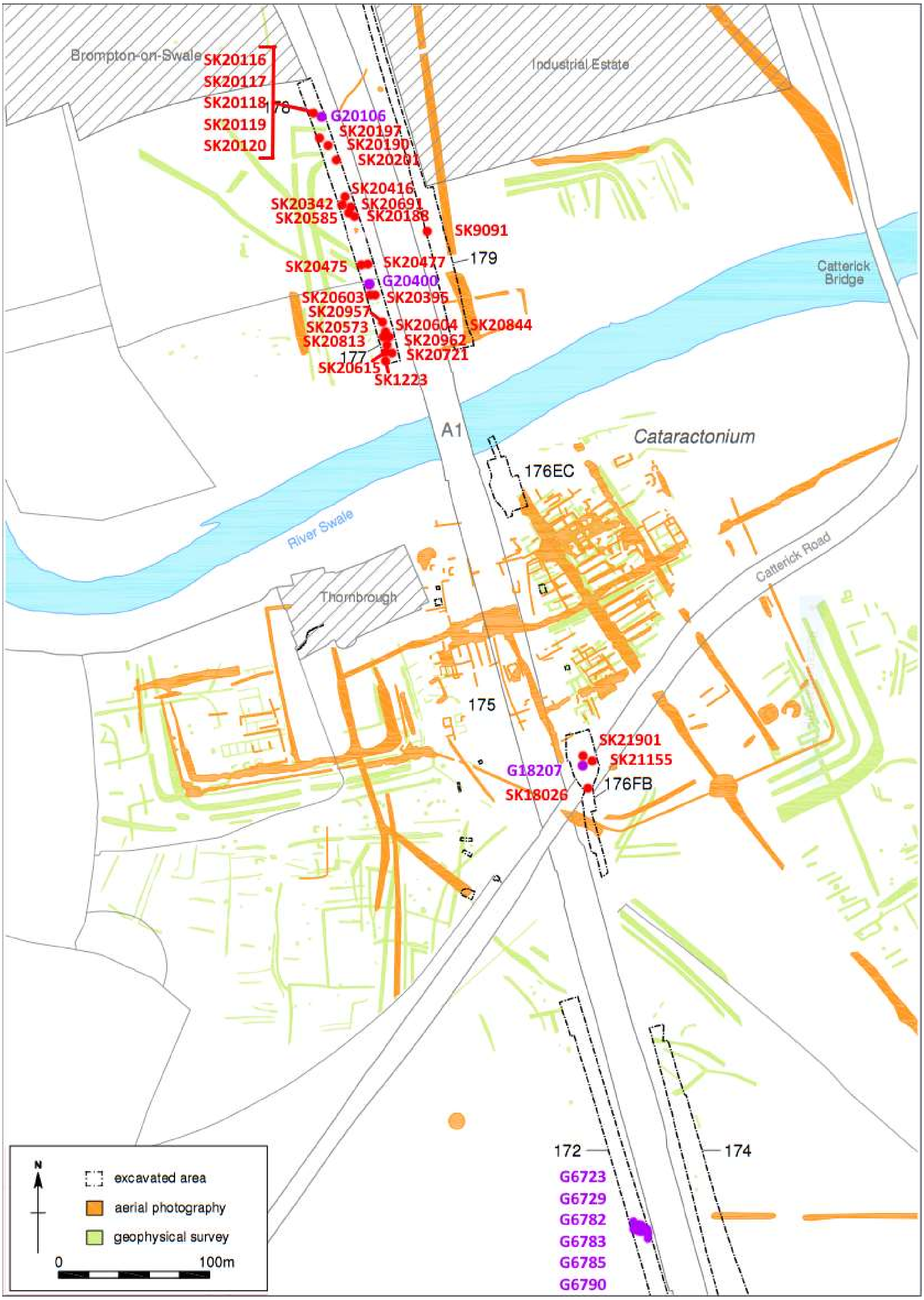


Figure 5.2.2: The locations of inhumation (red) and cremation (purple) graves at *Cataractonium*. Modified from Speed and Holst, 2019, Figure 4.2.

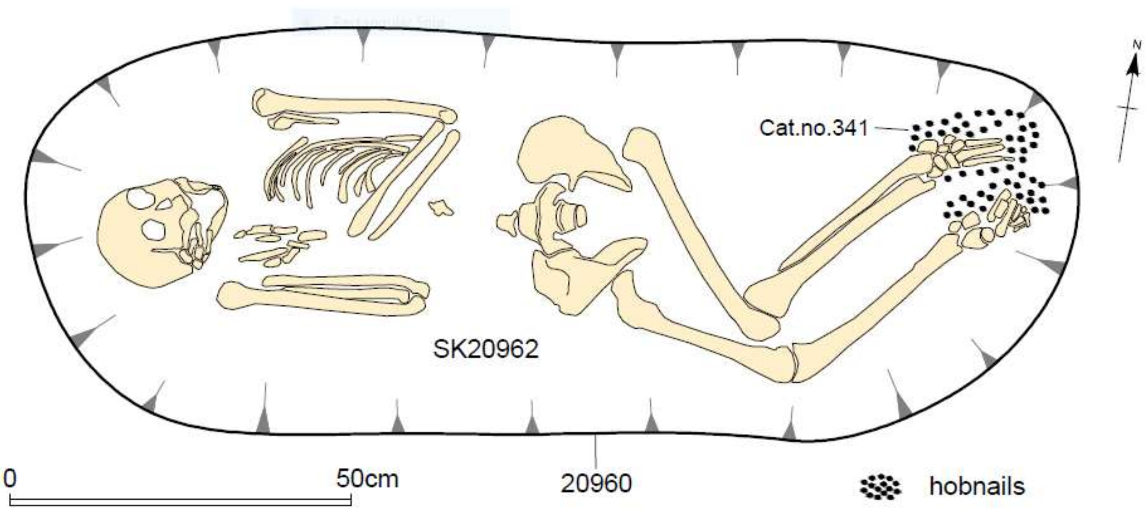


Figure 5.2.3: Grave plan of skeleton 20962, an adult male, showing the position of the hobnails (Speed and Holst, 2019, 300).

Skeleton	**Radiocarbon age years BP**	**Calibrated range**
SK20116	1758±34	210-385 AD
SK20117	1742±34	224-391 AD
SK20190	1799±34	140-420 AD
SK20197	1784±34	134-334 AD
SK20342	1765±30	241-427 AD
SK20395	1684±34	316-422 AD
SK20416	1737±34	231-392
SK20475	1754±34	220-440 AD
SK20573	1745±34	218-392 AD
SK20585	1780±34	160-420 AD
SK20603	1748±32	219-388 AD
SK20604	1763±34	210-430 AD
SK20615	1741±34	226-391 AD
SK20721	1741±34	220-510 AD
SK20813	1712±34	245-400 AD

SK20844	1739±34	220-510 AD
SK20957	1836±34	81-251 AD
SK20962	1774±34	135-344 AD

Table 5.2.1: Results of the radiocarbon dating on the individuals from Cataractonium included in this thesis. Data from Speed and Holst (2019).

5.2.2 Pocklington, Yapham Road

Pocklington is a town in the East Riding of Yorkshire, situated in a valley bottom on the western edge of the Yorkshire Wolds, about 20 km east of York. The excavation site at Yapham Road was situated on the north-west edge of the town, in the arable land of the Vale of York. The history of occupation in the area extends back to the Mesolithic period, though finds from earlier than the Iron Age are sparse suggesting use of the land was fleeting (Archaeological Services Durham University, 2019). The most significant finds in Pocklington have been from the Iron Age, with two large square barrow cemeteries including chariot burials discovered at both The Mile and Burnby Lane (Stephens, 2023). The Mile is not discussed in this thesis as it only contained Iron Age burials (Ponce and Holst, 2018), but Burnby Lane will be discussed later in this chapter (in section 5.4.5) as Early Medieval burials were found to have been inserted into the Iron Age barrows (Stephens, 2023). Excavations conducted by Archaeological Services Durham University at the Yapham Road site took place in 2016 prior to construction of a planned housing development. This was prompted by the need to investigate enclosures seen in both aerial photographs and geophysical surveys. During excavation these were confirmed to date to the Iron Age and Roman periods. The boundary ditches, post holes, and pits of domestic waste indicated the site was a rural settlement, occupied from the Iron Age to the late Roman period, with evidence of ridge and furrow ploughing indicating that the site turned to agricultural use from the medieval period onwards. A single iron manacle, identified as Künzing type, which were in use in the 1st-3rd centuries (Thompson, 1993), was suggestive of slaves having worked in the area. A total of 20 individuals, plus a quantity of disarticulated bone were discovered at Yapham Road. The majority were determined through radiocarbon dating of seven individuals (see Table 5.2.2 for the radiocarbon dates of the adult Roman individuals included in the dataset for this thesis) and analysis of site stratigraphy to date from the Iron Age and early Roman occupation, with six from the later Roman period. The graves were generally distributed to the south of the site, though they were not tightly clustered or grouped by date and the limits of the burial area most likely extended beyond the area of excavation. Of the six Roman burials, most were interred as part of ditch fills (Figure 5.2.6), though a neonate (Skeleton 21) was buried in a post hole, and an adolescent (Skeleton 12) was buried in a deliberately cut grave with a coffin, which was evidenced by the recovery of 43 iron nails. The later Roman phase of activity on the site also saw animal burials, three cows having been buried in adjacent pits (Figure 5.2.7), and a hen having been buried with one of the human adult males (Skeleton 18). This represented a continuation of behaviour from the Iron Age phase of the site, when two lambs were buried with a perinatal human. Similar animal burials were also found at Wattle Syke, discussed in section 5.3.7.

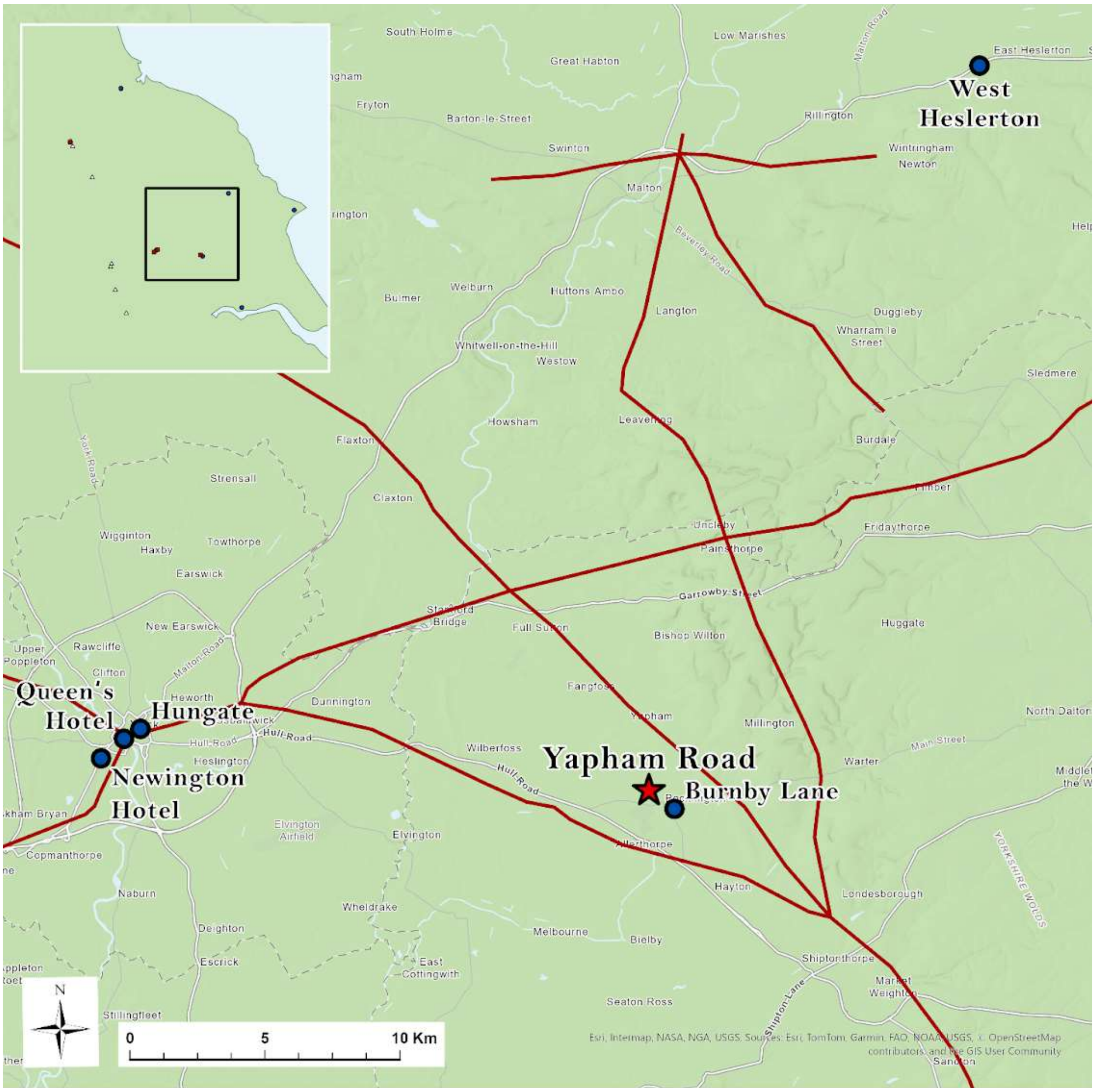


Figure 5.2.4: The location of the Yapham Road site, in relation to the modern landscape, other case study sites in this thesis, and the Roman road system (red lines). Basemap Esri, 2025; Roman road data McCormick et al. 2013.

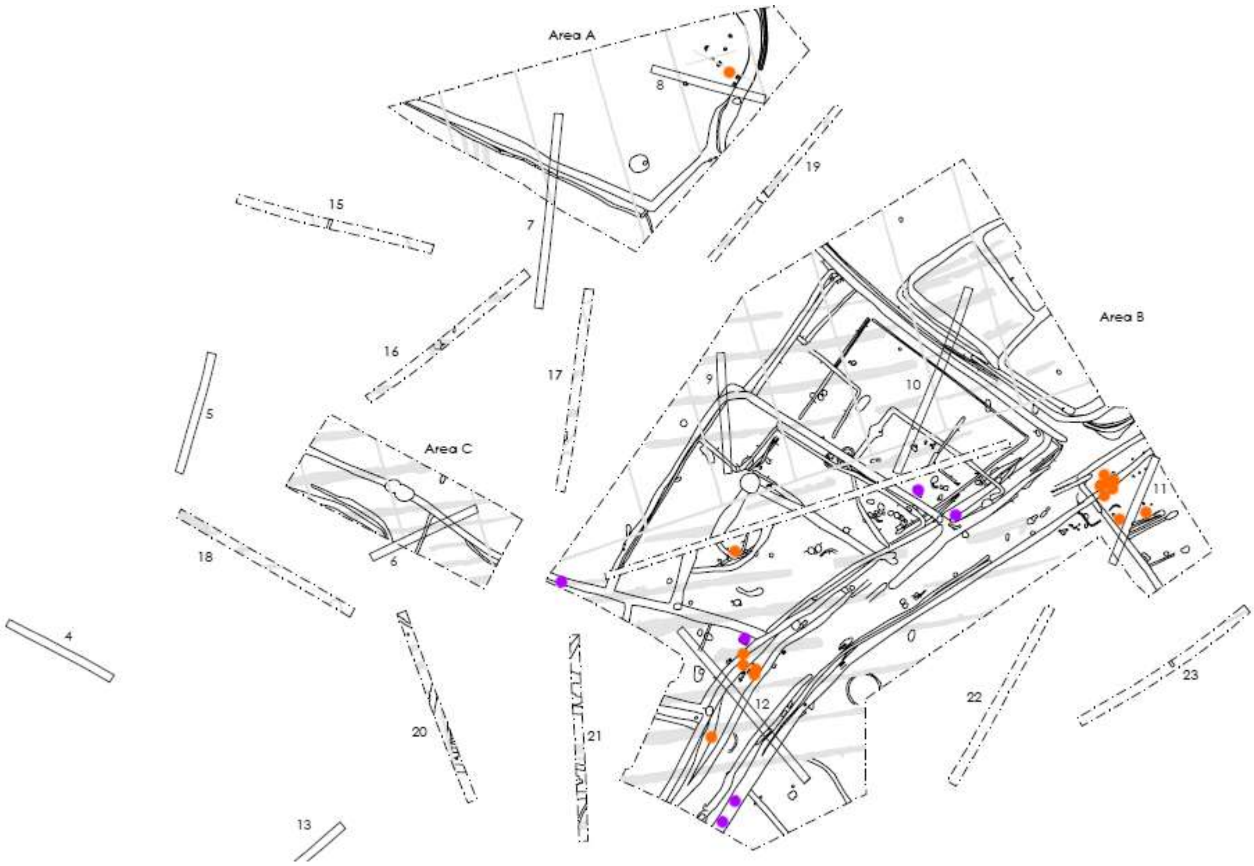


Figure 5.2.5: The distribution of burials in the excavated areas at Yapham Road. Iron Age burials are in orange and Roman burials are in purple. Adapted from Archaeological Services Durham University, 2019, Figure 4.

Figure 5.2.6: Skeleton 19 interred within a ditch (Archaeological Services Durham University, 2019, 408)

Figure 5.2.7: One of the cow burials from Yapham Road (Archaeological Services Durham University, 2019, 409).

The skeletal remains from the site were examined by Anwen Caffell, Lauren Kancle and Tessi Loeffelmann at Archaeological Services Durham University. In the group of Roman phase burials, four adults were present, with one adolescent and one neonate. This age distribution was very different to that seen in the late Iron Age and early Roman population, which comprised 10 infants, one juvenile, one adolescent, and four adults. The preponderance of infants in the Iron Age population was thought to indicate a change in burial practice over time, with the burial of adults within the ditches and pits of the settlement becoming more acceptable. Overall, the skeletal assemblage from Yapham Road was surprisingly well preserved given the degradation of bone usually seen in northern England. All Roman individuals were more than 70% complete, with the expected exception of the neonate who would have been far more difficult to recover due to the small size and friable nature of neonatal bones. Most individuals were determined to have good or very good surface preservation of the bones, and only minimal to moderate fragmentation. The thorough pathological analysis is laid out in detail in an as-yet unpublished report, which is, however, available online via the ADS (Archaeological Services Durham University, 2019). There has not been any further work on the assemblage from Yapham Road, and it has not featured in any syntheses of the burials of the region.

Skeleton number	**Radiocarbon age years BP**	**Calibrated range**
SK12	1714±31	249-395 AD
SK19	1716±32	246-395 AD
SK22	1758±35	210-385 AD

Table 5.2.2: Results of the radiocarbon dating of the late Roman phase individuals from Yapham Road. Data from Archaeological Services Durham University (2019).

5.2.3 York, Hungate

York sits at the confluence of the Ouse and Foss rivers, a location which has long been strategically important for trade between northern England and the continent. A Roman fort was established between the two rivers in 71 AD to support the conquering of the north, and the associated civilian settlement quickly grew in importance, becoming a colonia and seeing three emperors spend time in the city during their rule (Ottaway, 2004). Military and civilians alike were buried in several large mixed cemeteries located on the roads leading out of the city, including those found at the railway station, Trentholme Drive, and The Mount. There were also several smaller cemeteries and isolated burials spread around the city (Figure 5.2.9).

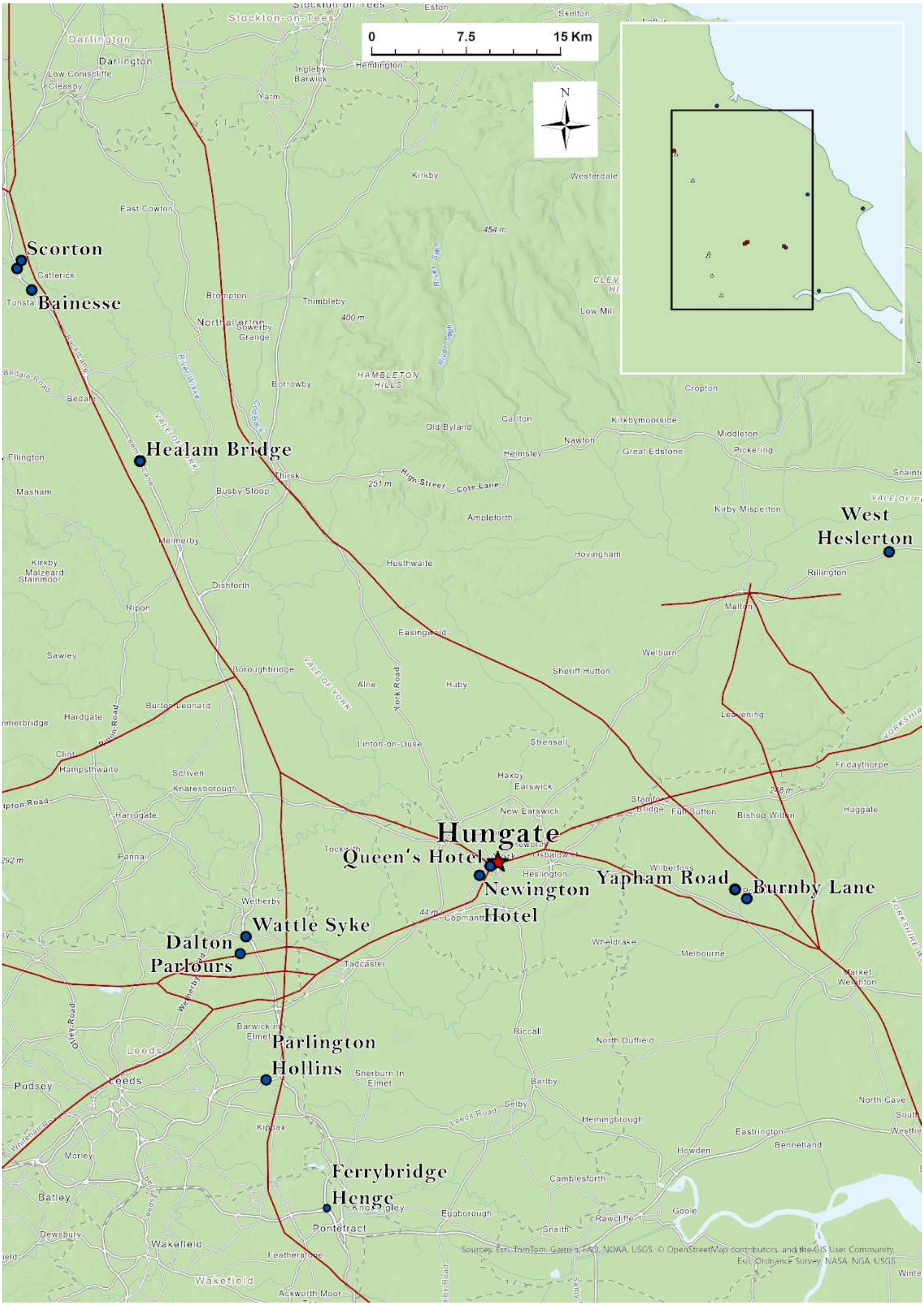


Figure 5.2.8: The central and well-connected location of York, including the Hungate site, in relation to the modern landscape, other case study sites in this thesis, and the Roman road system (red lines). Basemap Esri, 2025; Roman road data McCormick et al. 2013.

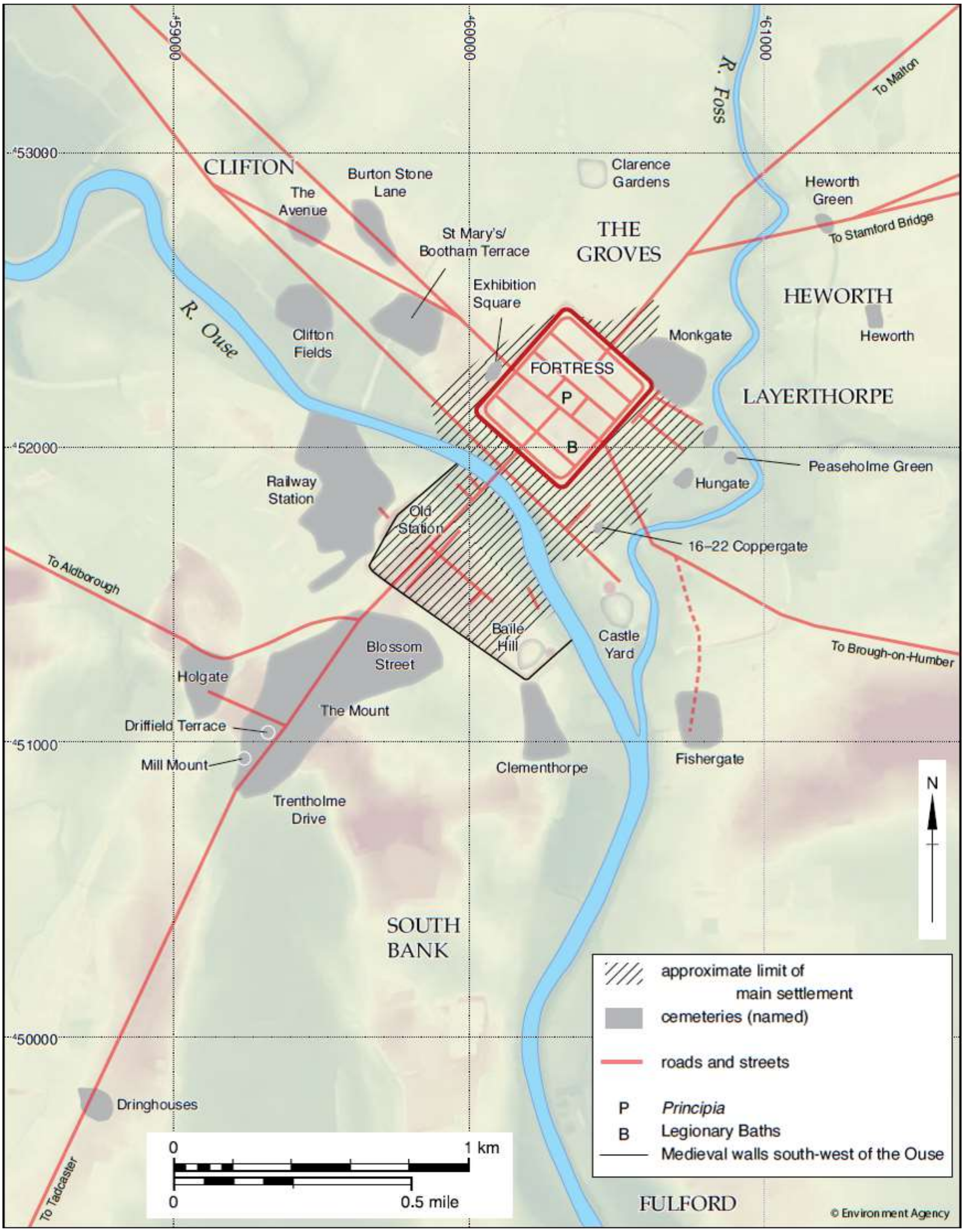


Figure 5.2.9: Roman York, with modern site names and river courses (Connelly and Malone, 2024, 8).

The site at Hungate was located between the fort and the Foss river, in an area demarcated in the early Roman period by a large ditch. The ditch was later filled in and became incorporated within the cemetery. Little evidence for pre-Roman occupation exists in the Hungate area and the wider city of York, with the exception of an Iron Age farming community at Heslington to the south east (Neal and Roskams, 2013), and occasional finds of flint tools throughout the city. Excavation of the site was carried out by York

Archaeological Trust from 2006-2011 in advance of development. Due to the planned inclusion of a basement car park, excavation was carried out to a depth of three metres, allowing the Roman period cemetery to be discovered despite the significant build up of soil from centuries of occupation on the site. In total, 11 cremation burials and 116 inhumation burials were excavated, with a further five potential grave cuts identified but not positively labelled as such due to the complete lack of skeletal material or grave furnishings present. Many of the inhumations were truncated by structures from later periods, in particular the viking-era sunken featured buildings. The burials were interpreted in the site monograph (Connelly and Malone, 2024) as representing two communities, as they were arranged into two distinct areas (Figure 5.2.10). The south west group was very uniform in distribution, and the north east group was more disorganised, and focused on the backfilled remains of the earlier Roman ditches. The cemetery was in use from the mid-2nd until the early 5th century. The cremations were the first deposits in the cemetery, and the bulk of the inhumations occurred from the mid-3rd to mid-4th centuries. The dating was largely determined by the style of the grave goods, which included glass vessels and hobnailed shoes, with two individuals subject to radiocarbon dating (see Table 5.2.3 for the radiocarbon date of the individual included in this thesis). One of the radiocarbon dated burials (SK46, an adolescent) was determined to be of early 5th- to early 6th-century date, not mid 3rd- to mid 4th-century as the grave goods had suggested.

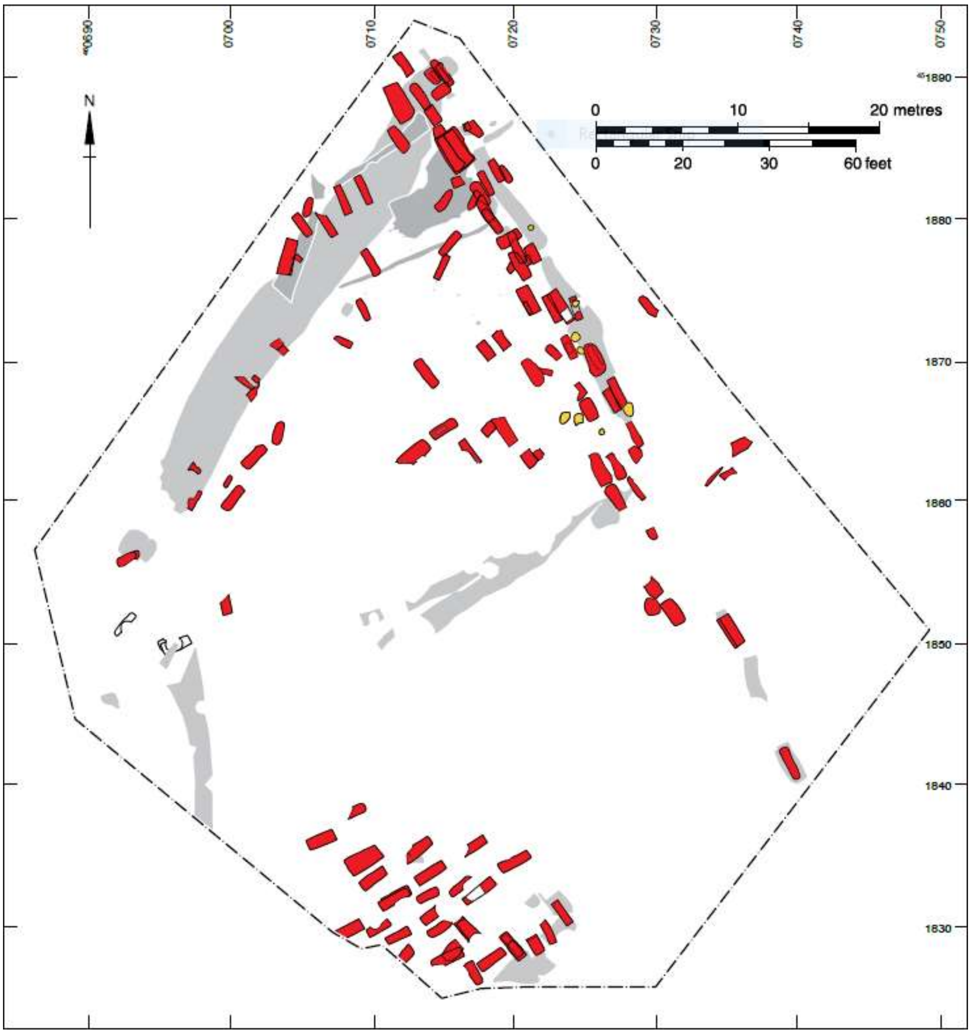


Figure 5.2.10: Plan of the Roman inhumation burials (red) and cremations (yellow). Connelly and Malone, 2024, 38.

Figure 5.2.11 [above]: Skeleton 74, only a coffin stain is visible (Connelly and Malone, 2024, 87).

Figure 5.2.12 [left]: Skeleton 60, 90% complete, demonstrating the variation in preservation across the site (Connelly and Malone, 2024, 67).

Osteoarchaeological analysis of the human remains from Hungate was undertaken by Malin Holst and Katie Keefe of York Osteoarchaeology, and Roxana Gomez, a Master's student at the University of York. From the 116 excavated inhumation graves, 105 individuals were analysed, as 11 graves contained no human remains. Preservation was generally poor, with only 27 in a good condition and 4 very good. Fragmentation was generally moderate to severe, and completion varied greatly (Figures 5.2.11 and 5.2.12). A total of 34 non-adults were identified, which was noted to be an unusually high proportion of the assemblage. Most of the non-adults were determined to be juveniles, with only 4 adolescents and 1 infant. The 71 adults were fairly evenly divided between the standard age categories, with a slight preponderance in the old middle adult category. The assessment of sex found there were 27 males compared to 23 females, but comments could not be made on any imbalance in the sex ratio as there were also 21 individuals who could not be assigned a sex due to their poor preservation. Unfortunately, the osteoarchaeological assessment was not conducted in great detail, due to time constraints, so the pathological information may be less thoroughly reported than standard. However, on the more positive side, the female skeletons were subsequently examined in more depth by Roxana Gomez for her Master's dissertation (Gomez, 2017), and Giulia Gallio of York Archaeological Trust (Gallio, 2018), both of whom found a greater prevalence of pathology, particularly dental pathology, in the females of Hungate in comparison to the males. The skeletal assemblage from Hungate has not been subject to further analysis since its excavation, despite being one of the largest Roman cemeteries of York subject to modern excavation techniques.

Skeleton number	Radiocarbon age years BP	Calibrated range
SK48	1710±30	250-420 AD

Table 5.2.3: Results of the radiocarbon dating of the individual from Hungate included in this thesis. Data from Connelly and Malone (2024).

5.2.4 York, Newington Hotel

As discussed above, York was established first as a Roman fort in the 1st century AD, and its strategic importance encouraged its growth over the next three centuries. The site of the former Newington Hotel is on Mount Vale in York, part of the main road running south west from the city to Tadcaster, on approximately the same route as the Roman road before it. The programme of excavation carried out by York Archaeological Trust in 2017 commenced with a watching brief and trial trenching, as the site was adjacent to the Trentholme Drive cemetery site, which was expected to extend beyond the modern property boundaries. The investigation quickly revealed the expected inhumation burials, and an open area excavation was conducted over the full area of the construction site, revealing a total of 76 inhumation burials and three urned cremations, plus a large amount of disarticulated bone. The bounds of the cemetery extended beyond the limits of excavation, with property boundaries, including that of Trentholme Drive, forming three edges and the fourth cut by the 20th-century swimming pool; so the total number of individuals interred in this cemetery is not known. The inhumation burials were not arranged in a uniform manner, with significant intercutting in the most crowded areas (Figure 5.2.14), and with a variety of body positions and orientations. Dating was based on the stratigraphy of the burials and the style of the ceramic vessels which comprised the majority of the sparse grave goods, and it was concluded that the individuals were interred between the 2nd and 4th centuries. The report from the excavation (Savine, 2017) was not published, but is available through the Archaeology Data Service.

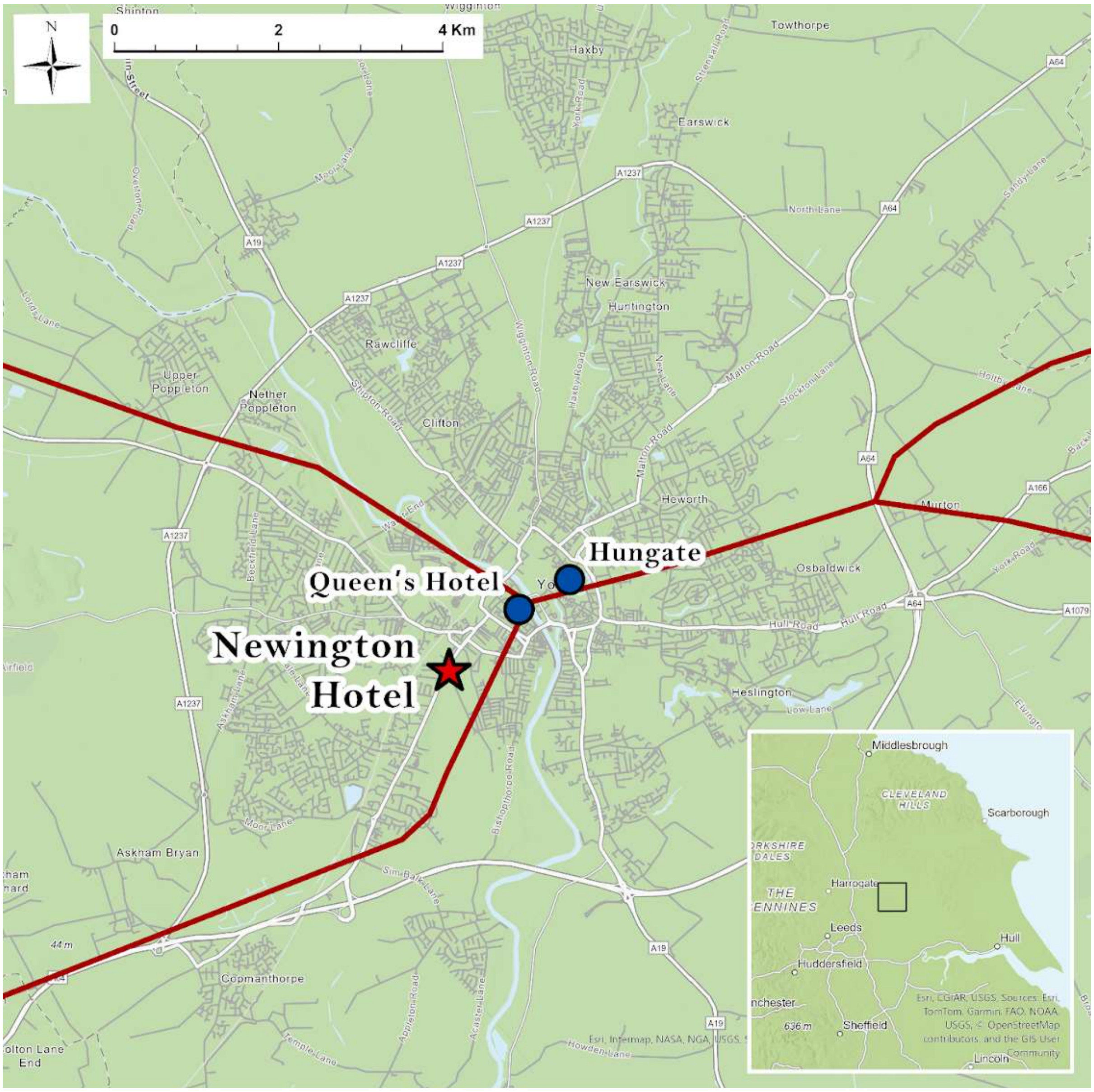


Figure 5.2.13: Modern York, with the approximate lines of the Roman road system (red) and the locations of Newington Hotel and the other case study sites for this thesis. Basemap Esri, 2025; Roman road data McCormick et al. 2013.

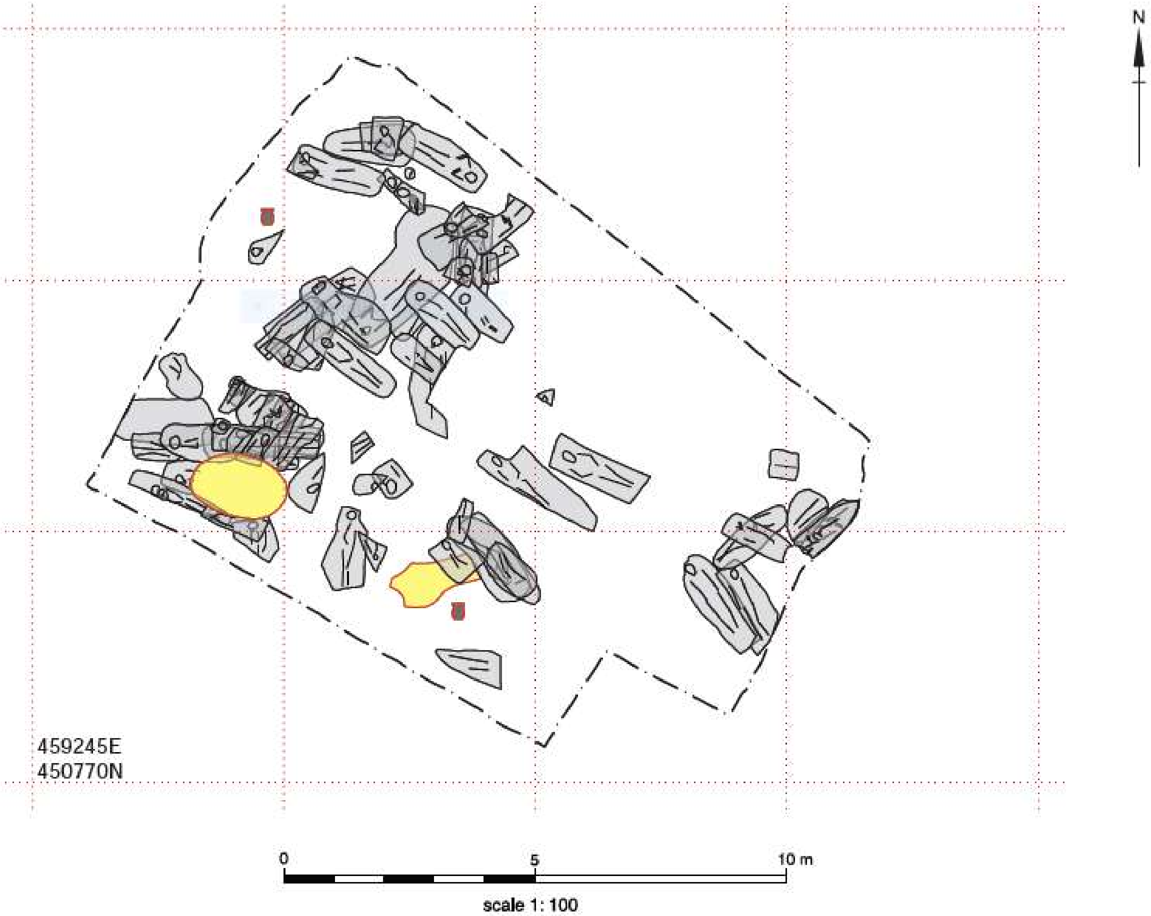


Figure 5.2.14: The layout of the excavated burials, showing the significant intercutting. The location of two charnel pits are in yellow (Savine, 2017, 149).

The skeletal assemblage from Newington Hotel was analysed by Katie Keefe and Malin Holst of York Osteoarchaeology, and the information contained in an unpublished report kindly shared with the author (Keefe and Holst, 2020). The preservation was variable, with most individuals having very good to moderate surface preservation, but 24 of the 76 burials had poor to very poor preservation due to the soil conditions being sandier and therefore more acidic in some areas of the site. There were also significant issues with truncation from intercutting burials and disturbance from the use of the land over the intervening centuries, so the majority of the skeletons were less than 60% complete (Figures 5.2.15 and 5.2.16). Of the 76 inhumation burials, 63 were determined to be adults at the time of their death, a group comprising 31 males, 13 females and 19 who were unable to be assigned a sex. This imbalance in the sex ratio was not thought to be unusual as Roman cemeteries generally have a heavy preponderance of males. Moreover, it was not such an extreme imbalance as that seen at Driffield Terrace, another Roman cemetery nearby where there were 66 males and one female (Caffell and Holst, 2012). Also typical of the Roman period was the lack of infant burials, with only one burial of a child under a year old among the 76 inhumations. The assemblage from the Newington Hotel site represents a significant addition to the cohort of Roman period burials in both York itself and in northern England generally, but it is yet to be included in any further studies of life and health in northern Britannia. The exception is a study which re-examined SK79 (adult male), who died after a below-knee amputation, and determined that highly specialised tools and techniques were used (Stead, 2023).

Figure 5.2.15 [above]: Skeleton 21, truncated by a 19th- or 20th-century drain (Savine, 2017, 171).

Figure 5.2.16 [left]: Skeleton 9, damaged by medieval ploughing (Savine, 2017, 170).

5.3 Mixed period sites

5.3.1 Catterick, Bainesse

Bainesse Farm is situated beside the A1(M) motorway in North Yorkshire, opposite the modern village of Catterick. As previously discussed (section 5.2.1), the wider area around Bainesse and Catterick is the Vale of Mowbray, and immediately to the north-west of the farm is Brough Beck, which drains into the River Swale. The Dere Street roadside satellite settlement was first discovered during building work on the farm in the 18th century, though its significance was not realised at the time (Wilson, 2002). Further construction work throughout the 20th century, on both the A1 road and neighbouring Marne Barracks site, uncovered more buildings from the Roman settlement, and numerous burials of both Roman and early medieval date (Wilson, 2002; Wilson et al. 1996). However, much like the burials excavated at *Cataractonium* in the years preceding the case study excavations, little to no analysis was conducted on most of the remains, with the exception of one juvenile burial discovered during construction of a radio mast (Taylor-Wilson, 2001).

During the 2013-2017 NAA excavations on the Leeming to Barton motorway upgrade, 232 inhumation graves were identified, along with 17 cremation burials. These were mostly clustered into one large area, the limits of which were beyond the limit of excavation, so the potential total of burials interred at Bainesse could be larger. Isolated burials were also identified across the site, in a field, a ditch, and four in house plots. The burials from Bainesse were determined to primarily date from the 1st to 5th centuries by a combination of radiocarbon dating (Table 5.3.1) and stratigraphic phasing, although this was complicated by some areas of the cemetery having particularly dense burials over up to six phases. Two burials from Bainesse were excluded from this study; one burial was determined through radiocarbon dating to date from the 10th century, while the isolated burial found in the ditch of a potential temporary camp was not able to be dated. However, overall, Bainesse is particularly significant in answering the questions posed by this thesis as several burials were securely radiocarbon dated to the 5th century, and retained Roman funerary styles, indicating a continuation of use of the settlement and cemetery after the loss of Roman rule.

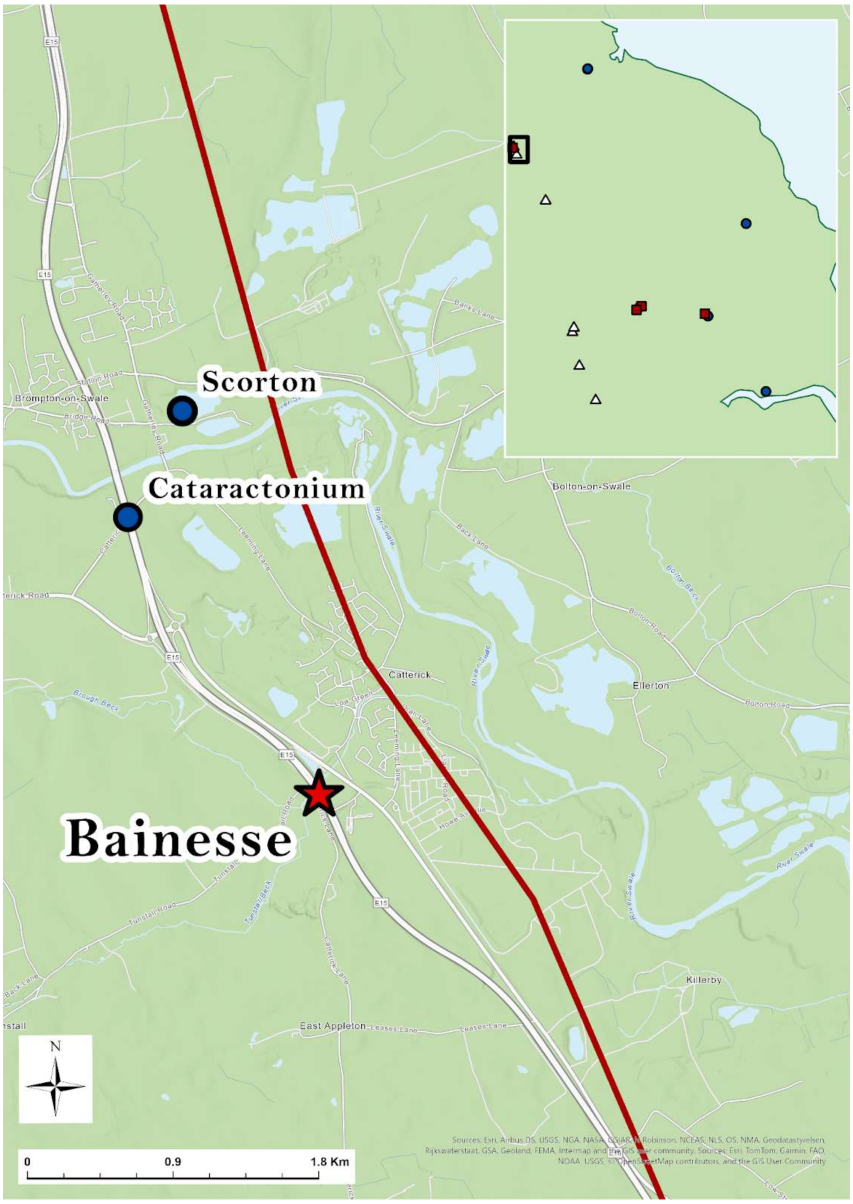


Figure 5.3.1: The location of the Bainesse cemetery in relation to modern Catterick, Dere Street (red line), and the Scorton and *Cataractonium* case study sites for this thesis. Basemap Esri, 2025; Roman road data McCormick et al. 2013.

Figure 5.3.2: Plan of the Bainesse cemetery, illustrating the density and intercutting of graves (Speed and Holst, 2019, 45).

The skeletal remains from Bainesse were examined by Malin Holst, Sophie Newman, Katie Keefe and Tessi Loeffelmann of York Osteoarchaeology, and published in the same monograph dedicated to the skeletal remains as those from *Cataractonium* (Speed and Holst, 2019). The preservation was much poorer than at *Cataractonium*, with 68 grave cuts containing no human remains and 43 only disarticulated and redeposited remains, the individuals having been heavily impacted by the centuries of successive burials (Figure 5.3.3) and the acidic sandy soil characteristic of Northern England. In total, 127 individuals from 121 grave cuts were examined, hindered by preservation which was assessed as being poor or very poor in over half the skeletons. Of the total assemblage, 95 were adults but less than half could be assigned a sex. Interestingly, two individuals (Grave 6 and Grave 7) were noted to have features suggesting an African or mixed-race origin, and were buried in adjacent plots, though no further analysis to test a potential familial relationship was conducted. The Bainesse population has been subject to one further study, a Master's dissertation which examined stable carbon and nitrogen isotopes and determined that weaning practices were very variable among the population, with weaning finishing anywhere from 2 to 5 years of age (Cocozza et al. 2021).

Figure 5.3.3: Bainesse cemetery during excavation, showing the density of burials (Speed and Holst, 2019, 44).

Skeleton (Grave number)	**Radiocarbon age years BP**	**Calibrated range**
G6	1906±32; 1925±31	191-212 AD; 1-137 AD
G7	1794±32; 1837±28	131-264 AD; 118-244 AD
G8	1788±25	215-390 AD
G10	1864±29	78-228 AD
G15	1734±32	238-388 AD

G16	1790±32	205-360 AD
G17	1840±32	84-243 AD
G18	1851±26	175-335 AD
G22	1896±32	51-217 AD
G23a	1866±25	79-222 AD
G23b	1662±26	330-427 AD
G26	1756±26	221-358 AD
G27	1734±26	255-410 AD
G28	1790±29	170-330 AD
G41	1731±29	243-385 AD
G44	1741±26	240-358 AD
G57	1650±32	330-435 AD
G61	1871±29	73-225 AD
G62	1796±27	145-260 AD
G67	1845±29	86-239 AD
G71	1834±29	116-247 AD
G78	1732±32	239-389 AD
G86	1916±32	150-255 AD
G87	1828±32	185-355 AD
G92a	1817±29	125-258 AD
G92b	1777±29	215-390 AD
G99	1762±29	211-381 AD
G106	1763±29	235-400 AD
G119	1829±32	165-350 AD
G120	1719±32	245-394 AD

G123	1723±32	244-391 AD
G125	1824±29	230-360 AD
G130	1772±25	210-340 AD
G140	1743±32	228-388 AD
G142	1801±29	175-330 AD
G143	1720±33	330-430 AD
G144	1724±32	244-391 AD
G154	1805±30	280-325 AD
G156	1863±29	170-265 AD
G158	1820±32	150-255 AD
G160	1606±32	380-470 AD
G165	1655±32	345-470 AD
G178a	1603±29	399-538 AD
G178b	1649±30	330-435 AD
G185	1518±25	425-465 AD
G186	1765±29	235-400 AD
G187	1510±32	420-465 AD
G197a	1678±32	320-420 AD
G198	1764±32	240-380 AD
G202	1852±29	85-234 AD
G208	1655±32	345-455 AD
G209	1581±32	405-549 AD
G213	1758±32	211-385 AD
G216	1555±30	421-570 AD
G217	1550±25	426-566 AD

G234	1657±32	335-460 AD
G237b	1649±32	350-435 AD
G239	1724±32	244-391 AD
G244	1680±32	325-455 AD
G254	1815±25	175-380 AD

Table 5.3.1: Results of the radiocarbon dating on the individuals from Bainesse included in this thesis. Data from Speed and Holst (2019, 50-215).

5.3.2 Dalton Parlours

Dalton Parlours villa site now lies under fields, situated 4 km south of Wetherby and 5 km west of Newton Kyme. The fertile agricultural land south of the River Wharfe and on the western edge of the Vale of York has a long and rich history of settlement. There are Neolithic henges at Newton Kyme (Boutwood, 1996) and Ferrybridge (section 5.3.3), about 22 km to the south east, and Bronze Age barrows in many of the surrounding villages (Clark, 1932; Keighley, 1981). Roman occupation included a settlement at Wetherby (Faull, 1981), a fort and vicus at Newton Kyme (Boutwood, 1996), and 1.3 km to the north of Dalton Parlours is the Iron Age and Roman settlement site of Wattle Syke (section 5.3.7). Many of the surrounding villages, such as Collingham, were firmly established during the medieval period and have remained occupied until this day, though Dalton Parlours itself was abandoned after the Roman period. The site of Dalton Parlours Villa was first noted during the 18th century when tree planting uncovered walls, and first excavated in 1854 by local antiquarians who identified the site as a villa, and recovered three skeletons (Heritage Gateway, 2023). The continued agricultural activity and exposed hilltop nature of the site eroded the topsoil, exposing new remains over the next century. The Archaeology Unit of West Yorkshire Metropolitan County Council were able to conduct an excavation of the villa in 1976, and extended their excavation until 1979 after Iron Age settlement was found beneath the Roman layers. After the excavation period, the site archive was passed to West Yorkshire Archaeological Services (WYAS), who conducted the post-excavation analysis and published the excavation report in a monograph (Wrathmell and Nicholson, 1990).

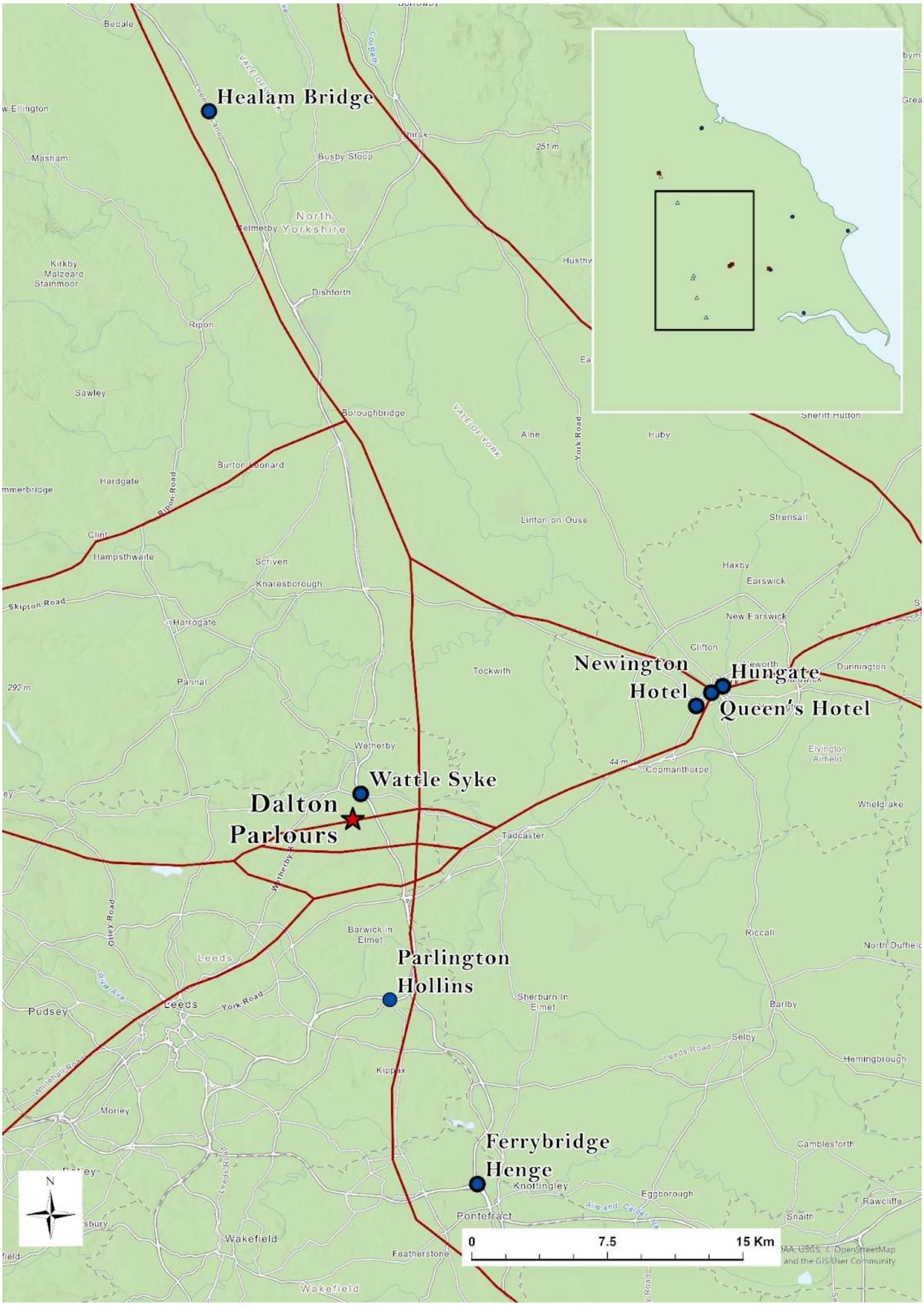


Figure 5.3.4: The location of Dalton Parlours villa site in the wider landscape, including the Roman road system (red lines) linking it with several of the other case study sites for this thesis. Basemap Esri, 2025; Roman road data McCormick et al. 2013.

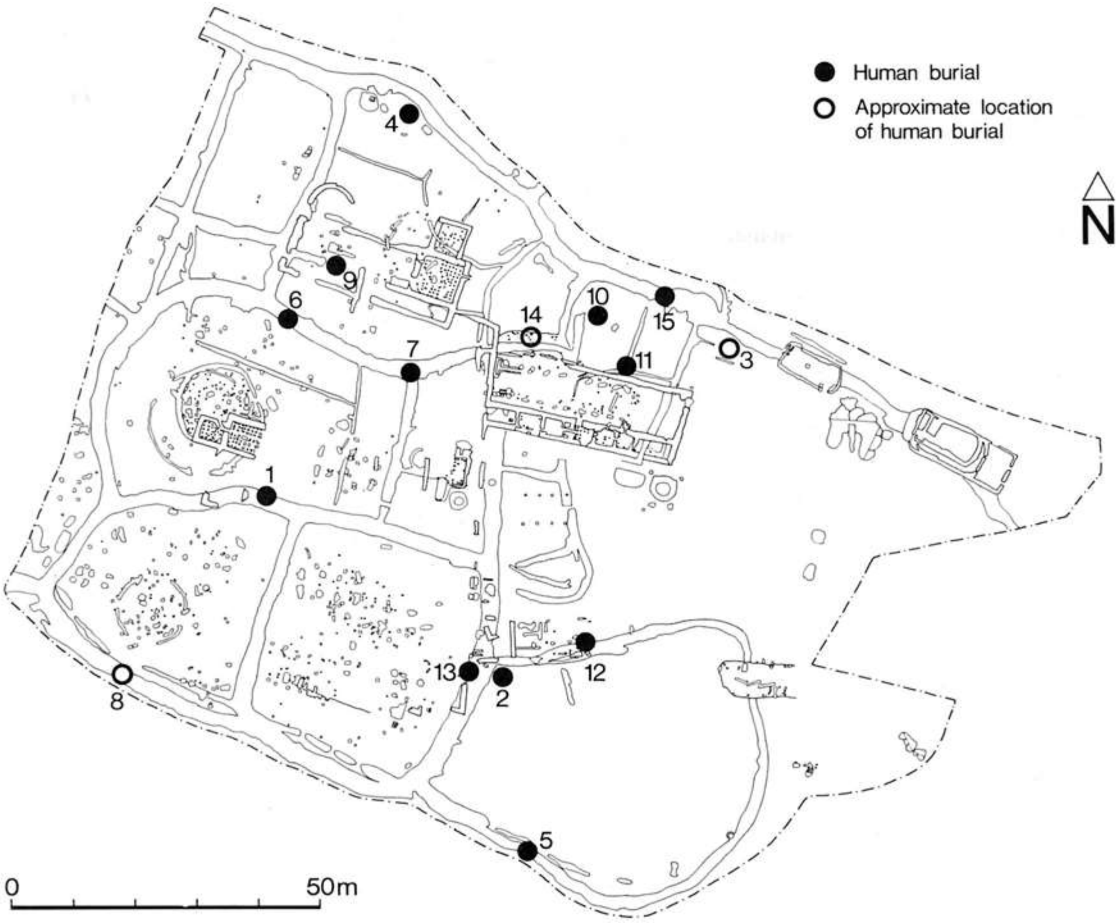


Figure 5.3.5: The locations of the burials within the Iron Age and Roman area of occupation (Wrathmell and Nicholson, 1990, 171).

During excavations, 15 isolated inhumation burials were discovered across the site, most interred within the Iron Age boundary ditches, though one infant burial was dug into the floor of the main residential villa building (Figure 5.3.5). Site stratigraphy and radiocarbon dating of two individuals (Table 5.3.2) were used to date the skeletons. This revealed one Iron Age individual, one early medieval individual and thirteen dating to the Roman period, ten of whom were infants. Burials 1-11 were examined by Keith Manchester, and burials 12-15, which were four additional infant burials that were discovered during post-excavation analysis, were examined later by Helen Bush. The skeletal report contained in the site monograph is minimal, each individual given only a few lines unless particularly well preserved. Among the assemblage were three Roman adults and one early medieval adult, all of whom were able to be given an estimated sex and age at death. The skeletal remains from Dalton Parlours have not been subject to many studies since their excavation. In one exception, Redfern (2018) suggests that Burial 10 could represent an enslaved person due to the prone burial position and pathologies such as healed fractures, periosteal reactions and sinusitis.

Skeleton	Radiocarbon age years BP	Calibrated range
10	1780±80	130-377 AD

Table 5.3.2: Results of the radiocarbon dating on the individual from Dalton Parlours included in this thesis. Data from Wrathmell and Nicholson (1990).

5.3.3 Ferrybridge Henge

Ferrybridge is located in West Yorkshire on the River Aire, on fairly flat and fertile ground at the edge of the Humberhead Levels. Finds from the area have included Mesolithic flints, Neolithic and Bronze Age barrows (Roberts et al. 2005), and a late Bronze Age hoard in nearby Ferry Fryston (Brown, 2007). In Castleford, about 5 km north, there was a Roman fort, and Pontefract, about 3 km south west, has substantial cemetery populations from the 7th century AD, and was described as a royal vill in 947AD (Roberts and Whittick, 2013). Ferrybridge Henge itself is a Neolithic henge, which was identified on aerial photographs and classified as a Scheduled Ancient Monument in the 1960s (legacy SAM no. WY/720; current list entry no. 1005789; Historic England, 2022a). It is the most visible part of an area which has since been revealed to hold many other ritual monuments spanning thousands of years. Apart from antiquarian excavations, which left few if any useful records, the complex of structures around Ferrybridge Henge were the subject of excavation and geophysical survey by West Yorkshire Archaeological Services (WYAS) from 1989 to 1992. Further WYAS excavations in 2001-2002 uncovered the skeletal assemblage included in this thesis (Roberts et al. 2005). These two phases of excavation were compiled into a monograph edited by Roberts et al. (2005). Excavations immediately to the south and west of the scheduled henge area were required before the construction of the Holmfield Interchange on the A1 motorway in 2005. This was because the aerial photography, which led to the scheduling of the henge itself, also revealed crop marks of smaller circular monuments, enclosures, pit alignments and field systems. The excavations found a total of 22 inhumations and 8 cremations spanning almost 5000 years from 3500 BC to 1400 AD (Figure 5.3.7). Of these inhumations, 19 were adults, two were young children, and one was an adolescent. The dates of the burials were estimated using the stratigraphy and clear phases of use of the different features on the site, and then confirmed with radiocarbon dating (Table 5.3.3). This allowed the identification of four Roman adults and one 7th-century adult burial from among the full site assemblage.

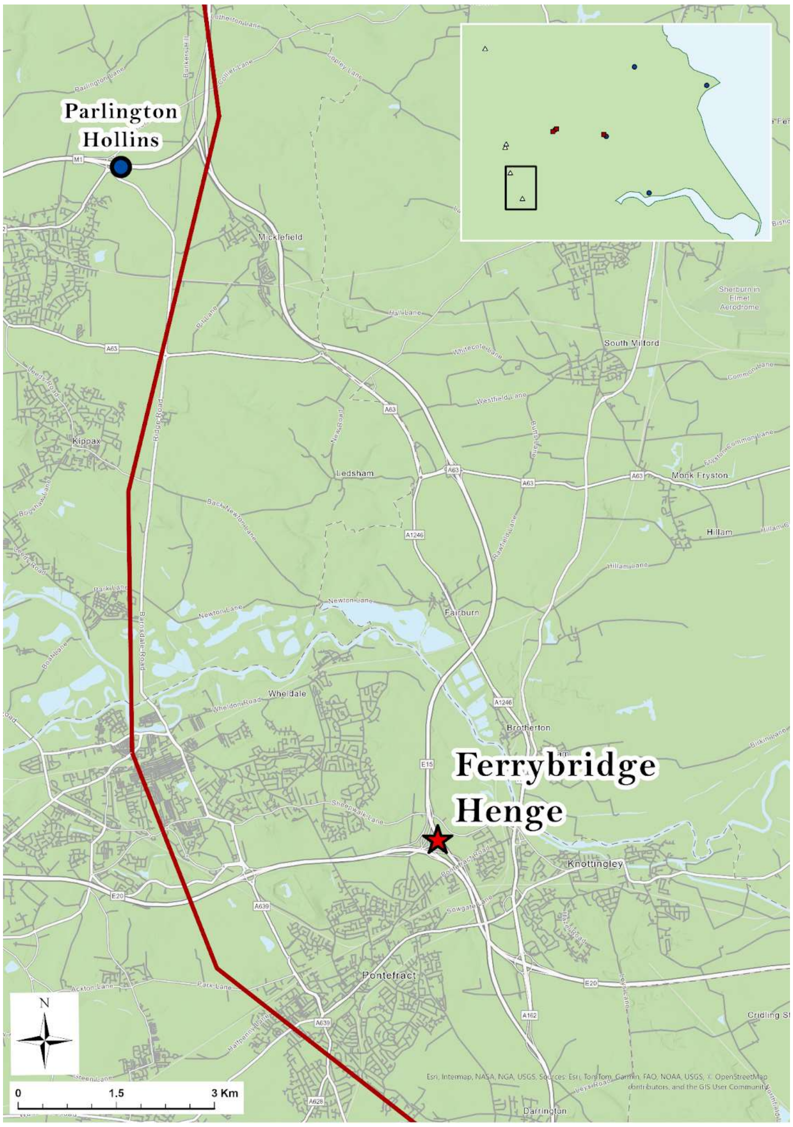


Figure 5.3.6: The location of Ferrybridge Henge and associated monuments, including the Roman and early medieval burials, in the modern landscape. Basemap Esri, 2025; Roman road data McCormick et al. 2013.

The osteological analysis was performed by Malin Holst. Although the original report is not published, nor made available via the Archaeology Data Service, a detailed overview is given in the site monograph. The site seemed to have very localised differences in soil conditions as preservation of the skeletal remains varied from very poor to excellent. The Roman and early medieval individuals were mostly assessed as having moderate to poor preservation. The small number of burials also limited the inferences which could be made by WYAS about the local populations in the Roman and early medieval periods. One notable quality of the Ferrybridge site is that half of all the inhumations were interred in the pit alignments, an uncommon practice in general and certainly not with so many on one site. The skeletal assemblage from Ferrybridge was sampled for carbon and nitrogen isotope analysis as part of the post-excavation programme of work, revealing that there was little change in diet across time as all periods showed evidence for mixed animal and vegetable protein sources, but with no marine additions. Two individuals (SK01, the early medieval adult, and SK04, a Roman adult) had higher $\delta^{15}N$ values than expected, which was interpreted as a sign they had eaten more pork than the other individuals. The skeletal remains have not been subject to analysis in many further studies, although data from the monograph was added to a much larger study on physical trauma in childhood by Mary Lewis (2013).

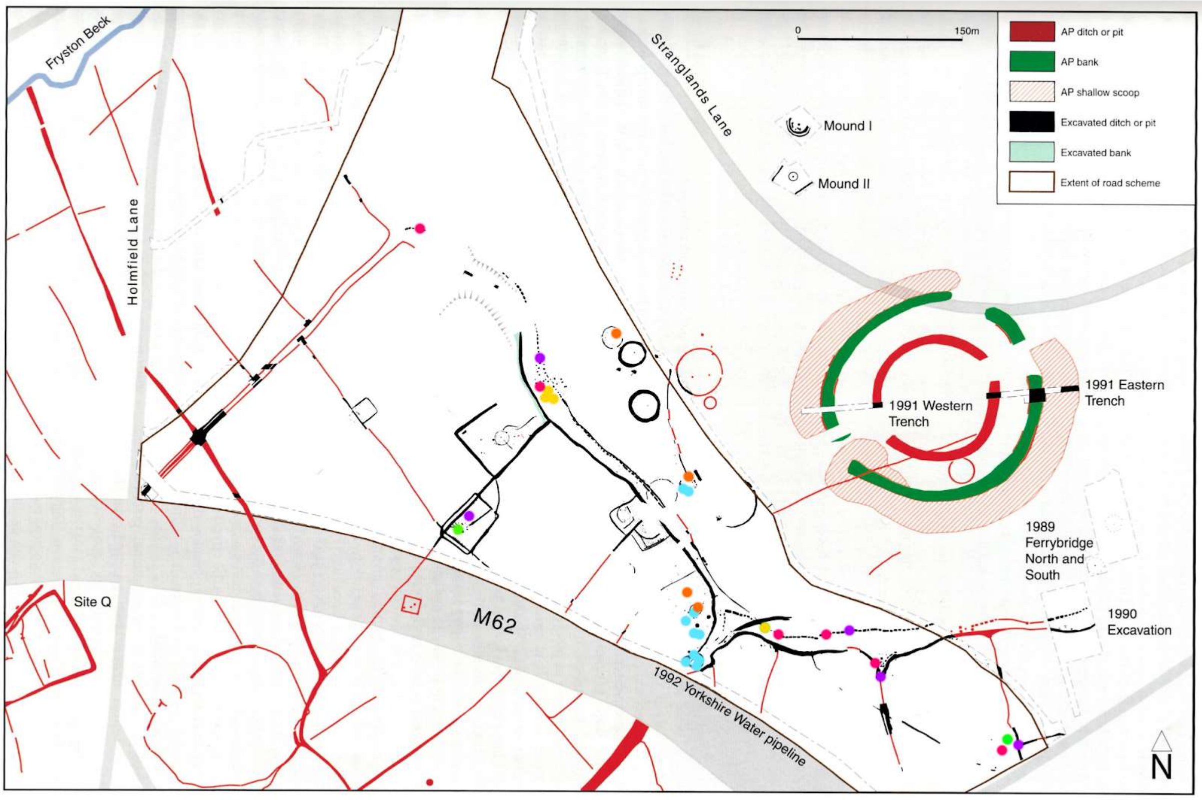


Figure 5.3.7: The distribution of burials across the excavated area at Ferrybridge. Neolithic burials are in blue, Bronze Age in orange, Iron Age in pink, Roman in purple, early medieval in green, and medieval in yellow. Adapted from Roberts et al. 2005, Figure 10.

Skeleton	Radiocarbon age years BP	Calibrated range
SK01	1400±45	600-770 AD
SK02	1825±45	130-250 AD
SK04	1725±45	250-390 AD
SK10	1790±50	130-330 AD
SK15	1855±60	80-240 AD

Table 5.3.3: Radiocarbon dates for the individuals from Ferrybridge Henge included in this thesis. Data from Roberts et al. (2005).

5.3.4 Healam Bridge

Approximately halfway between Aldborough to the south and Catterick to the north in North Yorkshire, the A1M crosses Healam Beck along the same line as Dere Street took in the Roman period. In this location, evidence of Roman occupation was discovered in 1949 during works on the road, and this was later claimed to be a fort (Hartley, 1971). The road travels through the Vale of Mowbray, a ridge of rich agricultural land situated between the River Swale and North Yorkshire Moors to the east and the River Ure and Yorkshire Dales to the west. In contrast to the wealth of Mesolithic, Neolithic and early Bronze Age flint deposits and structures surrounding Catterick (see section 5.2.1), 16 km to the south east at Healam Bridge no such evidence has been found. The area surrounding Healam Bridge is only known to have been populated during the Bronze Age and early Iron Age from palaeoenvironmental evidence including peat cores and pollen assessments, which show widespread tree clearance and growth of crops (Mitchell et al, 2011). The Roman settlement grew alongside Dere Street, a major thoroughfare from York to the north of the province, and was occupied into the 5th century. Evidence from the post-Roman period was mostly confined to the area north of the beck away from the core of the fort and vicus. Additional traces of early medieval occupation have been found around the village of Carthorpe, 1 km west of Healam Bridge, including pottery and burials (Meaney, 1964), but settlement seems to have moved further away from Dere Street throughout the middle and late Saxon eras.

Further upgrades to the road were proposed in the 1990s as part of the same project that led to the excavations in Cataractonium and Bainesse. As a result, a scheme of geophysical survey, trial trenching and fieldwalking was undertaken by Lancaster University Archaeological Unit in order to assess the nature of the archaeology and the area of land it covered. The complex settlement, including the clear square outline of a fort and surrounding evidence of occupation stretching over a kilometre of roadside, was subsequently given the designation of Scheduled Monument number 34736/2. Accordingly, the planned line of the motorway upgrade was shifted slightly to avoid the centre of the settlement. During construction in 2009-2010, the western edge of the settlement due to be buried beneath the motorway was excavated by NAA, where occupation spanning the 2nd-5th centuries was revealed (Ambrey et al. 2017). At least 36 inhumation and cremation burials were excavated across the site, mostly isolated or in small groups and widely dispersed (Figure 5.3.9). The exception was a group of 7 infant and 1 juvenile inhumations, and 1 adult cremation clustered in the west of the site around a structure interpreted as a mausoleum. The dates of the burials were determined through a combination of radiocarbon analysis (Table 5.3.4), and consideration of the stratigraphy of the site and relationships between the burials and other features.

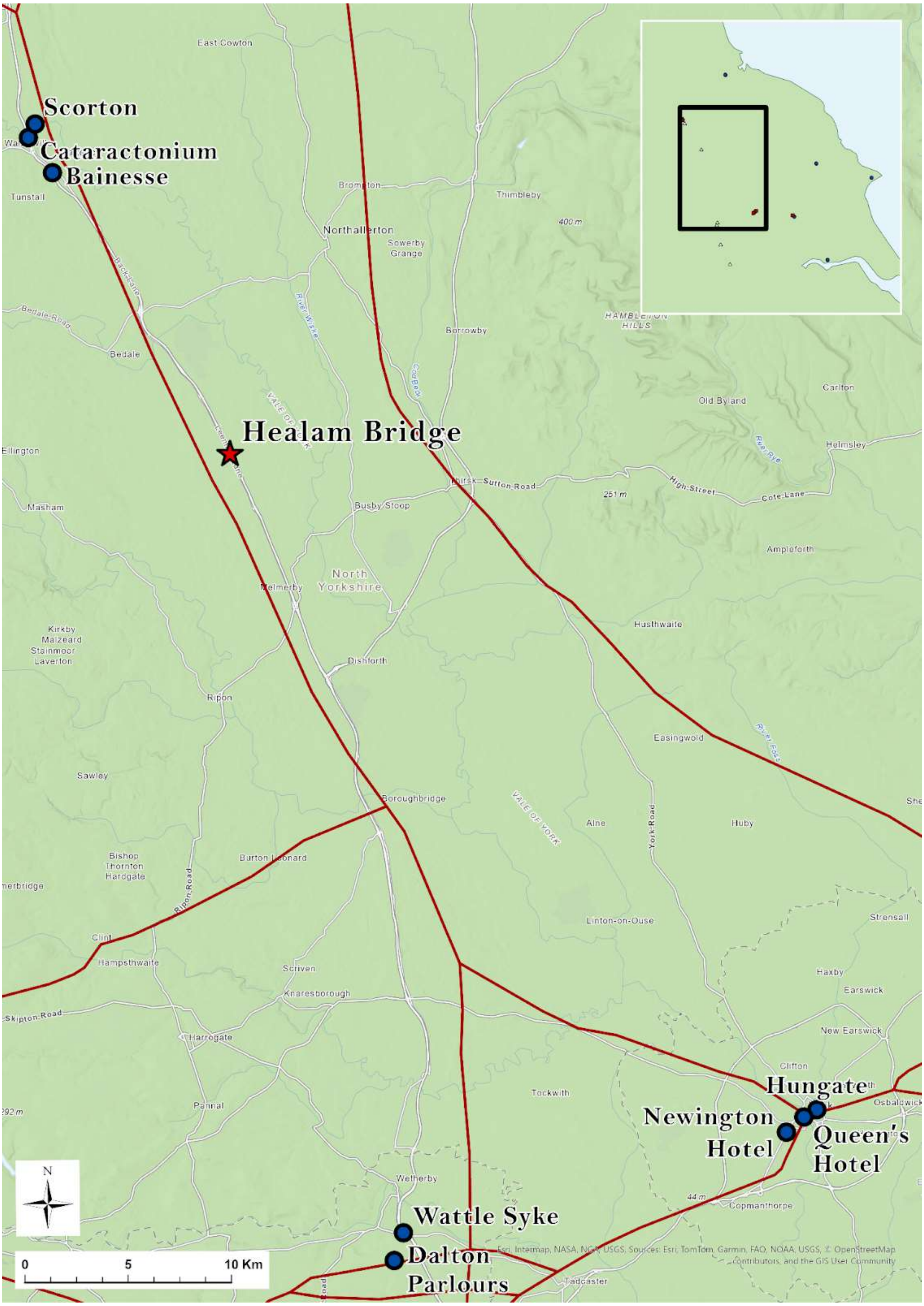


Figure 5.3.8: The location of Healam Bridge within the modern landscape, and in relation to the Roman road system (red lines), and other case study sites for this thesis. Basemap Esri, 2025; Roman road data McCormick et al. 2013.

Figure 5.3.9: Burial locations at Healam Bridge (Ambrey et al., 2017, 140). Phase 1 labels 1st and 2nd-century features, phase 2 is 3rd-century, phase 3 is late 3rd to early 5th-century, and phase 4 is 5th to 9th-century.

The post-excavation analysis of the human remains was conducted by Malin Holst and Katie Keefe of York Osteoarchaeology on behalf of NAA and the Highways Agency. Identification of five neonates during analysis brought the total number of articulated inhumations recovered to 29, of which 25 were from the Roman period and 4 from the early medieval. There was a high proportion of infants among the Roman individuals, 14 of the 25 skeletons being those who died around the time of birth. This may potentially be related to the strict rules requiring the burial of adults and older juveniles at a distance from the settlement during the Roman period. Alternatively, the unusually high number of infants was suggested by Holst and Keefe to be related to infanticide, particularly as this area appeared to have been delineated for infant burial. The remaining Roman individuals were 3 juveniles and 8 adults. Most of the adults could be assigned a sex based on their skeletal presentation, with 4 males and 3 females identified. Of the early medieval individuals, 3 were adults and the other was a juvenile. Two of the adults were not able to be assigned a sex, and the third was male. Overall, the skeletal remains from Healam Bridge had moderate to good preservation, but many were less than 50% complete which was noted to significantly hinder analysis. The early medieval individuals were particularly poorly preserved as they had been buried in an area of the site subject to regular ploughing. A thorough account of the analysis of the skeletal assemblage is given in the site monograph (Ambrey et al. 2017), including the assessment of one of the Roman juveniles, Skeleton 7303, who was believed to have Down's Syndrome (Figure 5.3.10). Since the publication of the monograph, the skeletal remains of the 29 individuals excavated at Healam Bridge have not been included in any further studies at the time of writing.

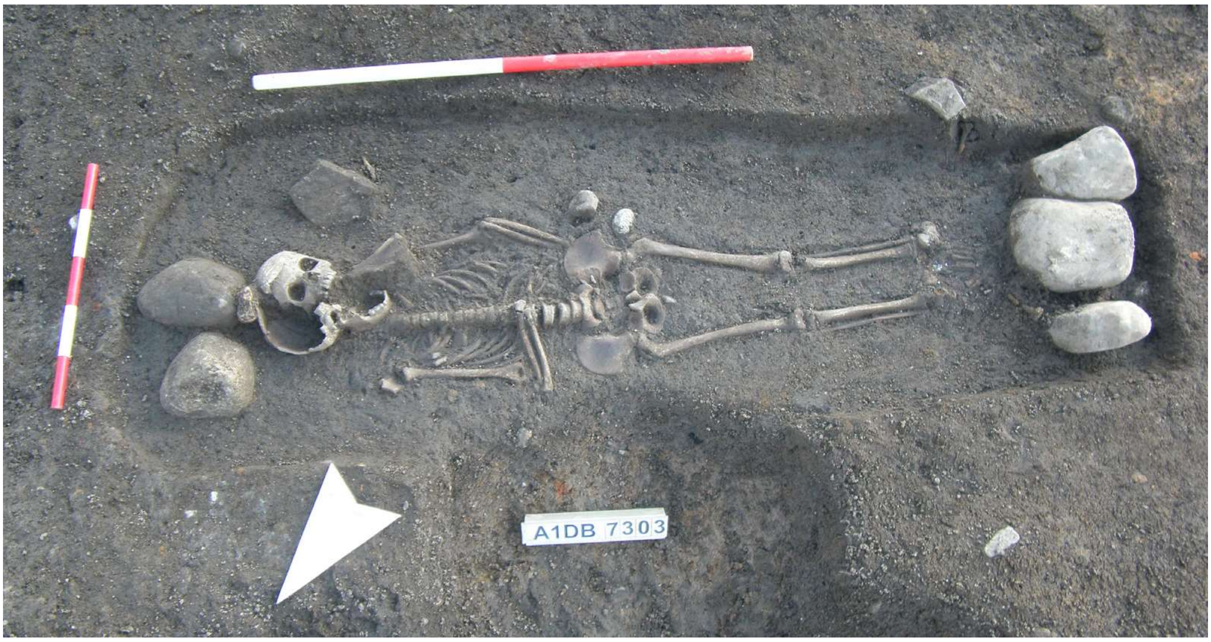


Figure 5.3.10: Skeleton 7303, interred immediately next to a building. This individual was around 10 years old and is believed to have Down's syndrome. (Ambrey et al., 2017, 44).

Skeleton	Radiocarbon age years BP	Calibrated range
8126	1730±35	235-403 AD
8247	1725±30	243-393 AD
2581/2590	1710±35	248-410 AD

5016	1635±35	339-536 AD
5026	1375±35	600-691 AD
5301	1255±35	671-870 AD
5305	Radiocarbon dating performed but years BP not reported	668-831 AD
1994/2210	1825±35	85-257 AD
7275	1865±35	72-235 AD

Table 5.3.4: Results of the radiocarbon dating on the individuals from Healam Bridge included in this thesis. Data from Ambrey et al. (2017).

5.3.5 Parlington Hollins

Prior to the construction of the road linking the M1 with the A1(M) east of Leeds, a number of archaeological sites, including that at Parlington Hollins, were identified in the agricultural landscape along the route from crop marks and fieldwalking carried out by NAA in 1992. The area sits to the north of the River Aire, between the Pennines to the west and the Vale of York to the east. The eastern end of the link road joins the A1(M) as it follows the line of the Roman Ridge Road, which runs north past Dalton Parlours (section 5.3.1) and Wattle Syke (section 5.3.7) to meet Dere Street (RRRA, 2018). Evidence for human occupation prior to the Iron Age is sparse in the area, a Mesolithic flint scatter having been discovered at Thorpe Stapleton about 9 km to the south-west of Parlington Hollins (West Yorkshire HER MWY2050), and Bronze Age structures known at Ledston about 6 km to the south of Parlington Hollins (Moorhouse, 1977). The most important Iron Age monument in the locality is the hillfort at Barwick in Elmet (Scheduled Ancient Monument number 1010924), though many smaller enclosures are also known from cropmarks (Roberts et al. 2001). Parlington Hollins was one of the few sites of interest along the road corridor to be identified initially by fieldwalking. It was then subject to geophysical survey by NAA in 1994 and WYAS in 1995, revealing a series of enclosures and other features. The fieldwalking finds of tile and pottery suggested these were Roman in date. Excavation of the site was carried out by WYAS from 1996-8 in two phases: one to the east of the Aberford Road, named Parlington Hollins East (PHE), and one to the west of the road, named Parlington Hollins West (PHW). The excavation discovered that use of the site had extended from the Iron Age, through the Roman period, and into the early medieval period. Features from the Roman period included enclosures, smaller ditches and pits related to agricultural and quarrying activity, which was theorised to be part of a villa complex (Holbrey and Burgess, 2001). From the early medieval period, two sunken featured buildings, also known as *Grubenhäuser,* were the only evidence, thought to represent continuation of use of the site, but perhaps with a slight shift in location of the most intense activity. From around these features, a total of 6 inhumation burials and one cremation were excavated, most of which had been deposited in ditches of earlier date. Only one burial had been made in PHW, the other five interred in PHE in an earlier cluster of two, and a later cluster of three. The skeletons were dated to the late Roman/early medieval period by radiocarbon dating (Table 5.3.5). The earlier skeletons were buried in a crouched position, and the three later skeletons were in extended supine position (Figure 5.3.12). One of the later burials, Skeleton 880, had been decapitated and the head placed between the feet. This is a characteristically Roman style of burial seen in a post-Roman individual, indicating some level of continuity in culture and funerary ritual after the collapse of Roman control in the region. Three further sites excavated in the A1-M1 link road scheme had cremation burials, but no inhumations, so were not included in this work.

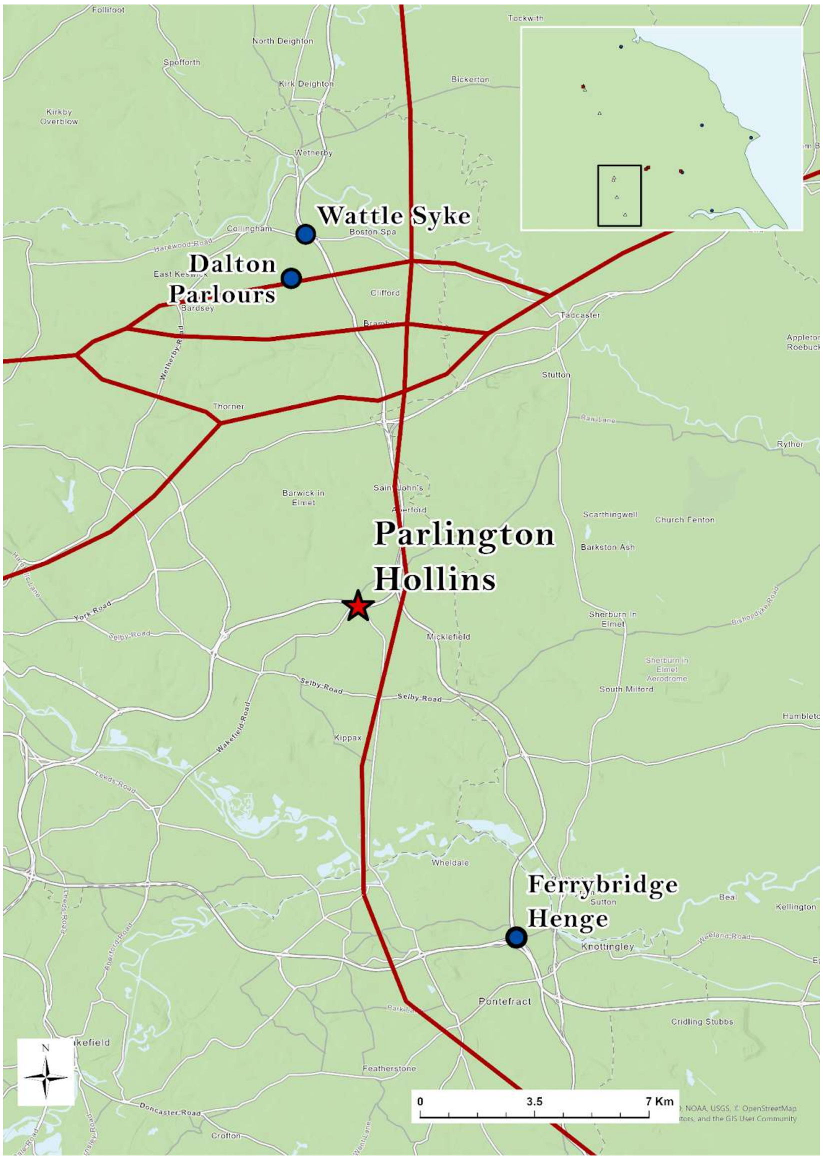


Figure 5.3.11: The location of Parlington Hollins within the modern landscape, and in relation to the Roman road system (red lines), and other case study sites for this thesis. Basemap Esri, 2025; Roman road data McCormick et al. 2013.

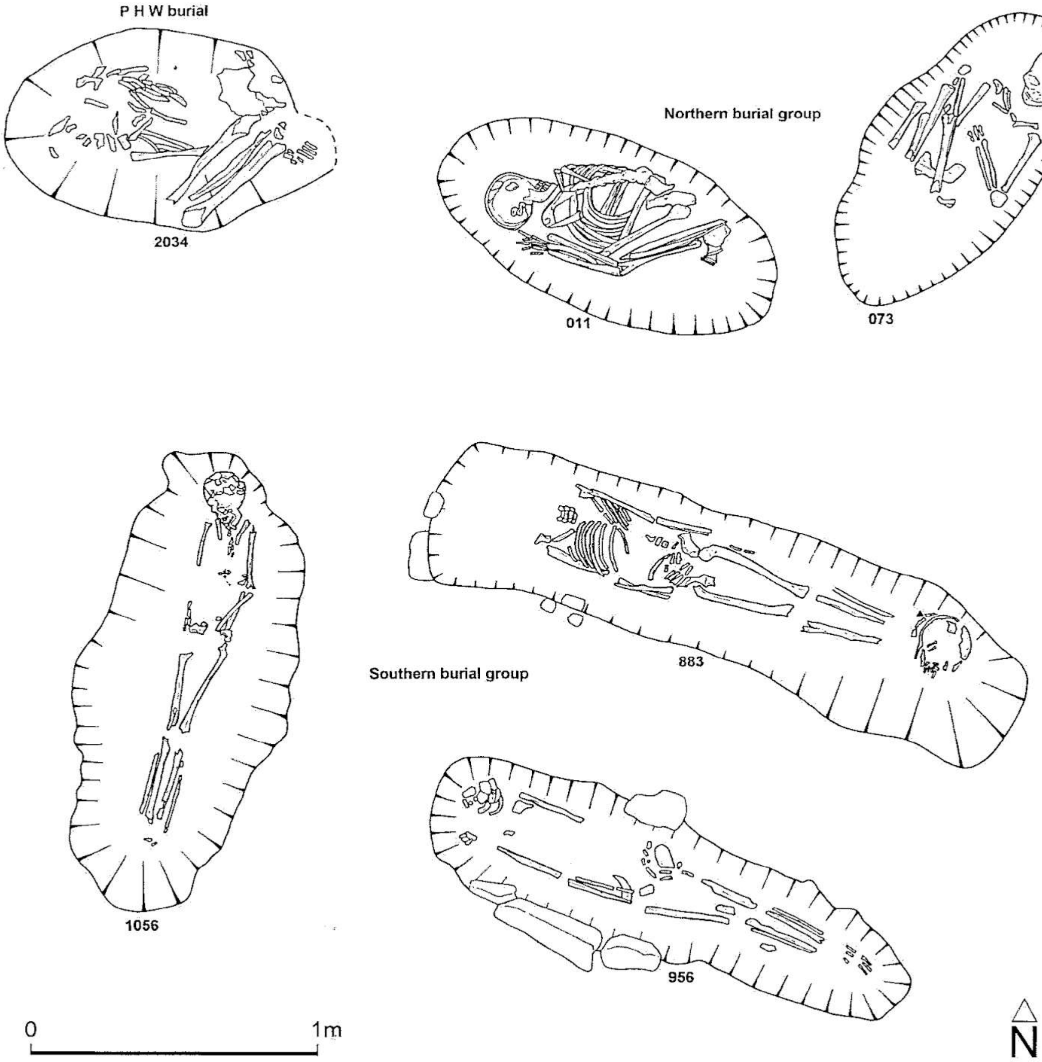


Figure 5.3.12: The body positions of the inhumations at Parlington Hollins. Grave locations not shown in relation to each other. (Holbrey and Burgess, 2001, 97).

Analysis of the six human skeletons found at Parlington Hollins was carried out by Sue Boulter of WYAS. The assemblage was described as having fair to poor surface preservation, with a high degree of fragmentation and moderate completeness. As with the other case study sites, the soil conditions and agricultural activity in the area likely caused this damage, which hindered the osteological assessment. Despite this it could be determined that all but one were adults at the time of their deaths, with one juvenile estimated to be 12-15 years old. This lack of infant burials was likely due to poorer preservation of smaller bones, or a differential burial custom for children. Of the adults, one was estimated to be male, three female, and one was undetermined. A reasonably thorough report of the pathological assessment was included in the site monograph (Boulter, 2001). The osteological report states that Skeleton 880 had no evidence of cut marks to indicate perimortem decapitation, despite having clearly been disarticulated before burial. It also mentions that Skeleton 009 had a similar modified burial position and lack of perimortem trauma, but this was not discussed in the excavation report (Holbrey and Burgess, 2001) so it is unclear whether the turned skull of Skeleton 009 was deliberate or taphonomic. The inhumed individuals from Parlington Hollins have not been included in further work since the publication of the monograph.

Skeleton	Radiocarbon age years BP	Calibrated range
009	1730±60	233-392 AD
075	1630±60	347-488 AD
880	1500±80	440-637 AD
1008	1605±40	407-504 AD
2009	1785±45	145-322 AD

Table 5.3.5: Radiocarbon dates for the individuals from Parlington Hollins included in this thesis. Data from Roberts et al. (2001).

5.3.6 Scorton

Scorton is a modern village in North Yorkshire, approximately 2.5 km north-east of Catterick in the Vale of Mowbray. As previously discussed (section 5.2.1), this fertile agricultural land sits west of the Yorkshire Moors, and is passed by Dere Street, the main Roman road to Hadrian's Wall. The excavated site itself is not in Scorton village, but is further to the south-west, on a slight promontory across the River Swale from the modern village of Catterick Bridge. Wessex Archaeology conducted an evaluating series of trial trenches and a geophysical survey in 1997 (Ellis, 1998; Ellis and Moore, 1998), and Northern Archaeological Associates carried out larger scale excavations between 1998 and 2000 due to planned quarrying activity at Hollow Banks Farm (Speed, 2002a; b). This latter programme of work uncovered evidence of human activity on the land stretching back to the Mesolithic period. In addition to the Mesolithic flint scatters, there were Neolithic and early Bronze Age pit alignments and possible houses, Iron Age enclosures and a field system, a Roman field system and part of a marching camp which extended past the limits of the excavation. Two previously unknown cemeteries were discovered during the course of excavations, lying south of the contemporaneous enclosures on what would have been the north bank of the Swale before the river moved to its modern course. One comprised 15 inhumation burials dated to the late Roman period by the style of the grave goods. The grave goods – crossbow brooches (Figure 5.3.13) and belt buckles – implied the individuals had been part of the military and may have had continental origins. The second cemetery, comprising 102 inhumation burials and three cremations, was separated from the Roman cemetery by approximately 30 metres (Figure 5.3.15) and was dated to the Anglian, or early medieval period, also by the style of the grave goods, which included weapons, glass beads and annular brooches. The spatial separation and differentiation in funerary style were taken in the report to imply that the two cemeteries were discrete locales, though the spit of land separating the two was not excavated. Despite the limits of both cemeteries being discovered, it is still possible burials were lost during topsoil stripping because there was no expectation of finding a cemetery, and both the human remains and the changes to the soil colour and texture indicating the outline of the graves were elusive in nature (Speed, 2002a).

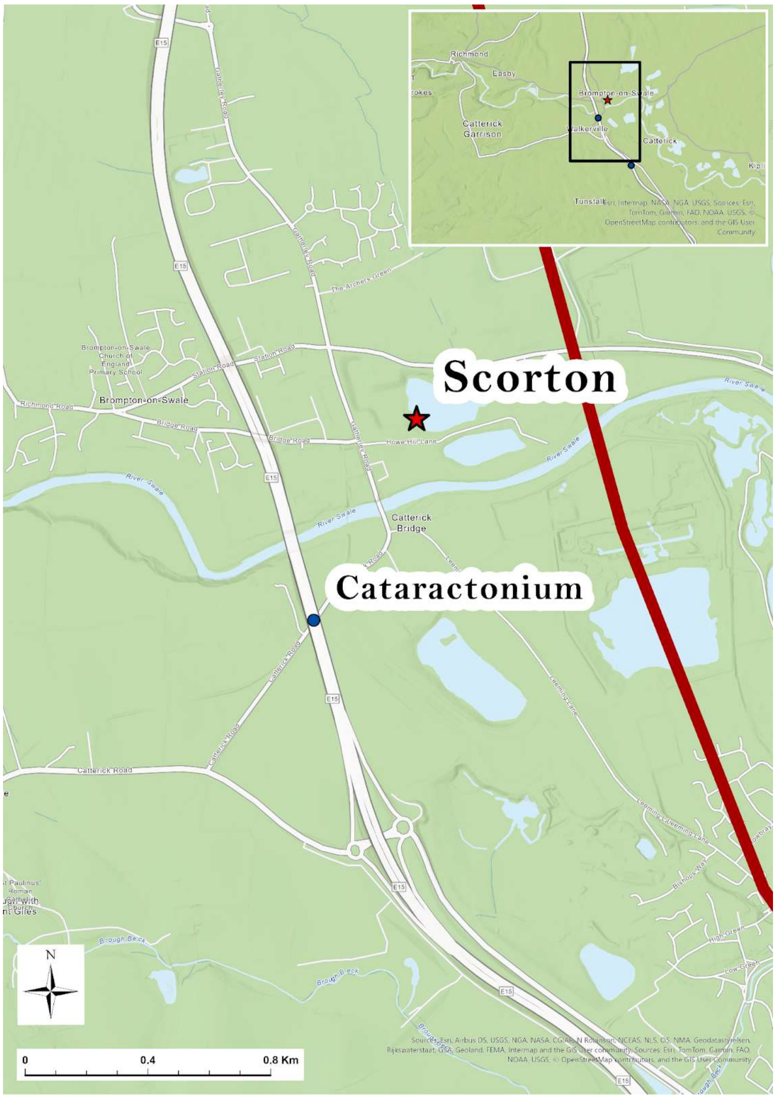


Figure 5.3.14: The location of the Roman and early medieval cemeteries at Scorton Quarry, Dere Street, and *Cataractonium*. Basemap Esri, 2025; Roman road data McCormick et al. 2013.

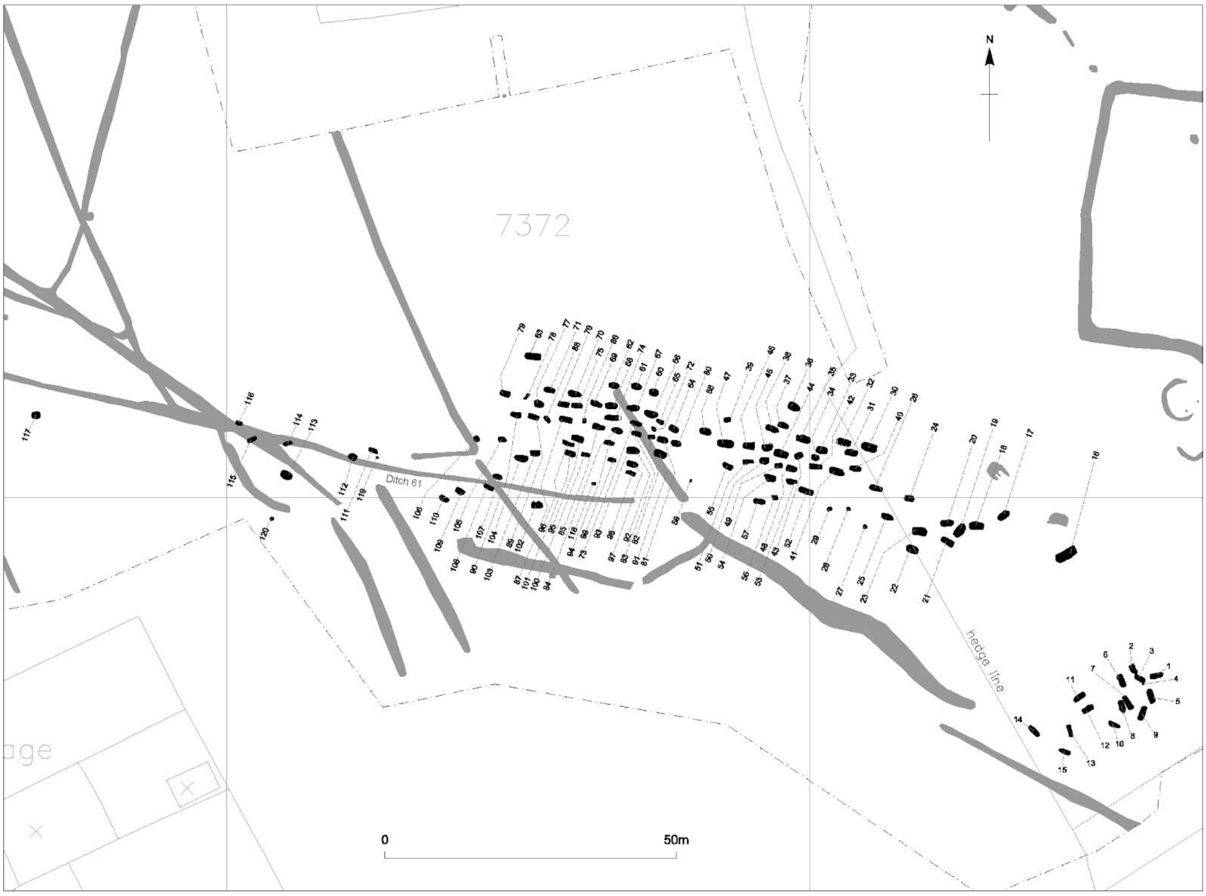


Figure 5.3.15: Locations of the Roman (bottom right cluster) and early medieval (larger central cluster) burials at Scorton (Speed, 2002, 12).

The Roman and early medieval burials were all analysed by Joy Langston of Northern Archaeological Associates. Preservation was generally very poor, with severe degradation and loss of cortical bone widespread, and very low completeness: only eight individuals were more than 50% complete, and only 68 of the 117 graves contained any human remains at all, though two contained more than one individual. None of the individuals were affected by truncation or intercutting by subsequent graves. The Roman assemblage represented the remains of 12 individuals, all of whom were adults at the time of death, There was not an even distribution of sexes: only one female was identified, compared to three individuals of undetermined sex and eight males. The early medieval cemetery had a less restricted demography in contrast, with nine children aged between four and ten at death identified, 58 adults and three adolescents, who were described in a varying manner as "12-15 years", "skeletally immature" and "<20" (Speed et al., 2002a, 7; 137; 138). Among the adults there were 10 females and six males, the remaining 46 could not be assigned to either sex. It was noted that no neonatal remains were found, indicating that the communities likely had different burial rites for infants; neonatal bones are generally more resistant to degradation than those of children, so the survival of bone in several children's burials strongly suggests the absence of infant burials rather than their complete decomposition. The results of the skeletal analysis have not been published, instead being confined to an unpublished report and catalogue kindly shared with this author by

Greg Speed (Speed, 2002a; c). Nine of the Roman individuals were later subject to an isotopic study aimed at discovering their geographic place of origin, due to the continental-style crossbow brooches discovered in the majority of graves, which determined that at least six were likely to be migrants from continental Europe (Eckardt et al. 2015). The isotopic data was further studied by Redfern and colleagues (2018), who compiled isotopic studies of Roman populations from around Britain and found that those with non-local isotopic signatures had a lower age at death on average, though it was not mentioned whether this applied when considering the Scorton cemetery alone. The funerary style in the early medieval cemetery has been compared to seven contemporary cemeteries from around England (Harrington et al. 2020), and found to be most similar in variety of body position and orientation to the other northern cemeteries, Sewerby (section 5.4.6) and West Heslerton (section 5.4.7). However, despite the cemetery's size and importance as a rare 6th-century assemblage, the skeletons have not been part of any subsequent studies.

5.3.7 Wattle Syke

Wattle Syke is currently the name of a road in West Yorkshire, situated 2 km south of Wetherby between the villages of Collingham and Boston Spa. The Roman villa at Dalton Parlours is just 1.3 km to the south of Wattle Syke, and as discussed in section 5.3.2, a wealth of evidence for occupation from the Neolithic period onwards has been discovered in the wider area. The Iron Age and Roman settlements at Wattle Syke were identified from cropmarks, and first excavated by WYAS in 1990 ahead of work on the A1. During this excavation, three burials were discovered, but no analysis of them has ever been published so they could not be included in this thesis. Further work on the road necessitated trial trenching by WYAS in 2005, uncovering another three burials, followed by a full open area excavation by WYAS in 2007 which found 54 burials. The excavations were later reported in a monograph (Martin et al. 2013), which also detailed the results from the analysis of the 57 burials found in 2005 and 2007. Assessment of the grave goods, including jewellery in the late Roman burials and a knife in the early medieval burial, stratigraphic relationships, and radiocarbon dating (Table 5.3.6), determined that there were 37 Roman burials present, and one early medieval individual from the 7th century, the remaining 19 dating from the Iron Age. Animal burial was also practised at Wattle Syke, with partial skeletons of cattle, pigs, sheep and horses found in both Iron Age and Roman contexts, representing a continuation of this cultural practice. Five of the late Roman graves (Skeletons 2, 3, 5, 7 and 29) contained chicken bones in addition to the human skeletal remains, like that of Skeleton 18 from Yapham Road (section 5.2.2).

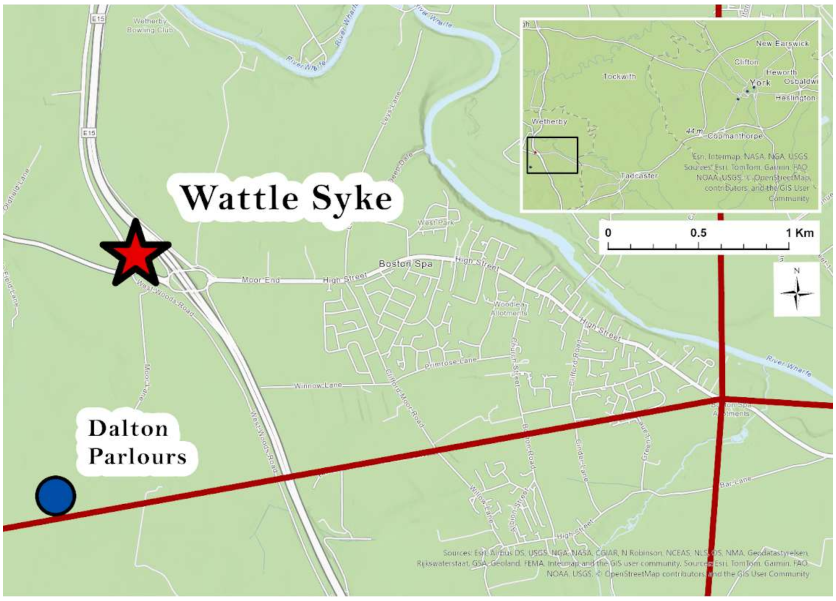


Figure 5.3.16: The location of the Wattle Syke site in relation to the modern village of Boston Spa, the villa site at Dalton Parlours, and the Roman Road system. Basemap Esri, 2025; Roman road data McCormick et al. 2013.

Figure 5.3.17: The distribution of the late Roman graves among the domestic features at Wattle Syke (Martin et al., 2013, 100).

The analysis of the skeletal remains was carried out by Anwen Caffell and Malin Holst of York Osteoarchaeology. The soil of the site was dry and alkaline, meaning for the most part the skeletal remains had good surface preservation and remained robust so were not too fragmented. One exception was the early medieval individual, who was severely fragmented but still able to be examined. A notable feature of the assemblage was the high proportion of infant remains. Of the 37 Roman individuals, 12 were adults, 24 were perinates, and the other was a juvenile. The full report of the skeletal analysis remains unpublished, including through the Archaeology Data Service, but the site monograph published by WYAS contains much of the important detail on the burials (Martin et al. 2013). Subsequent analyses of the Roman period human remains from Wattle Syke have focused on the infant burials. For example, a discussion of Roman infant burial practices includes Wattle Syke as an example of the way rural Roman communities often buried infants within the settlement instead of outside as was required by law (Carroll, 2018). Another study noted the spatial association between human infant burials and animal burials (Chadwick, 2015).

Skeleton	Radiocarbon age years BP	Calibrated range
SK1	1710±30	250-390 AD
SK4	1760±30	235-335 AD
SK6	1725±30	250-380 AD
SK7	1690±30	260-410 AD
SK23	1755±30	235-335 AD
SK29	1725±30	250-380 AD
SK39	1780±30	210-330 AD
SK44	1410±30	610-655 AD

Table 5.3.6: Results of the radiocarbon dating on the individuals from Wattle Syke included in this thesis. Data from Martin et al. (2013).

5.4 Early medieval sites

5.4.1 Bamburgh, Bowl Hole

The most northerly of the case study sites, Bamburgh sits on the east coast of Northumberland, roughly 70 km north of Newcastle, 10 km south of Lindisfarne, and 30 km south-east of the modern Scottish border terminus. Located above Hadrian's wall, this region was not Romanised to the same extent as the more southerly areas of the province, but was under the control of the military and imperially approved local leaders for much of the Roman occupation of Britain (Birley, 1976). The most striking feature of the area is Bamburgh Castle, built in the 11th century on a rock outcrop overlooking the village and the coast. Excavations within the Castle boundaries have found evidence for continuous occupation since at least the Iron Age, and it has been theorised that the Roman settlement developed naturally into a seat of royal Northumbrian power in the same way as Catterick, and several forts on Hadrian's Wall such as Birdoswald (Kirton and Young, 2017). The cemetery site is located in the sand dunes next to a feature known locally as "Bowl Hole", approximately 300 metres south-east of Bamburgh Castle itself. It was first discovered in 1817 when a storm blew away enough sand to reveal the tops of stone-lined graves. The details of antiquarian investigations are unknown, but at least one excavation was conducted in 1894, which recovered several burials (Society of Antiquaries of Newcastle, 1904). Though marked on the 1886 Ordnance Survey map, the exact location of the site was then lost until the Bamburgh Research Project, an independent group set up in 1996 to investigate the history of Bamburgh Castle, carried out a series of trial trenches in 1997. Having located the cemetery, larger scale excavations were conducted between 1998-2007, revealing 99 articulated burials and several contexts of disarticulated bone representing at least 28 individuals. The burials were densely laid out, though minimal intercutting had occurred (Figure 5.4.3), and the edges of the cemetery were not revealed so the full number of individuals originally interred in the dunes is unknown, though it is almost certain that many were lost to the sea over centuries of erosion. The results of the excavation and skeletal analysis have been published in a variety of ways, including a PhD thesis (Groves, 2006), papers (Groves, 2011; Groves, 2010; Groves et al. 2009), and web pages designed for the general public (Accessing Aidan, 2024), but there is no comprehensive report covering the full assemblage in a scientific manner. The cemetery was dated to the sixth and seventh centuries based on the style of the grave goods, which included beads and knives, though few graves contained any objects, and this range was confirmed with radiocarbon dating of three individuals (Table 5.4.1)

Figure 5.4.1: The isolated location of Bamburgh in the modern landscape, and in relation to the Roman road system (red lines), and other case study sites for this thesis. Basemap Esri, 2025; Roman road data McCormick et al. 2013.

Figure 5.4.2: A closer look at the location of the Bowl Hole cemetery in relation to the modern village of Bamburgh, and the Lindisfarne Monastery on Holy Island. Basemap Esri, 2025.

Figure 5.4.3: Plan of the graves excavated by the Bamburgh Research Project 1997-2007 (Groves et al., 2013, Figure 2).

The skeletal assemblage from the Bowl Hole was originally analysed by Joy Langston, and then reassessed by Sarah Groves for her PhD thesis. In total, there were 29 non-adults, most of whom were between the ages of five and ten at death. There were also 62 adults, comprising 31 males, 28 females and three individuals of undetermined sex. Eight of the individuals listed in the Digital Ossuary, the website designed to inform the general public about the Bowl Hole cemetery (Accessing Aidan, 2024) were found in 2007, the final year of excavations, after the analysis by Groves had been completed, and were reinterred with the rest of the assemblage without any information being learned from them. The preservation was generally good, without a great degree of surface degradation or fragmentation (Figure 5.4.4). The exceptions to this were the individuals buried in deeper graves which cut into the underlying clay, who had much poorer preservation, with no skeletal remains surviving at all in seven graves. The relative paucity of neonates in comparison to older children is similar to that seen at Scorton, and may indicate differential burial rites for those who died as infants. In general, the population were thought to be of high status due to their greater than average stature and the amount of dental disease indicative of a rich diet. Prior to their reinterrment, 78 individuals from the Bowl Hole cemetery were subject to analysis of strontium and oxygen isotopes to determine their origins (Groves et al. 2013). The geology of Bamburgh is distinct enough that seven individuals could be determined to have grown up nearby. However, the majority came from further afield, mostly Ireland, western Scotland and southern England, but five were found to be of Scandinavian origin, and seven from the Mediterranean region. Despite the value of this large, well-preserved assemblage from a location of such historical importance, few further studies were conducted on the skeletons from Bamburgh before they were reinterred. The exception is one work by Budd and colleagues, which examined the changing concentration of lead in dental enamel through time, and included four individuals from Bamburgh in the early medieval assemblage. They found that lead exposure varied between individuals, but was generally greater in the Roman and medieval periods, and lower in the prehistoric and early medieval periods (Budd et al., 2004).

Figure 5.4.4: Skeleton 150, showing good preservation and completeness (Accessing Aidan, 2024).

Skeleton number	Radiocarbon age years BP	Calibrated range
129	1337±35	640-730 AD
130	1424±33	560-670 AD
134	1290±35	650-780 AD

Table 5.4.1: Radiocarbon dates from the individuals from Bamburgh included in this thesis. Data from Groves et al. (2009).

5.4.2 Melton

On the outskirts of Hull, 5 km west of the Humber Bridge, is the village of Melton in the East Riding of Yorkshire. It sits in a thin strip of flat, arable land between the south slope of the Yorkshire Wolds and the wetlands of the Humber Estuary, and its advantageous geographic location has induced people to settle there since at least the Bronze Age. Many archaeologically significant sites and finds are known from the area around Melton. Prehistoric finds include Neolithic and Bronze Age occupation and burials at Melton Quarry about 1.5 km to the north-west of the site (Evans et al. 2021), and Bronze Age boats on the Humber shore at Ferriby (Ferriby Heritage Trust, 2013) about 2 km south of the site. Roman villas were also found at Melton Quarry (Mackey, 1999) and Brantingham about 5 km west of the site (Liversidge et al. 1973), and the Roman town and fort of *Petuaria*, now called Brough, about 3.5 km west of the Melton site (Wacher, 2015). Prior to upgrades to the A63 road in the early 1990s, aerial photographs were examined which led to the discovery of a “ladder settlement”, an Iron Age community surrounding a central trackway, as well as extensive medieval ridge and furrow field systems. Geophysical survey by WYAS and trial trenching by NAA in 1993 focused on the ditches and determined that they had been in continuous use from the Iron Age until around 200 AD, during the Roman occupation. The NAA trenches also identified a 12th- to 14th-century structure, demonstrating the continuity of occupation at the site for millennia. Further trial trenches excavated by WYAS in 2002 identified more Roman ditches as well as post-medieval platforms. The site was then subject to a full excavation by On-Site Archaeology (OSA) in 2004-5. This uncovered a wealth of enclosure ditches, pits, roundhouses and other wooden structures, Bronze Age and Iron Age barrows, an Iron Age cemetery, and other burials. In total, 27 inhumations and six cremation deposits were excavated from the site. The cremations were Bronze Age, and found clustered around the Bronze Age round barrow. Of the inhumations, 20 were Iron Age and arranged in a linear cemetery, with one isolated individual of uncertain Bronze- or Iron Age date buried near the Bronze Age round barrow. One inhumation was of the Roman period, a neonate who was buried in a post hole. The final five inhumations were early medieval, from the 7th century, and buried in a cluster near the crossroads of two trackways across the site. The majority of the burials were subject to radiocarbon dating (Table 5.4.2), and the others were dated based on their relative positions to those that had been radiocarbon dated. The full results of the excavation were published in a monograph by OSA (Fenton-Thomas, 2010).

Figure 5.4.5: The location of the Melton site within the modern landscape, showing its relationship to the Roman crossing of the River Humber. Basemap Esri, 2025; Roman road data McCormick et al. 2013.

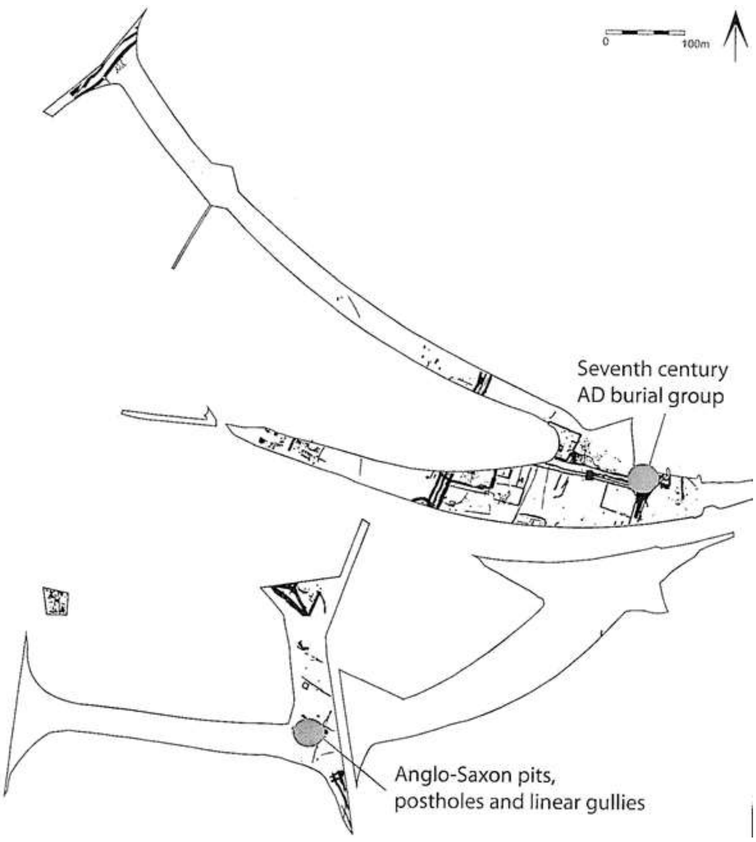


Figure 5.4.6: Plan of the Melton excavation showing the locations of early medieval features (Fenton-Thomas, 2010, 226).

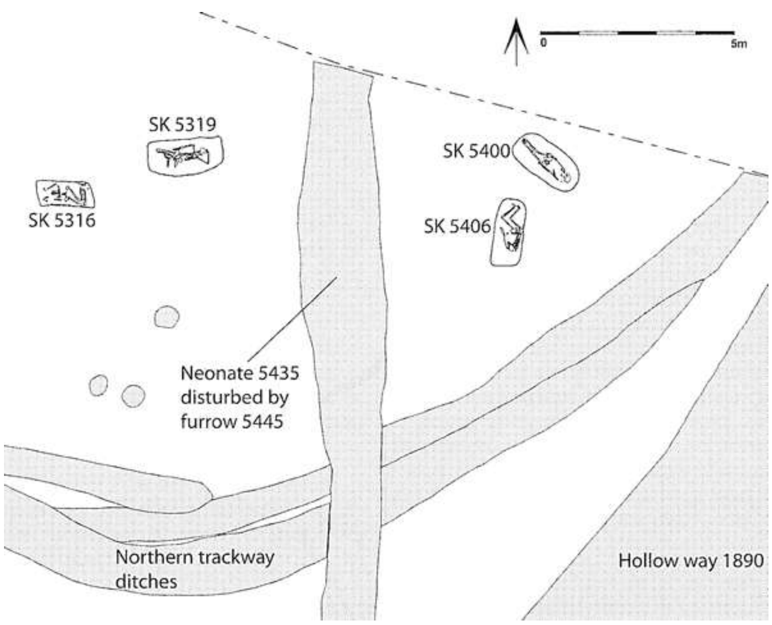


Figure 5.4.7: Locations of the early medieval burials (Fenton-Thomas, 2010, 234).

The osteological analysis of the human remains was carried out by Anwen Caffell and Malin Holst of York Osteoarchaeology. The skeletal assemblage was generally well preserved. The adult individuals generally had little fragmentation or damage to the surface of the bones, with the infants and young children generally the most poorly preserved. The single Roman burial was that of a well-preserved neonate, so it was not suitable for inclusion in this study of adult skeletons. Therefore, for the purposes of this thesis, Melton was classified as a site with only early medieval burials. The early medieval individuals were preserved well enough to allow estimation of sex and age. Four of the five were adults at the time of their death, with the sole juvenile aged between two and five years of age. The adults were equally distributed in terms of sex, with two male and two females. The burials had been arranged in what were called 'family' clusters by the excavators, as there were two groups: one with a male and a female, and the other with a male, female and juvenile (Figure 5.4.7). The skeletal report in the monograph contains a thorough account of the analysis of the skeletons and their demographic and pathological information. The Roman and early medieval skeletal remains have been neglected in further studies since their original excavation, though their Iron Age counterparts have been part of several, including a genetic study (Martiniano et al. 2016) which compared them to the early medieval skeletons of Norton Bishopsmill (section 5.4.3).

Skeleton number	Radiocarbon age years BP	Calibrated range
5319	1507±41	430-640 AD
5400	1378±36	590-700 AD
5406	1509±38	430-640 AD

Table 5.4.2: Radiocarbon dates calculated for the individuals from Melton included in this thesis. Data taken from Fenton-Thomas (2010).

5.4.3 Norton, Bishopsmill

Norton-on-Tees (hereafter referred to as 'Norton') is a town incorporated into the north of Stockton-on-Tees, in County Durham. The site sits on the area of flatter arable land east of the Pennines and north of the North York Moors, around 500 metres west of Billingham Beck, which drains into the Tees. Evidence for human activity in the area before the early medieval period remains scarce; only a few fragments of worked flint and Roman pottery having been discovered on the Bishopsmill site with no record of similar materials being found elsewhere. Evidence of occupation is even more scarce, with one undated post hole and ditch found in an excavation in the modern town centre (Durham Archaeological Services, 1993). However there is a long history of finds of skeletal material in the village, including articulated individuals, but many have since been lost without detailed records ever having been made. In brief these remains span several thousand years from the Bronze Age through to the 17th century, though the majority are early medieval. These include the East Mills cemetery discovered in 1982 (section 5.4.4), and the Bishopsmill cemetery discovered in 1994.

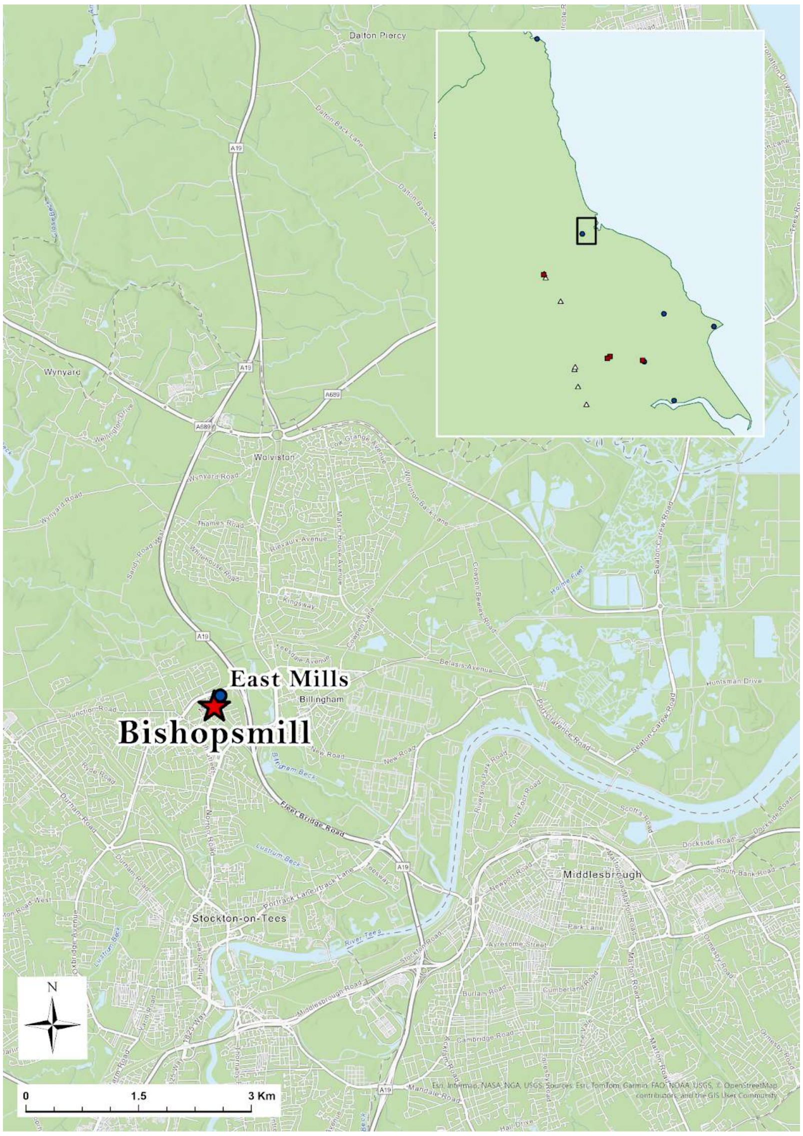


Figure 5.4.8: The location of Bishopsmill in the modern landscape surrounding the Tees river. Basemap Esri, 2025.

The first skeleton at Bishopsmill was found by workmen in 1994, and excavations to explore this by Cleveland County Archaeology Section (CCAS) were carried out immediately. These uncovered another 10 articulated skeletons, though the report of this excavation remains unpublished. Further planned development of the school led to an evaluation and trial trenching scheme in 2003 by Tees Archaeology, the successor to CCAS. Human burials were immediately apparent in these trial trenches, so the excavation was opened up to cover the entire development area. In total 98 grave cuts were identified, though only 89 were excavated including four double burials. A considerable amount of disarticulated bone was also recovered from a pit thought to have been used as a place to dispose of disturbed bone when new graves were dug. On examination, 107 individuals were identified from the articulated burials and disarticulated crania. The limits of the cemetery were not identified, though the discovery of a human skull in 1935, in the roots of a fallen tree about 50 metres from the site implied it stretched at least that far, so the total number buried at Bishopsmill remains unknown. Several of the graves excavated in 2003 were truncated by the foundation trenches of the school buildings erected in the 1970s, indicating the cemetery stretched underneath them and therefore an unknown number of individuals had been destroyed. The cemetery was dated to the 7th-10th centuries by analysis of the style of the iron chest fittings discovered in many graves, and confirmed with the radiocarbon dating of four individuals. These were carefully selected to represent each phase of burial, as the cemetery consisted of neatly organised rows which changed angle between each phase (Figure 5.4.9). Only the individuals from the earliest phase were included in the full dataset for this project (Figure 5.4.10), of which one, Skeleton 190, was radiocarbon dated (Table 5.4.3). The results of the excavation and osteological analysis are contained in an unpublished Tees Archaeology report (Johnson, 2005), kindly provided by Robin Daniels from Tees Archaeology for the purposes of this research.

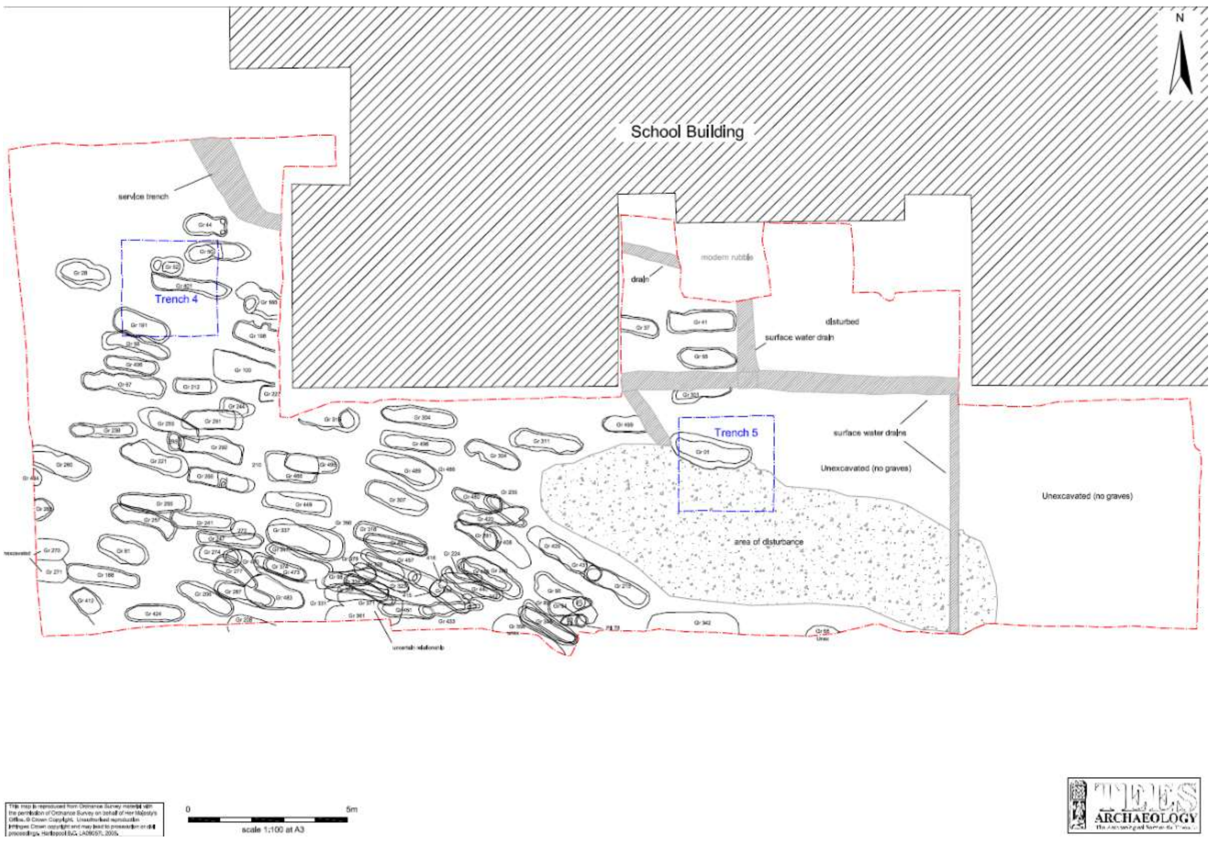


Figure 5.4.9: Plan of the location of all burials excavated at the Bishopsmill site (Johnson, 2005, Figure 3).

Figure 5.4.10: The earliest phase of burials, which were included in the dataset for this thesis (Johnson, 2005, Figure 4).

The post-excavation analysis of the 86 individuals from the cemetery was carried out by Joanna Higgins of Tees Archaeology. As expected, the preservation was generally poor due to the typical waterlogging, soil conditions and intercutting graves (Figure 5.4.11), though a significant amount of the damage was caused by the use of heavy plant during the construction of the school. Of the 89 excavated graves, 6 contained no human remains at all, and only 32% of the skeletons were over 75% complete, with many of the missing elements likely to have been deposited in the charnel pit. Forty-nine percent of individuals were severely fragmented, thought to be due to the movement of heavy vehicles over the site during the original construction of the school, and 43% had poor surface preservation due to the soil conditions. In total, 74 of the 86 individuals were determined to be adults at the time of death. Among the subadults, most were older children and adolescents, with only one child aged between 1 and 5 years. This unusual mortality profile is similar to that seen at Pocklington Burnby Lane (section 5.4.5) and may be indicative of differential burial ritual for infants, poorer preservation of the tiny neonatal bones, or difficulties with their excavation. In the adult group, most were young or young middle adults, though poor preservation meant that 24 of the 74 adults could not be categorised more specifically. Poor preservation also hampered estimations of sex, with only 19 males and 18 females identified, the remaining 37 individuals labelled as indeterminate. The report and full catalogue created by Joanna Higgins is contained within the unpublished post-excavation report (Johnson, 2005).

Figure 5.4.11: Skeletons 466 (left) and 495 (right), illustrating the poor bone preservation and intercutting at the Bishopsmill site (Johnson, 2005, plate 8).

The population from the 7th-10th century Bishopsmill cemetery has been included in many Master's dissertations since it was excavated, most of which draw comparisons between it and the 6th-century Norton cemetery, East Mills. These conclude that the individuals from Bishopsmill were a distinct population from those at East Mills due to their distinguishable non-metric traits (Valme, 2012). Their diet was different, containing more rich and aquatic foods, resulting in lower rates of metabolic conditions and higher rates of dental disease (Hillman, 2013; Fotaki, 2012; Usher, 2012; Valme, 2012). One study by Groves compared both Norton cemeteries to those of Bamburgh (section 5.4.1) and Castledyke in Lincolnshire, examining signs of musculoskeletal stress alongside the type and number of grave goods. Groves concluded that the Bishopsmill cemetery was dissimilar to the rest in that the individuals with the lowest physical stress tended to be buried without grave goods, whereas it was more standard for those without grave goods to exhibit more evidence of physical labour (Groves, 2006). One individual – labelled NO3423, though this number does not correspond to any individual in the original report – was also included in the aDNA study summarised in section 5.4.2, and found to be distinct from Roman and Iron Age populations from York (Martiniano et al. 2016). However, it should be noted that the full sample size only consisted of 7 Romans and 1 Iron Age individual, in addition to the individual from Bishopsmill, so the results should be regarded as tentative. The funerary style of the Bishopsmill cemetery has also been studied. For example, Solange Bohling (2020) compared early medieval cemeteries across England for her Master's dissertation, and found that burial rites for disabled individuals differed very little from those who were able bodied. In addition, Elizabeth Craig's PhD thesis (2010) examined middle Saxon cemeteries from northern England to show great variability in funerary rites in contrast to the burial style in southern England which had previously been thought uniform across the country. Craig (2010) also mentions the uniquely northern early medieval practise of chest burials. She later explored this in more depth in a paper which finds individuals buried in domestic chests were more likely to show signs of extreme mechanical stress and trauma, including those from Bishopsmill (Craig-Atkins, 2012).

Skeleton	Radiocarbon age years BP	Calibrated range
190	1225±65	660-790 AD

Table 5.4.3: Radiocarbon date for the individual from Bishopsmill included in the dataset of this thesis. Data from Johnson (2005).

5.4.4 Norton, East Mills

The other early medieval cemetery in Norton-on-Tees, was earlier in both date of use and excavation than the cemetery at Bishopsmill. The large cemetery was discovered accidentally in 1982 when children found bones eroding from the bank of a hollow-way, Mill Lane. That skeleton, G1, was excavated by police and subsequently confirmed to be of early 6th-century AD date by archaeologists who examined the beads recovered from the grave. CCAS carried out a geophysical survey in the playing-field in 1983. Trial trenches were dug in 1984 in the immediate vicinity of G1 and in random locations across the field to determine the extent of the burials. This was followed by an open area excavation across 1984-5, which was conducted by hand due to the shallow nature of the burials and the disarticulated bone scattered throughout the topsoil as a result of past agricultural activity. In total the excavations uncovered 117 inhumation graves and 3 cremation burials. They determined that the limits of the cemetery were represented by Roman field boundary ditches in the south and west, the marsh in the east, and the bank down to the hollow-way in the north. It is therefore likely that all burials from the site were recovered in the 1982-5 excavations, though there is of course the possibility that prior erosion in the bank of the hollow-way revealed more skeletons that were not subject to any official recording. The skeletal remains of 125 individuals were recovered, 121 of those from the inhumation graves. Several instances of double burials were excavated, including two double burials of a child with an adult male, one of a young adult male with an adolescent female (Figure

5.4.14), and one of two adult females (similar to the Sewerby double burial discussed in section 5.4.6). The period of use of the cemetery was dated to approximately 520-620 AD, spanning roughly three generations of 30-40 people. Dating was performed by analysis of the grave goods, including weapons and brooches, but no radiocarbon dating has been subsequently attempted. The results of the excavation and a full grave catalogue including skeletal analysis were published in a monograph by CCAS (Sherlock and Welch, 1992).

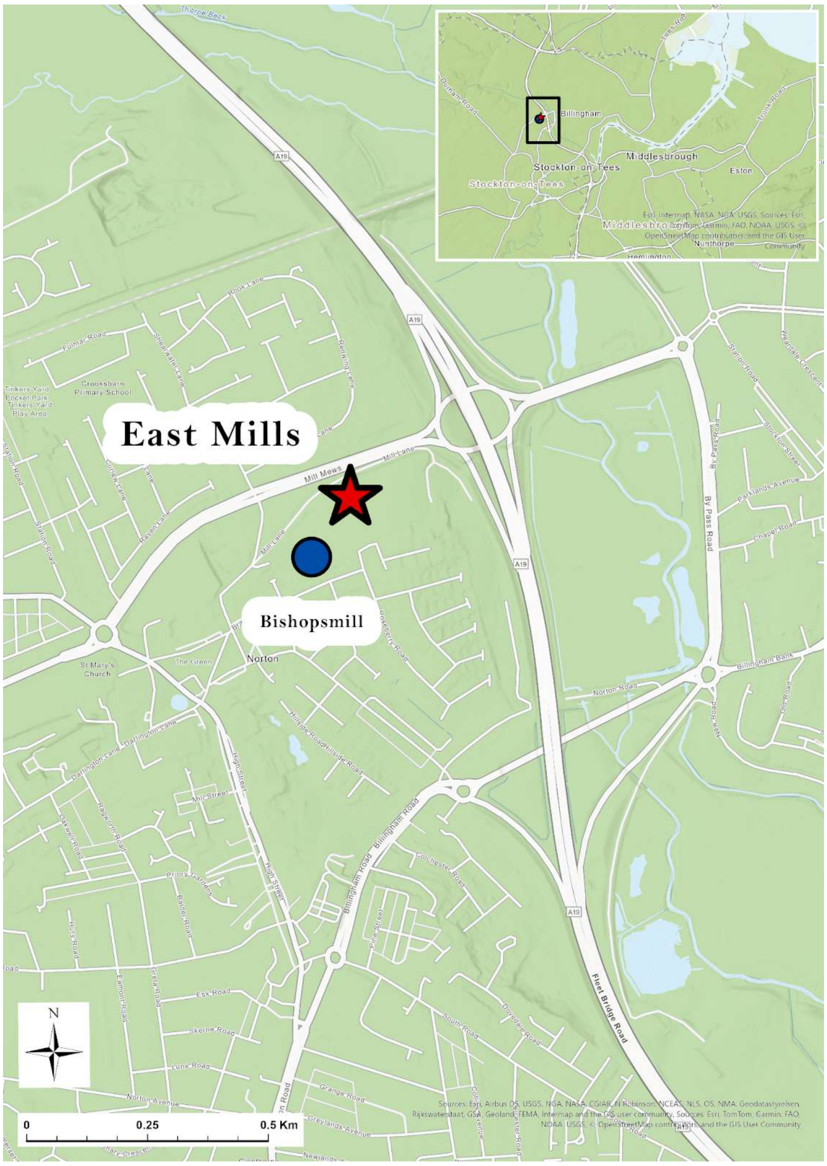


Figure 5.4.12: A more detailed map of the relationship between the Bishopsmill and East Mills cemeteries within Norton-on-Tees. Basemap Esri, 2025.

Figure 5.4.13: East Mills cemetery plan (Sherlock and Welch, 1992, 11).

The analysis of the skeletal remains from Norton's East Mills cemetery was carried out by David Birkett and Sue Anderson of CCAS. The general state of preservation was poor due to the soil conditions, shallow depth of burial and disturbance from ploughing. Of the 117 inhumation graves, 11 contained no human remains, and only 44 of the 121 individuals identified were described as "anywhere near complete" (Sherlock and Welch, 1992, pp. 107). Eighty-four of the inhumation burials were recorded as adults, and 37 as non-adults. The cemetery had an unusual profile of non-adult mortality as the most common age at death was between 14 and 16 years of age, with only two individuals identified under the age of 2. This is perhaps an indication that perinates and infants were given differential burial treatment, but may also be due to the small bones being vulnerable in the acidic soil. It is unlikely that any infant burials were missed because excavation was conducted by hand. Among the adults, the majority were placed in either the Young Adult (18-25) category, or the Young Middle Adult (26-35) category, with only 12 determined to have died past the age of 35. The poor preservation of the assemblage did not seem to hinder the assessment of age or sex, as only 18 adults could not be more specifically aged, and only 15 could not be assigned a sex. While sex was also assigned based on grave goods wherever present, only the osteological sex was used in this thesis, from which 37 males and 35 females were identified. The site monograph contained a grave catalogue and a report on the skeletal pathologies, though neither of these were presented in a satisfactory amount of detail. It was particularly noted, however, that there was an unusually high prevalence of humeral septal apertures, indicating that the population was very interrelated.

Figure 5.4.14: Skeletons 57 and 58 (left and centre), interred as a double burial. Skeleton 59 (right) was in a separate grave cut (Sherlock and Welch, 1992, 24).

In the years since its excavation, the skeletal population from East Mills has been included in the above listed dissertations (Hillman, 2013; Usher, 2012; Valme, 2012), drawing comparisons between it and the cemetery at Bishopsmill. Degenerative joint disease in the East Mills assemblage alone was the subject of another Master's dissertation, which concluded the populations suffered a very high rate of joint disease, more so than contemporary populations (Geisel, 2013). The funerary style and layout of the cemetery was examined by Nick Stoodley (2011), who concluded that age in adults was less indicative of number and type of grave goods than in contemporary cemeteries. He also suggested that the burials were placed in four zones, each in use consecutively rather than simultaneously. Sayer and Wienhold (2013) contest the idea of four plots, however, having developed a method for statistically determining grave clustering, which supported the original suggestion (Sherlock and Welch, 1992) that an east and a west cluster were present, separated by a 5 metre wide north-south gap.

5.4.5 Pocklington, Burnby Lane

As previously discussed for the Yapham Road site (section 5.2.2), Pocklington sits in a valley bottom on the landward edge of the Yorkshire Wolds, 20 km east of York. It is surrounded by the arable land of the Vale of York to the west, and the chalk wolds to the east. Previous finds in the town have included a Neolithic arrowhead (Archaeology Data Service, 2023), a Roman coin hoard (Historic England, 2022b) and medieval settlement remains. The most significant finds in Pocklington date to the Iron Age, when at least two cemeteries were in use in the area which would later become the town. One of these, at The Mile, is not discussed in this thesis as it only contained Iron Age burials (Ponce and Holst, 2018). However the second, Burnby Lane, comprised four Bronze Age round barrows and 85 Iron Age square and circular barrows, with early medieval secondary burials inserted into the western barrow group (Stephens and Ware, 2020). The Burnby Lane site was excavated by MAP Archaeological Practice in 2015, in advance of planned building on the land, which was known from aerial photography to have archaeological features including numerous enclosures interpreted as barrows, and several linear features. Prior to excavation, geophysical survey and trial trenching confirmed the presence of a square barrow cemetery with inhumations. The 2015 excavation by MAP Archaeological Practice recovered 158 Iron Age and early medieval burials, with a further 6 recovered in a 2017 excavation, totalling 164 inhumations on the site. The excavations also recovered one early medieval cremation burial, and a quantity of disarticulated bone mostly found with the early medieval burials. Through analysis of the grave goods, including brooches and knives, and confirmation with radiocarbon dating, 41 of the burials were determined to date from the early medieval periods, specifically the 5th and 6th centuries (Caffell and Holst, 2022). However, the results of the radiocarbon dating programme were not included in the report and so cannot be included here.

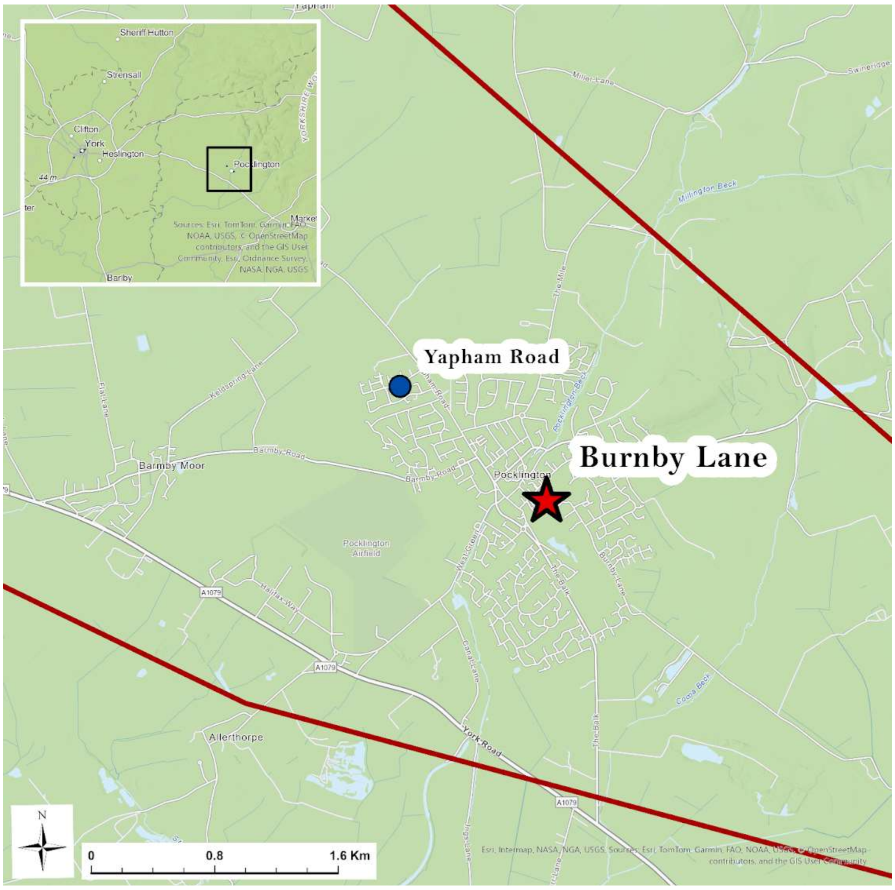


Figure 5.4.15: The location of the two case study sites within the modern town of Pocklington, and in relation to the approximate course of the Roman roads. Basemap Esri, 2025; Roman road data McCormick et al. 2013.

Post-excavation analysis of the remains was carried out by Anwen Caffell and Malin Holst of York Osteoarchaeology. Unlike the skeletons from Yapham Road in Pocklington discussed earlier (section 5.1.2), those from Burnby Lane showed a high degree of fragmentation and poor surface preservation due to plough damage and the acidic sandy soil. The majority were determined to have poor surface preservation and severe fragmentation, with completeness mostly falling between 40% and 60%, limiting the information that could be recorded for each individual. Despite this, most individuals were able to be assigned a sex and age category with only eight simply labelled as “18+”. The non-adults were represented by 11 individuals from mostly the older juvenile and adolescent categories, a similar distribution to that seen at Norton Bishopsmill, which may be due to different burial practices or poorer preservation for infant skeletons. The adult population, 30 individuals, was mostly comprised of those in the old middle adult and mature adult categories. Distribution of males and females was roughly equal, though 7 of the 30 adults were not able to be assigned a sex. The results of this analysis and thorough notes on the pathologies identified on the bones are contained in an unpublished report available on the ADS (Caffell and Holst, 2022), with the report of the full excavation still pending. To date, the early medieval population of the site has only been the subject of one further study, which examined dietary isotopes in both the Iron Age and early medieval individuals. This revealed that both populations likely had very similar omnivorous terrestrial diets supplemented by fish from the local rivers (Fox, 2019).

5.4.6 Sewerby

The modern village of Sewerby is located on the coast of the East Riding of Yorkshire, on the southern edge of the Flamborough Headland and north of Bridlington. It is part of the Great Wold Valley, the area surrounding the Gypsey Race stream which rises on the Yorkshire Wolds and meets the sea at Bridlington. The area has sites and finds from a variety of periods, including a Neolithic axe (Yorkshire Archaeological Journal, 1964 pp. 165), Bronze Age barrows (Humber HER numbers 559 and 567) and Roman villas (Allen et al. 2018). There is no evidence of occupation during the period of use of the cemetery, except for a single pot sherd described as Anglo-Saxon. Finds from the medieval predecessor to the current village have been scarce, though it is recorded in the Domesday Book of 1086 (Brigham et al. 2008). The cemetery was discovered by construction workers in 1958, leading to an excavation led by Philip Rahtz in 1959 which recorded 38 graves; there were a total of 49 when added to those irreparably damaged by the construction. In 1974 a further excavation adjoining the original was conducted under the supervision of Susan Hirst in preparation for more construction work. This recorded 10 more graves, giving a total of 59, though the limits of the cemetery were never determined so those recovered represent an unknown proportion of the full population. The style of the grave goods, including brooches, beads and shield bosses, and the variety in body position and orientation determines the cemetery’s 6th and 7th-century date. Both excavations and the subsequent analyses were published in a monograph written by Susan Hirst (1985).

Figure 5.4.16: The location of Sewerby within the modern landscape, and in relation to the Roman road system (red lines), and other case study sites for this thesis. Basemap Esri, 2025; Roman road data McCormick et al. 2013.

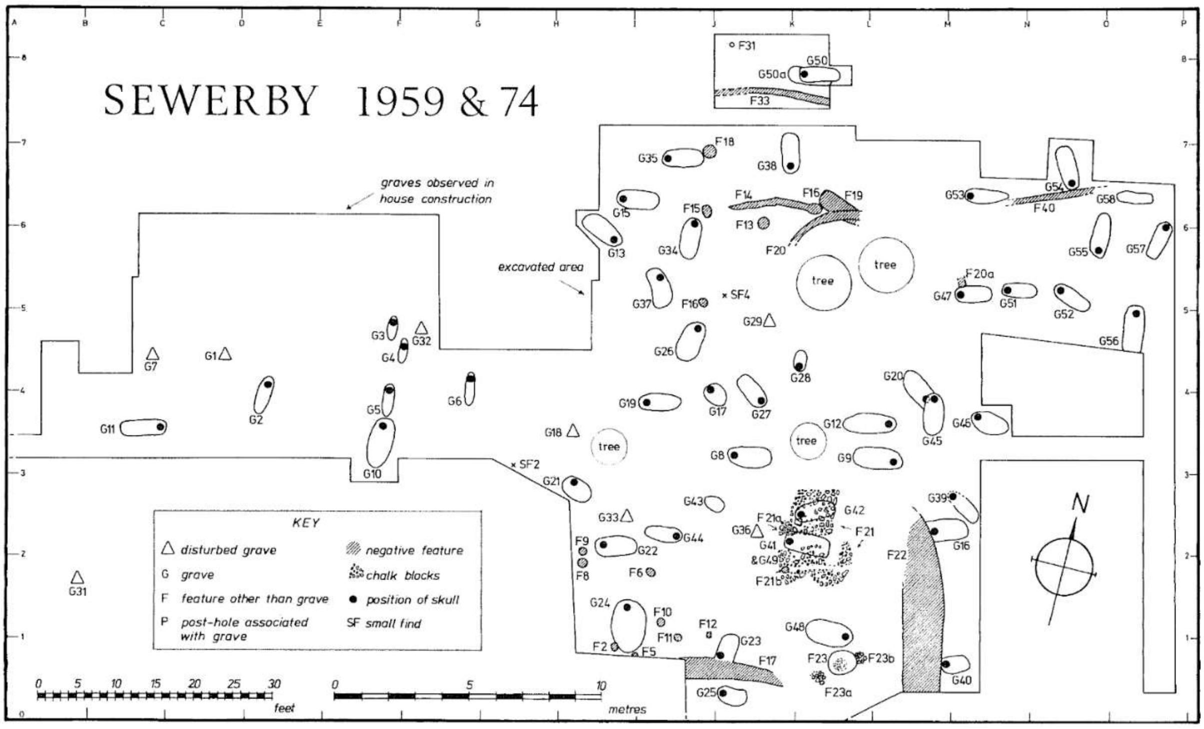


Figure 5.4.17: Plan of the excavations at Sewerby showing the locations of the burials (Hirst, 1985, 26).

Following the 1959 excavation, some of the skeletal remains were examined by Don Brothwell. The rest of the assemblage, including the individuals excavated in 1974 were examined by Justine Bayley. There is little information to be gleaned from either the short section on the human bone printed in the site monograph (Hirst, 1985) or the full report by Bayley and Brothwell included on microfiche. This is due to poor preservation from soil conditions, damage from farming activity, and the fact they were examined in an uncleaned state. The original 11 discovered during the construction work have even less information available, having been disposed of by the construction workers, with only vague notes made such as "humerus only" and "said to be heads to north" (Hirst, 1985, Table 1). From the information recorded it is unclear how age, sex and social status may have affected the distribution of burials, especially as the extent of the cemetery is not known. Interestingly, however, the three prone burials discovered were all determined to be female.

There have been few studies looking at the Sewerby population in depth since its discovery, despite the scarcity of large 6th-century cemeteries in the area. The cemetery has been used as part of a larger dataset a few times, with both Whitehouse (2017) and Harrington et al. (2020) discussing early medieval funerary practices, while Buckberry (2004) compares early and late Anglo-Saxon funerary ritual and expression of status. More prevalent have been disagreements on what Hirst describes as "the live burial". She interpreted Grave 41 in this way as the skeleton was prone, both arms bent so the hands were roughly at shoulder level, and the right leg was flexed at the knee so the foot was only just below the ground surface (Figure 5.4.18). A partial quernstone was placed on top of the pelvis, supposedly to hold the individual down. Grave 41 was also the upper of a double burial, being directly above Grave 49 with no evidence of recutting in the grave edges. Hirst combines the unusual position and double grave to produce the theory that the older individual of Grave 41 had in some way wronged that of Grave 49, and been punished for it. Subsequently, this interpretation has been challenged in a number of reviews. Grainger (1986) argued that the simplest way to escape would be to rise onto hands and knees, not bending one foot upwards, and that the fragment of quernstone could not have been sufficient to stop a person doing so. He also noted that the torso of the individual was fully extended, showing no signs of the lateral movement which would have been possible even under a truly heavy weight, an idea which was repeated by Reynolds (1988). The small size of the quernstone fragment was also highlighted by Boddington (1987), who provided the alternate theories that the individual could either have been buried carelessly, or slumped in the grave as the lower burial decayed and collapsed, to explain the unusual position. Another suggestion was that the individual was killed by fire, the heat causing muscles to contract and contort the body (Anderson, 1994). This focused debate over the 'live burial' has resulted in the neglect of the potential well of information presented by the large 6th-century assemblage, an unusual resource for the area.

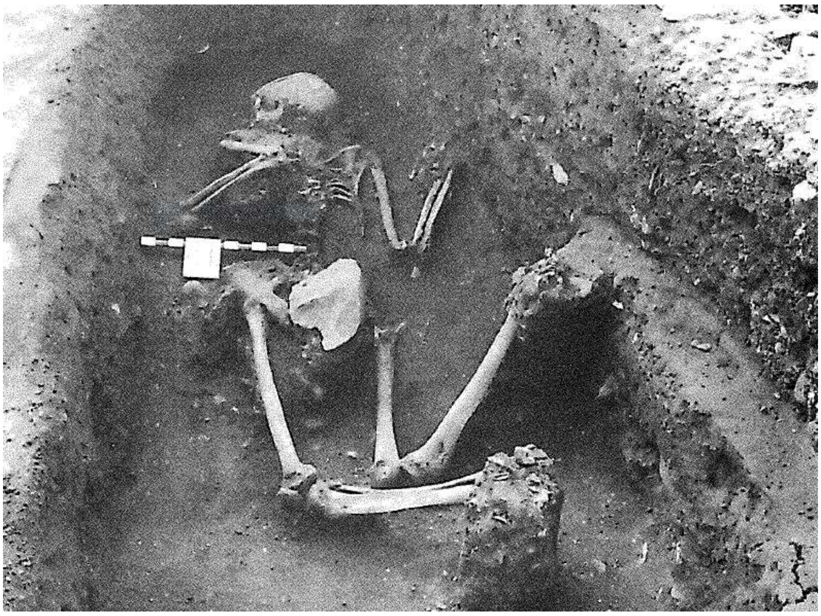


Figure 5.4.18: The so-called “live burial”, showing the unusual body position and broken quernstone (Hirst 1985, plate IIb).

5.4.7 West Heslerton

West Heslerton is a village in North Yorkshire on the northern edge of the Yorkshire Wolds, about 13 km east of Malton. The modern village is about 1 km west of the site of the Anglian cemetery. It sits on a band of sand and gravel that forms the border between the Wolds and the Vale of Pickering, the flat and fertile area surrounding the River Derwent. The Vale has a long history of human occupation, the earliest known settlement being the famous Mesolithic site at Star Carr, 13 km to the east (Milner et al. 2018). Evidence of Mesolithic occupation has also been found in the West Heslerton cemetery site itself, in addition to a Neolithic and Bronze Age ritual landscape comprised of timber circles and a barrow cemetery, likely located purposely on the slight chalky hill (Powlesland et al. 1986). Iron Age and Roman activity on the site is only represented by a pit alignment and trackway, with settlement at this time found about 2 km east of the cemetery area. The site was originally discovered in 1977 when human remains were found during quarrying activity. The salvage excavation performed by Humberside Archaeological Unit uncovered 36 inhumations. Further excavations were necessitated by continued quarrying from 1978-1987, and these were undertaken by The Landscape Research Centre under the direction of Dominic Powlesland, and uncovered a further 158 inhumations, 15 cremations and one horse burial. Out of a total 194 human inhumation burials, the grave good assemblages including brooches and weapons, and stratigraphic relationships determined that 185 were from the Anglian period, likely interred between 475 AD and 650 AD. During these excavations, the boundaries of the cemetery were found on all sides, but around 25% of the site was covered by road and therefore inaccessible for study. The results of the cemetery excavation and skeletal assessment were published by Powlesland and colleagues in a two-volume monograph (Haughton and Powlesland, 1999), and the extensive excavations over the rest of the parish have been relayed in numerous reports (e.g. Powlesland et al. 1986; Powlesland, 2003; Powlesland, 2004; Powlesland, 2012).

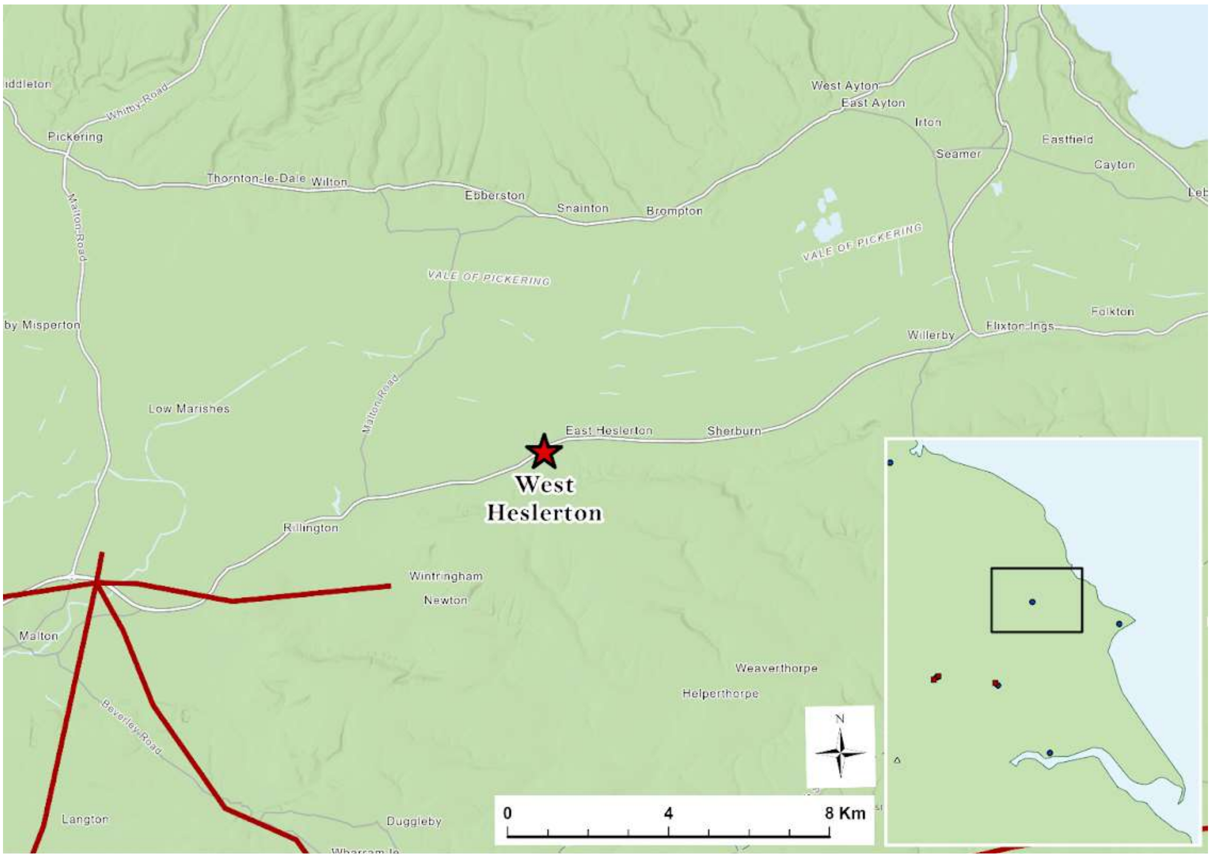


Figure 5.4.19: The location of West Heslerton within the Vale of Pickering, in relation to the Roman road system. Basemap Esri, 2025; Roman road data McCormick et al. 2013.

Osteological analysis of the first 50 skeletons to be recovered was conducted by Jean Dawes, a nurse, and the full assemblage, including those 50, were later analysed by Margaret Cox. However, in the site monograph, only the report by Cox is included as the assessments were very similar for each skeleton examined twice. Overall, the skeletal assemblage from West Heslerton was very poorly preserved due to the site's chalky and sandy nature, compounded by plough damage, quarrying, and theft. As a result, 16% of graves were completely void of any human remains and a further 34% containing only fragments of teeth and bone. The eroded and fragmentary condition of the remains meant that 55 individuals could not be sorted into broad adult and juvenile groups, with 99 Anglian burials determined to be adults. Of these, 42 could not be assigned a sex even tentatively, 33 were either female or probably female and 24 either male or probably male. It was suggested by Haughton and Powlesland that a small number of burials could be grouped together as they were taller and more gracile than the majority, and their graves were furnished with weapons.

Figure 5.4.20: Plan of the excavations at West Heslerton, showing the early medieval graves in relation to the prehistoric activity on the site. (Haughton and Powlesland, 1999)

The skeletal assemblage and burial customs have been subsequently studied many times. Williams (2007) examined the funerary style and concluded that the deposition of weapons in graves represented an emotive act by a mourner and did not necessarily have a connection to the individual's position in life. The cemetery is used by Reynolds to support many of his observations of early medieval deviant burial customs, including the high proportion of prone burials in northeastern England and the typical shallow depth of said burials (Reynolds, 2009). Further commentary on burial practises includes the doctoral thesis of Buckberry (2000), who noted that West Heslerton was the only known example of juveniles being buried away from the main cemetery during the early medieval period, and Sayer (2020) who argued that the clustering of burials was linked to status, as reflected in the number and style of grave goods interred with each individual. Isotopic analysis of the population revealed immigration throughout the period of use of the cemetery, with juveniles and adults, males and females represented in the immigrant population, which the authors suggested shows a migration stream not an invasion (Montgomery et al. 2005). Gretzinger and colleagues analysed the aDNA of early medieval populations from across Western Europe, including 42 individuals from West Heslerton. They concluded that 75% of the population from West Heslerton were almost entirely of continental northern European ancestry, in accord with the other populations analysed, which demonstrated increasing continental northern European ancestry in the south and east of England during the early medieval period (Gretzinger et al., 2022). Finally, 33 early medieval individuals, as well as three Bronze Age and five Iron Age individuals from West Heslerton were included in the study of lead isotopes by Budd and colleagues (section 5.4.1).

5.4.8 York, Queen's Hotel

The Queen's Hotel, after which this site is named, was an 18th-century building demolished in 1973, standing on the corner of Micklegate and Skeldergate in York city centre, close to the west bank of the River Ouse. As discussed above (section 5.2.3), York was originally established as *Eboracum*, a Roman fort and associated civilian settlement, later attaining the status of *colonia* (Crabtree, 2018). In the 5th and 6th centuries, the city was mostly abandoned, before being repopulated as *Eorforwic* in the 7th century, with the inhumations at the Queen's Hotel site the earliest known post-Roman burials in the city (Mainman, 2019).

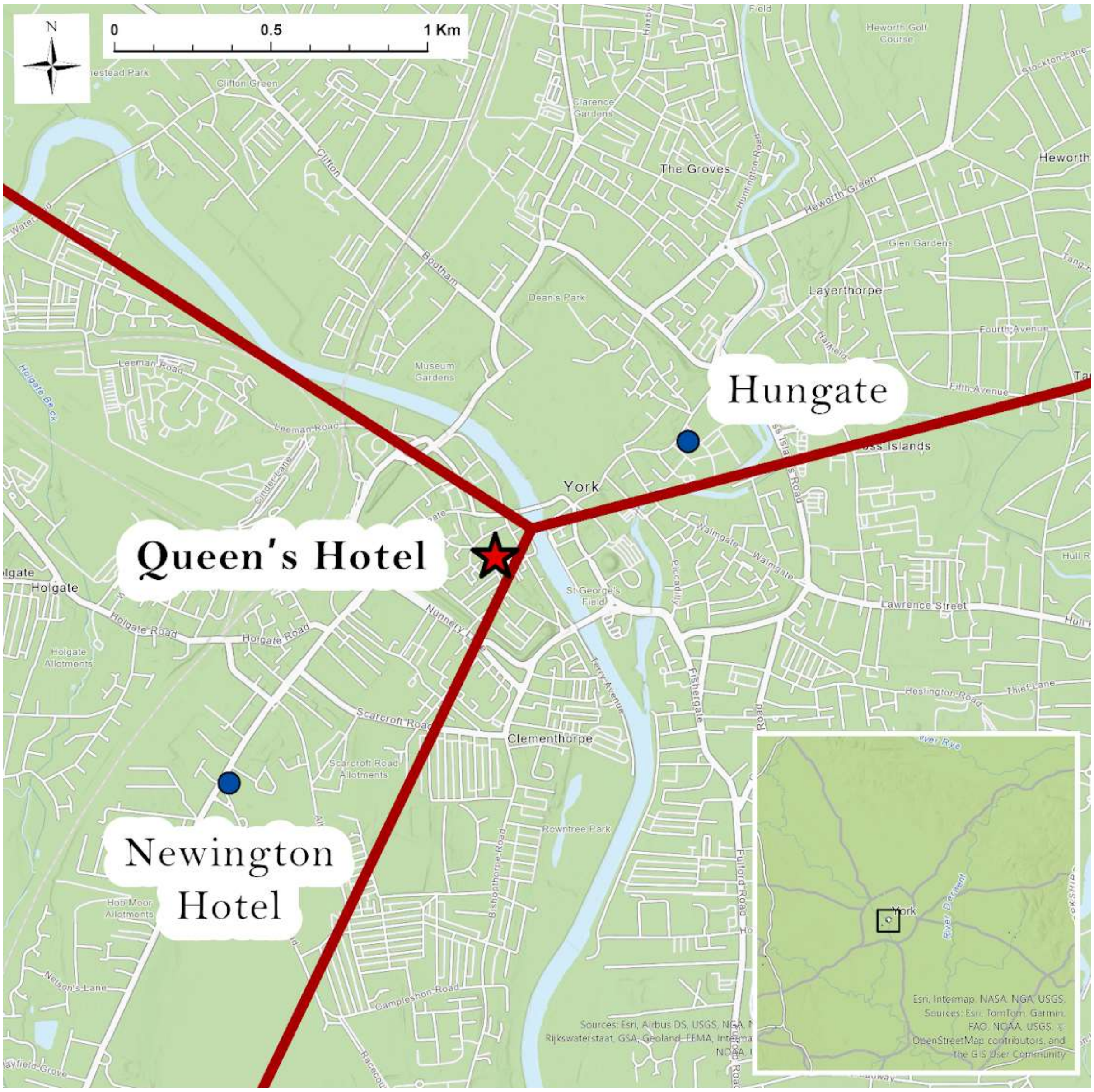


Figure 5.4.21: The location of the Queen's Hotel site within the modern city of York, in relation to the approximate location of the Roman roads approaching the city (red lines). Basemap Esri, 2025; Roman road data McCormick et al. 2013.

Due to the site's location in the heart of a city known for its millennia long history, it was left empty for over a decade after the demolition while negotiations ensued between archaeologists and prospective developers. Eventually, in 1988, York Archaeological Trust was able to conduct a watching brief as the top layers of demolition rubble, and successive layers of occupation dating back to the 10th century were removed (Brann, 1988). The 10th- and 11th-century remains corresponded to the Viking occupation of the city, and were subject to a more thorough excavation between 1988-89. It was found that some of the structures were cut into post-Roman and Roman features, entirely rearranging the previous street plan and creating the property boundaries seen in the 1852 Ordnance Survey map several centuries later. The post-Roman evidence consisted of a layer of grey soil over the demolition debris from the Roman buildings, with numerous pits and stake holes cut into it, and a row of post holes cut into the top of a substantial Roman wall. A subsequent programme of radiocarbon dating determined that this activity dated to the early-7th century, with a complete lack of evidence for occupation over the 5th and 6th centuries (Petts, 2016). Excavation continued to a depth of 7.5 metres below the modern street level, uncovering a substantial rectilinear Roman building with walls over a metre thick, surviving more than three metres high in some places. The sheer size of the structure led to the suggestion that it was from an important public building, perhaps the forum or a bathhouse, in the *Colonia*. The original interim reports from York Archaeological Trust mention three human skeletons which were found in the layer of grey soil, resting against the Roman wall, with no visible grave cuts suggesting they had simply been dumped there (Brann, 1989). However, later discussions of the site (e.g. Petts, 2016; McComish, 2015; Tweddle, 1999) mention four burials, and the osteological report (Keefe and Holst, 2016) discusses four burials and one disarticulated cranium, and it appears that this discrepancy in numbers originates from an error in the initial report.

The skeletal assemblage from Queen's Hotel was examined by Katie Keefe and Malin Holst of York Osteoarchaeology. The preservation of the bones was generally found to be poor or very poor, with a moderate degree of fragmentation. All four articulated skeletons were determined to be adults at the time of their deaths, and all were assigned a sex: two males and two females. The disarticulated skull was determined to be from an adult female individual (SK 7161), but was not included in this study due to the incomplete nature of the burial and accompanying lack of context. The burials were radiocarbon dated to the 7th century AD (Table 5.4.4), in agreement with the stratigraphic chronology of the site. No further studies have utilised the human remains from the Queen's Hotel site, despite their important position in the history of the city of York and the wider area.

Skeleton number	**Radiocarbon age years BP**	**Calibrated range**
6064	1305±18	661-722 AD
7118	1398±18	614-662 AD
7137	1405±18	609-660 AD
7147	1305±18	661-722 AD

Table 5.4.4: Radiocarbon dates for the individuals from Queen's Hotel included in this thesis. Data from York Historic Environment Record (2012).

Chapter 6: Results from the compilation of literature

This chapter lays out the results of the analysis of the data collected from existing osteological reports on the case study sites. All of the individuals selected from both published and grey literature for this thesis were those who had been determined to be adults over the age of 18 at the time of their death. In total, the full dataset comprised 656 individuals: 263 Roman and 393 early medieval. This chapter will examine the distribution of sex and age at death, and the prevalence of each pathology in turn. The prevalence of each pathology will be compared between the time periods, and further compared based on sex, age at death, and settlement type, in order to discover which factors impacted the health of the populations from northern England at this time.

The prevalence of a condition in a skeletal assemblage is typically calculated in two ways: crude prevalence and true prevalence. Crude prevalence is the percentage of individuals with the pathology out of the full number of individuals in the skeletal assemblage. True prevalence is the percentage of skeletal elements presenting a condition out of the total number of those elements present in the assemblage (Powers, 2012). In this work, as the osteological information reported in the monographs, specialist reports and grey literature was so varied in its detail and specificity, true prevalence will be calculated as the percentage of individuals with a pathology out of the number of individuals with the necessary skeletal element preserved, because information on the level of separate skeletal elements in each individual was not available for the majority of case study sites. This modified true prevalence will allow maximum use of the dataset available, while accounting for the poor skeletal preservation inherent to the region, which had a widespread negative effect on the osteological analysis.

6.1 Age distribution

Only individuals determined to be adults over the age of 18 at the time of their death were chosen to be included in the compiled dataset for this work. All individuals were assigned to the standardised age categories developed by Falys and Lewis (2011), with the decisions taken on individuals originally assigned to non-standard categories described in section 4.2. Briefly, the categories are:

- Young Adult (YA) 18-25
- Young Middle Adult (YMA) 26-35
- Old Middle Adult (OMA) 36-45
- Mature Adult (MA) 46+
- Adult (A) 18+

The most abundant age category was Young Middle Adult, of which there were 188 individuals, 28.7% of the full assemblage. The next most populous category was Adult; for those who were not preserved well enough to determine a more specific age at death. There were 176 individuals in the Adult category, 26.8% of the dataset. Young Adult was the next largest with 103 individuals (15.7%), then Mature Adult with 102 individuals (15.5%). Finally, Old Middle Adult had the fewest individuals with only 87, or 13.3% of the full dataset. This distribution presented an uneven profile for survival in adulthood, with the greatest peak in age at death between 26 and 35 years of age, and a subsequent slight peak in those who lived more than 46 years (Figure 6.1.1), deviating from the standard attritional model in which the greatest numbers of individuals die as either infants or older adults.

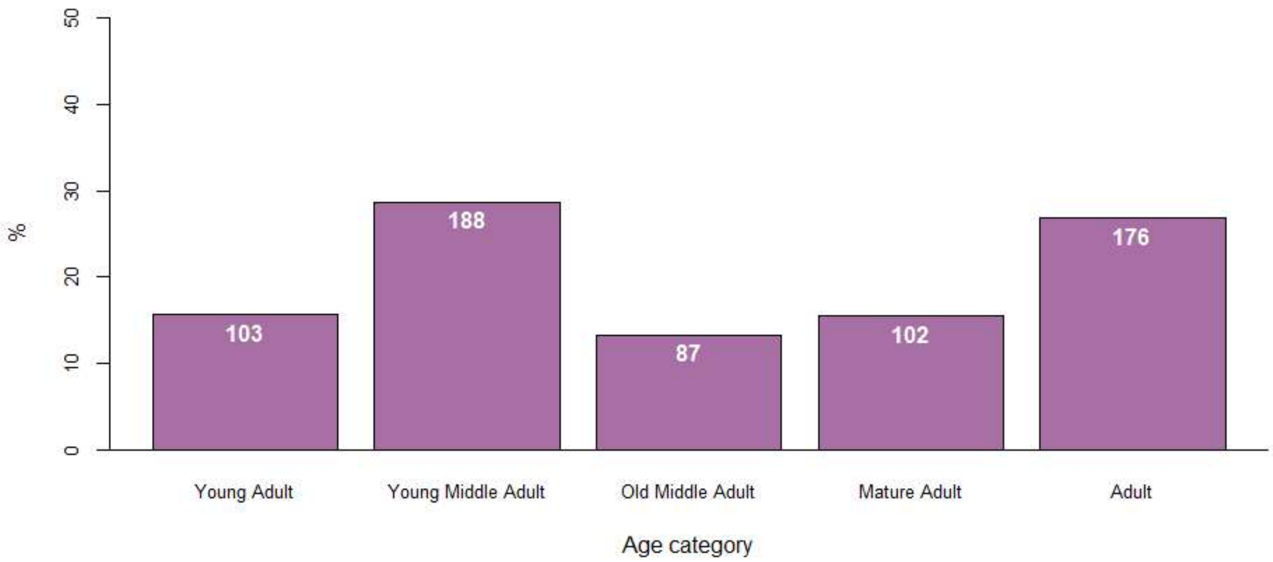


Figure 6.1.1: The percentage of individuals from the full dataset assigned to each age category. Bar labels give the number of individuals in the category.

6.1.1 Inter-period comparison of age-at-death

Assessing the age at death within each time period revealed broadly similar mortality profiles, though a greater proportion of individuals were assigned to the Young Adult and Young Middle Adult categories in the early medieval period. For the Roman period, the most common category was Adult, those who were not able to be assigned a more specific age due to taphonomic damage, with 78 individuals out of 263 total (29.7%). When discounting this group, the most common age at death in the Roman population was Young Middle Adult, with 68 individuals dying between the ages of 26 and 35 (25.9%). The Young Adult, Old Middle Adult, and Mature Adult categories all had 39 individuals assigned to them, each 14.8% of the Roman population. Similarly, the early medieval assemblage had the most individuals assigned to the Young Middle Adult category, with 120 (30.5%), a greater number than those simply labelled Adult of which there were 98 individuals (24.9%). Young Adult and Mature Adult were the next largest categories with 64 and 63 individuals respectively (16.3% and 16%). The early medieval assemblage had the fewest individuals assigned to the Old Middle Adult category, with 48 thought to have died between 36 and 45 years of age (12.2%). It can be seen that a smaller percentage of Roman period individuals were in the Young Adult and Young Middle Adult categories compared to early medieval people, implying that those who survived to adulthood in Roman Britain were more likely to live into older age, whereas the early medieval people would likely die in younger adulthood. This is supported by the greater percentage of Roman individuals in the Old Middle Adult category compared to early medieval individuals (Table 6.1.1, Figure 6.1.2). This association between the time period and the different distributions of age at death was determined to be significant by Pearson's Chi-squared test ($p < 0.05$).

Period	**YA 18-25**		**YMA 26-35**		**OMA 36-45**		**MA 46+**		**A 18+**		**All**
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**
Roman	39	14.8	68	25.9	39	14.8	39	14.8	78	29.7	263
Early medieval	64	16.3	120	30.5	48	12.2	63	16.0	98	24.9	393
All	103	15.7	188	28.7	87	13.3	102	15.5	176	26.8	656

Table 6.1.1: The number (N) and percentage of individuals in each age category within each time period, and in the full dataset.

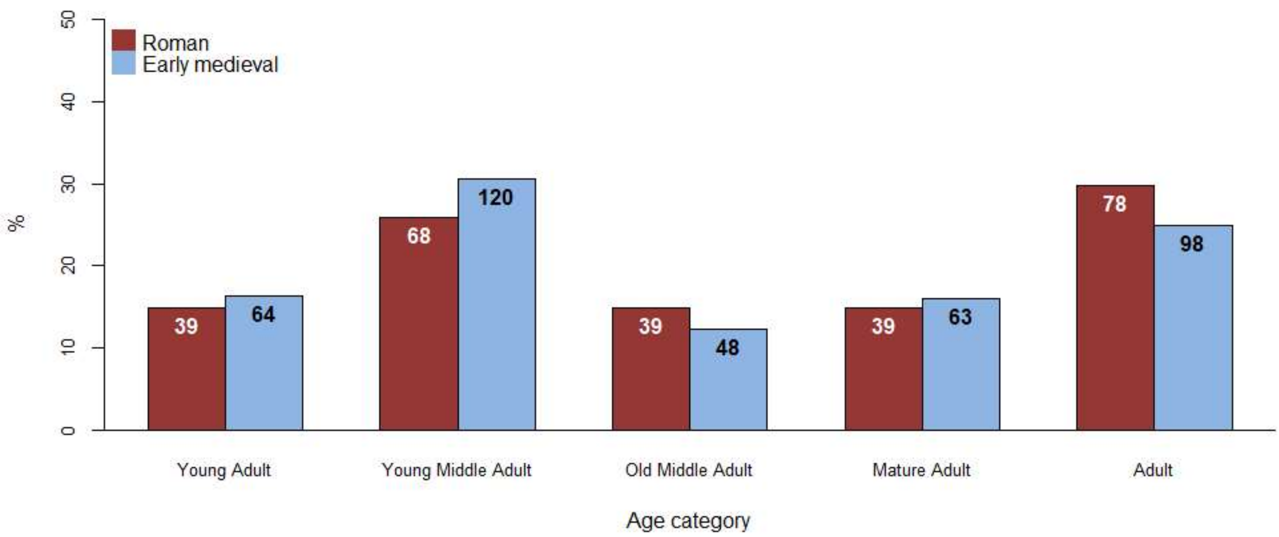


Figure 6.1.2: The percentage of individuals from each time period assigned to each age category. Bar labels give the number of individuals in the category.

6.2 Sex distribution

All 656 individuals included in the dataset compiled for this thesis were determined to have been adults over the age of 18 at the time of their death, meaning sex determination was attempted in all cases. Due to the poor preservation and high degree of fragmentation of individuals from all sites included, determination of sex was not always successful, so the greatest number of individuals, 203 (30.9%), were simply labelled as undetermined. There were 165 individual skeletons confidently assessed as male (25.2%), and 142 confidently assigned to the female category (21.6%). There were also numerous individuals who showed more ambiguous indicators for either sex: 82 were described as probable male (12.5%), and 62 were probable female (9.5%). In addition to these standard categories, two individuals were recorded as being of indeterminate sex as they were well preserved for analysis, but presented such ambiguity in their indicators of sex that they could not be otherwise grouped. The male and probable male, female and probable female, and undetermined and indeterminate categories were combined for the further analysis of the interactions between biological sex and health in life. This showed approximately 37.7% of individuals were male, compared to 31.1% female and 31.3% of undetermined sex. Hence an imbalance towards the males was revealed (Table 6.2.1).

6.2.1 Inter-period comparison of sex ratio

When separating the sample by period it became clear that the disparity in sex was entirely due to the Roman population. Combining the 'male' and 'probable male' categories, and 'female' and 'probable female' categories again for the Roman period skeletons revealed a total of 112 males (42.6% of all Roman period individuals) compared to only 69 females (26.2%). The early medieval population, by contrast, had an exactly even split of males and females with 135 (34.4%) of each. Human populations naturally tend towards a slight preponderance of males (Ritchie and Roser, 2019), with the much greater preponderance of males in the Roman period assemblages indicating the presence of some divide in the treatment of males and females either before or after death. The percentage of individuals that were of unassigned sex was roughly equal in each population at 30.8% for the Roman group and 31.0% for the early medieval group, making it unlikely that enough Roman females were missed in analysis to cause the great disparity in sex ratios.

Assigned sex	Roman		Early medieval		All	
	N	%	N	%	N	%
Male	65	24.7	100	25.4	165	25.2
Probable male	47	17.9	35	8.9	82	12.5
Indeterminate	1	0.4	1	0.3	2	0.3
Probable female	24	9.1	38	9.7	62	9.5
Female	45	17.1	97	24.7	142	21.6
Undetermined	81	30.8	122	31.0	203	30.9
All	263	100	393	100	656	100

Table 6.2.1: The number (N) and percentage of individuals assigned to each sex category within the full dataset and separated by time period.

6.2.2 Inter-sex comparison of age-at-death

The age at death was compared for each sex (Figure 6.2.1), to discover whether the mortality profile differed between males and females. Within the full dataset spanning both time periods, there was little difference between the percentage of males and females within each age category, indicating mortality did not differ based on sex. Slight differences appear in some categories when considering the periods separately. In the Roman period, a greater percentage of males were found to have died between the ages of 18 and 25 than that of females, while a greater percentage of females died after the age of 46. In the early medieval populations, a slightly greater percentage of females were assigned to the Young Adult category, while the other age categories were evenly populated by the sexes. However, there was not determined to be any overall significance to associations between sex and age at death in either period, when assessed by Pearson's Chi-squared test ($p > 0.05$). The only significant association as determined by Pearson's Chi-squared test was that between individuals of undetermined sex and the Adult category. This link is simple: those who were not preserved well enough to assign a sex were also not preserved well enough for an accurate age assessment. This connection was maintained when considering the Roman and early medieval populations separately (Figure 6.2.2); 68.3% (56/82) of Romans of undetermined sex and 61.8% (76/123) of early medieval people of undetermined sex were assigned to the Adult category (Table 6.2.2).

Period	Sex	YA 18-25		YMA 26-35		OMA 36-45		MA 46+		A 18+		All
		N	%	N	%	N	%	N	%	N	%	N
Roman	Male	16	14.3	39	34.8	21	18.8	21	18.8	15	13.4	112
	Female	7	10.1	22	31.9	15	21.7	18	26.1	7	10.1	69
	Undet.	16	19.5	7	8.5	3	3.7	0	0.0	56	68.3	82
Early medieval	Male	21	15.6	50	37.0	22	16.3	30	22.2	12	8.9	135
	Female	26	19.3	53	39.3	18	13.3	28	20.7	10	7.4	135
	Undet.	17	13.8	17	13.8	8	6.5	5	4.1	76	61.8	123
All	Male	37	15.0	89	36.0	43	17.4	51	20.6	27	10.9	247
	Female	33	16.2	75	36.8	33	16.2	46	22.5	17	8.3	204
	Undet.	33	16.1	24	11.7	11	5.4	5	2.4	132	64.4	205

Table 6.2.2: The number (N) and percentage of individuals of a certain sex and time period assigned to each age category.

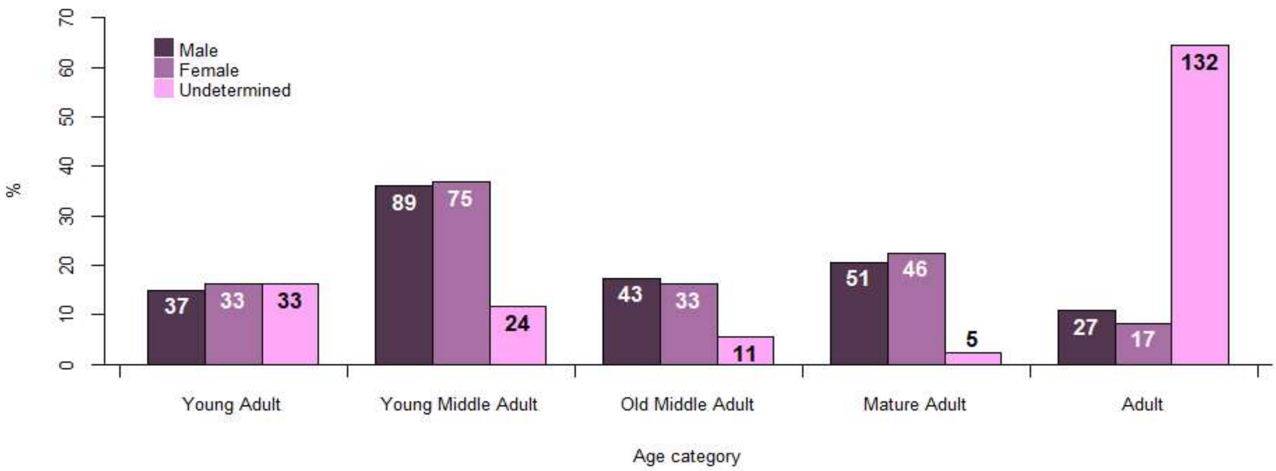


Figure 6.2.1: The percentage of individuals of each sex assigned to the different age categories. Bar labels give the number of individuals in the category.

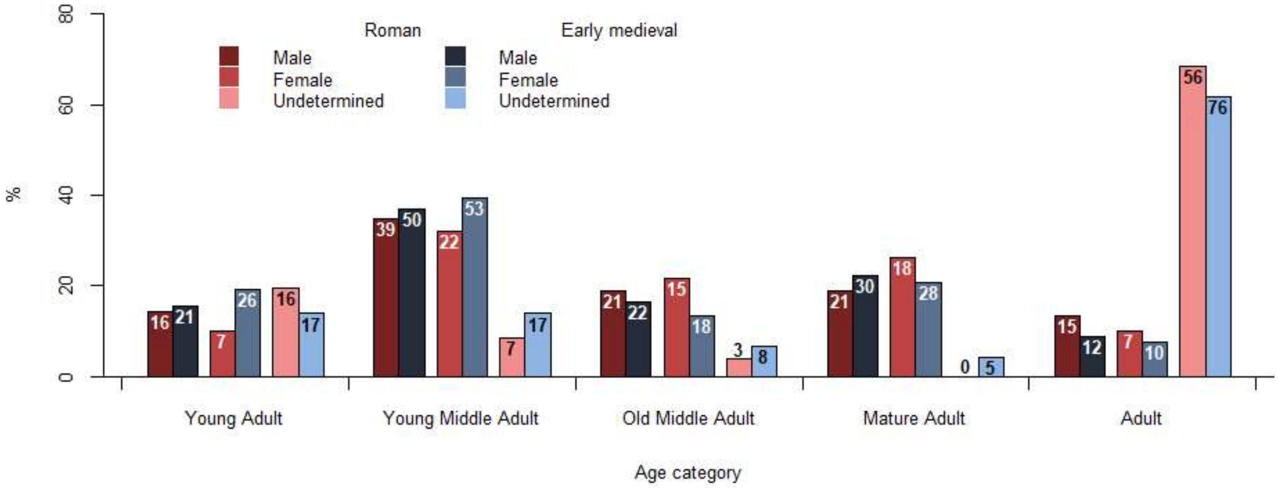


Figure 6.2.2: The percentage of individuals in each age category, when divided by sex and time period. Bar labels give the number of individuals in the category.

6.3 Cribra orbitalia

Within the total assemblage of 656 individuals, 68 were recorded to have cribra orbitalia. For this condition, the true prevalence was calculated as the number of individuals with cribra orbitalia recorded in either or both orbits, out of the number of individuals who had at least one orbit preserved to the necessary standard for assessment, because the condition was most often simply reported as either present or absent. A total of 291 individuals had neither orbit preserved well enough for observation of the condition, so the true prevalence of the condition was 18.6%, or 68 out of the remaining 365 (Table 6.3.1).

6.3.1 Inter-period comparison

The full aggregated dataset was divided by period to test the hypothesis that the societal change after the Roman withdrawal would have negatively impacted people's health. From the Roman period skeletons, 48 individuals of 263 total, or 151 with preserved orbits, showed characteristic signs of cribra orbitalia, a true prevalence of 31.8%. In contrast, only 20 skeletons from the 393 early medieval period individuals, 214 of which had at least one orbit, had cribra orbitalia, a true prevalence of 9.3%. This difference was determined to be significant by Pearson's Chi-squared test for association ($p < 0.05$), showing cribra orbitalia was a less common affliction in the early medieval period (Table 6.3.2).

Period	Total individuals (T)	Number of individuals with skeletal element (S)	Number of individuals with condition (N)	Crude prevalence (N/T)	True prevalence (N/S)
Roman	263	151	48	18.3%	31.8%
Early medieval	393	214	20	5.1%	9.3%
All	656	365	68	10.4%	18.6%

Table 6.3.1: The number of individuals with cribra orbitalia, and the prevalence of the condition, from the full dataset and in each time period.

	Roman		Early medieval	
	Present	Absent	Present	Absent
Observed	48	103	20	194
Expected	28	123	40	174
Adjusted residual	5.4	-5.4	-5.4	5.4

Table 6.3.2: The contingency table used in the Chi-squared test for association, with associated post hoc adjusted residual scores.

6.3.2 Inter-sex comparison

Further interrogation of the dataset was necessary to tease out potential connections between an individual's sex, age at death, geographic location and settlement type, and their likelihood of developing cribra orbitalia. Considering sex, it is known that males and females can experience different levels of susceptibility to different conditions, so it was necessary to test the amassed skeletal population for this to ensure that differing sex distributions between the time periods were not responsible for different rates of pathology. From the 247 males in the full dataset (Table 6.3.3), 35 were identified as having cribra orbitalia, a true prevalence of 20.1%. In the females, 27 out of 204 had the condition, a lower true prevalence of 17.2%. However this difference was not determined to be significant by Pearson's Chi-squared test for association ($p > 0.05$), indicating that broadly, sex did not impact the likelihood of the individuals from the case study sites developing cribra orbitalia. The prevalence of cribra orbitalia in those of undetermined sex was 17.6%, which was also not significantly different to either the males or the females, supporting the inference that sex had no impact on the development of the condition.

6.3.3 Intra-period sex comparison

When comparing the prevalence of cribra orbitalia by sex in each period separately, there was also determined to be no significant association of the condition with sex, demonstrating that the differing prevalence of cribra orbitalia between the periods was not created by the disparate sex ratios of each period. In the Roman males, the prevalence of the condition was 32.9%, and in Roman females it was slightly lower at 29.6%, which was not determined to be significant by Pearson's Chi-squared test ($p > 0.05$). Similarly, the association between prevalence of cribra orbitalia and sex in the early medieval males and females was found not to be significant by Pearson's Chi-squared test ($p > 0.05$), the true prevalence being 8.7% in the males, compared to 10.7% in the females. The individuals of undetermined sex had the highest prevalence of cribra orbitalia in the Roman period (33.3%) and the lowest in the early medieval period (5.3%), but neither of these represented enough of a difference from either of the other sex categories in the period that an association could be identified by Pearson's Chi-squared test ($p > 0.05$). Instead it is very likely the poorer preservation which had hindered the assignment of sex also impacted the identification of the condition, and the calculation of the true prevalence; 67 Romans and 104 early medieval people of undetermined sex did not have either orbit preserved.

6.3.4 Inter-period sex comparison

Considering the prevalence of cribra orbitalia across the time periods in each sex, it becomes clear that males and females were not uniformly affected by the societal changes. In males, the true prevalence of cribra orbitalia in the Roman period was 32.9%, whereas in early medieval males it was 8.7%. The large decrease in the condition in the early medieval period was determined to be significant by Pearson's Chi-squared test ($p < 0.05$). While the prevalence of cribra orbitalia decreased between the Roman and early medieval periods in both males and females, the association with time period in females was relatively smaller, with the true prevalence of the condition being 29.6% in the Roman females and 10.7% in those from the early medieval period. This was determined to be significant by Pearson's Chi-squared test ($p < 0.05$), though the adjusted standardised residual was smaller (3.0 for females, 4.0 for males; Table 6.3.4), showing that the deviation from the expected number of cases of cribra orbitalia in each time period was not as strong as it was in the males. Comparing those of undetermined sex revealed a large decrease across the time periods similar to that of the males; in the Roman period the true prevalence of cribra orbitalia in those of undetermined sex was 33.3%, and in the early medieval period it was 5.3%. However, only one early medieval individual of undetermined sex had the condition, meaning the numbers were not great enough to validate a Pearson's Chi-squared test. From the inter-period comparison within each sex it is clear that cribra orbitalia was much less common in the early medieval period, regardless of the sexes being compared. However, it should also be noted that the effect was not as striking in the females, indicating there were differences in the way people's lives were changed by the societal transition, and these differences were based on sex.

Period	Sex	Total individuals (T)	Number of individuals with skeletal element (S)	Number of individuals with condition (N)	Crude prevalence (N/T)	True prevalence (N/S)
Roman	Male	112	82	27	24.1%	32.9%
	Female	69	54	16	23.1%	29.6%
	Undet.	82	15	5	6.1%	33.3%
Early medieval	Male	135	92	8	5.9%	8.7%
	Female	135	103	11	8.1%	10.7%
	Undet.	123	19	1	0.8%	5.3%
All	Male	247	174	35	14.2%	20.1%
	Female	204	157	27	13.2%	17.2%
	Undet.	205	34	6	2.9%	17.6%

Table 6.3.3: The number of individuals of each sex with cribra orbitalia, from the full dataset and in each time period.

	Male				**Female**			
	Roman		Early medieval		Roman		Early medieval	
	Present	Absent	Present	Absent	Present	Absent	Present	Absent
Observed	27	55	8	84	16	38	11	92
Expected	16	66	19	73	9	45	18	85
Adjusted residual	4.0	-4.0	-4.0	4.0	3.0	-3.0	-3.0	3.0

Table 6.3.4: The contingency tables used in the Chi-squared test for association for the inter-period comparison of sex, with associated post hoc adjusted residual scores.

6.3.5 Inter-age category comparison

The skeletal assemblage was also divided into their assigned age at death categories (listed in section 6.2 above) to test for associations between the childhood stress represented by cribra orbitalia and adult longevity. This revealed apparent variation in the prevalence of cribra orbitalia between the age categories within the sample as a whole (Table 6.3.5), with the Old Middle Adult and Mature Adult categories presenting the greater prevalences of 25% (15/60) and 20.9% (18/86) respectively (Table 6.3.3). The prevalence of cribra orbitalia in Young middle Adults was 16.3% (20/123), closely followed by that of the Young Adult category at 15.8% (9/57). Those in the Adult category had a slightly lower true prevalence of cribra orbitalia, at 15.4% (6/39). The slight differences in the prevalence of cribra orbitalia between the age at death categories were not determined to be significant by Pearson's Chi-squared test for association ($p > 0.05$).

6.3.6 Intra-period age category comparison

The prevalence of cribra orbitalia in each age category was compared within each time period to ensure that any difference in the age-at-death profile between the periods was not responsible for the changing prevalence of cribra orbitalia. The lack of a significant association between age at death and the presence of cribra orbitalia persisted when each time period was considered separately. In the Roman assemblage the greatest prevalence of 38.7% (12/31) was seen in the Mature Adult category and the lowest prevalence in the Young Adult category at 25.0% (6/24). In the early medieval assemblage the prevalence of cribra orbitalia was highest in the Old Middle Adult category at 13.3% (4/30), whereas the lowest prevalence rate was found in the Adult category, where no cases were seen. While the Pearson's Chi-squared tests performed did not indicate any association between cribra orbitalia and age at death in either time period, the division of the dataset into so many small categories resulted in several groups having less than five cases, invalidating the Chi-squared test. However it can be seen that the prevalence of cribra orbitalia in each period was relatively similar across the age categories, with the difference seen between the two periods both within and between age categories.

Period	**Age at death**	**Total individuals (T)**	**Number of individuals with skeletal element (S)**	**Number of individuals with condition (N)**	**Crude prevalence (N/T)**	**True prevalence (N/S)**
Roman	YA 18-25	39	24	6	15.4%	25.0%
	YMA 26-35	68	49	13	19.1%	32.7%
	OMA 36-45	39	30	11	28.2%	36.7%
	MA 46+	39	31	12	30.8%	38.7%
	A 18+	78	17	6	7.7%	35.3%

Period	Age at death	Total individuals (T)	Number of individuals with skeletal element (S)	Number of individuals with condition (N)	Crude prevalence (N/T)	True prevalence (N/S)
Early medieval	YA 18-25	64	33	3	4.7%	9.1%
	YMA 26-35	120	74	7	5.8%	9.5%
	OMA 36-45	48	30	4	8.3%	13.3%
	MA 46+	63	55	6	9.5%	10.9%
	A 18+	98	22	0	0.0%	0.0%
All	YA 18-25	103	57	9	8.7%	15.8%
	YMA 26-35	188	123	20	10.6%	16.3%
	OMA 36-45	87	60	15	17.2%	25.0%
	MA 46+	102	86	18	17.6%	20.9%
	A 18+	176	39	6	3.4%	15.4%

Table 6.3.5: Number of individuals with cribra orbitalia in each age category, from the full dataset and in each time period.

6.3.7 Settlement type comparison

The type of settlement was also considered as a factor which could influence the amount of people who developed cribra orbitalia. While the populations of the early medieval period could not be considered for this, as all settlements of the 5th-7th centuries in the study area were small and rural in character, the Roman period sites were grouped into urban and rural to pinpoint health differences between town-dwellers and those of the countryside. The number of individuals from urban cemeteries was higher, at 221 compared to 42 from rural environments, a predictable result of greater population density creating larger cemeteries, and more frequent modern development in the same towns making their discovery more likely. Among the 48 Roman period individuals recorded as having cribra orbitalia, 42 were from the urban group of cemeteries and six from the rural group (Table 6.3.6). Considering the total population sizes and the number of individuals preserved well enough for assessment in those groups, the prevalences were similar, at 33.6% for the urban population and 23.1% for the rural. The slightly greater prevalence associated with the urban group was not determined to be a significant association when Pearson's Chi-square value was calculated ($p > 0.05$).

Settlement type	Total individuals (T)	Number of individuals with skeletal element (S)	Number of individuals with condition (N)	Crude prevalence (N/T)	True prevalence (N/S)
Urban	221	125	42	19.0%	33.6%
Rural	42	26	6	14.3%	23.1%

Table 6.3.6: Number of individuals with cribra orbitalia from the urban and rural cemeteries of the Roman period.

6.3.8 Summary of the findings for cribra orbitalia

Overall, the analysis of the collated data has shown that cribra orbitalia was a more common condition in the Roman period than the early medieval. This pattern prevailed regardless of sex and age at death. The character of the settlement was also not related, as urban and rural populations presented similar levels of cribra orbitalia.

6.4 Dental enamel hypoplasia

Considering the whole dataset of 656 individuals, it was seen that 203 individuals had an enamel defect in at least one of their teeth. The true prevalence for this condition was calculated as the number of individuals recorded to have dental enamel hypoplasia, out of the number of individuals who had at least one tooth preserved for analysis, because the condition was not often reported on a tooth-by-tooth basis. Of the full assemblage, 529 individuals had at least one tooth preserved for analysis, and so the true prevalence rate of dental enamel hypoplasia was 38.4% (Table 6.4.1).

6.4.1 Inter-period comparison

The Roman and early medieval populations were then considered separately to assess the potential change in prevalence of dental enamel hypoplasia over time. From the assemblage of 263 Roman individuals, or 215 with the required preservation, 131 were recorded as having the condition, a true prevalence of 60.9%, far higher than the prevalence from the total sample. In contrast, among the early medieval group of 393 individuals, 314 with preserved dentition, there was only a true prevalence rate of 22.9%, much lower than seen in either the full assemblage or the Roman period individuals (Table 6.4.1). The difference between the prevalence rates in the Roman and early medieval groups was determined to be significant by Pearson's Chi-squared test for association, showing that those living in the Roman period were more likely to develop dental enamel hypoplasia.

Period	Total individuals (T)	Number of individuals with skeletal element (S)	Number of individuals with condition (N)	Crude prevalence (N/T)	True prevalence (N/S)
Roman	263	215	131	49.8%	60.9%
Early medieval	393	314	72	18.3%	22.9%
All	656	529	203	30.9%	38.4%

Table 6.4.1: The number of individuals with dental enamel hypoplasia, and the prevalence of the condition in each time period and from the full dataset.

	Roman		**Early medieval**	
	Present	Absent	Present	Absent
Observed	131	84	72	242
Expected	83	132	120	194
Adjusted residual	8.8	-8.8	-8.8	8.8

Table 6.4.2: The contingency table used in the Chi-squared test for association, with associated post hoc adjusted residual scores.

6.4.2 Inter-sex comparison

Sex was tested to examine its association with the development of dental enamel hypoplasia during childhood, as it can influence susceptibility to stress and also impacts the treatment of an individual within society. Among the dataset as a whole, there were 247 individuals determined to be male, of which 89 had the enamel defects characteristic of dental enamel hypoplasia, a true prevalence of 41.8%. Of the 204 females, 78 had dental enamel hypoplasia, a true prevalence rate of 42.2%. Among the individuals of undetermined sex, however, the true prevalence rate of dental enamel hypoplasia was 27.5% (Table 6.4.3), considerably lower than that seen in the determined sexes. Comparing the prevalence of dental enamel hypoplasia in only males and females with Pearson's Chi-squared test found no significant association ($p > 0.05$). Including the undetermined sex category meant sex was found to have a significant effect on the number of individuals who had developed the condition during their lives ($p < 0.05$). Together, the lack of distinction in prevalence between males and females, and the significantly lower prevalence in individuals of undetermined sex implies that while sex did not impact the formation of the condition in life, those who were too poorly preserved to be properly assessed for sexing characteristics were also too poorly preserved for the identification of pathological conditions, despite the true prevalence being calculated from those who were recorded as having examinable dentition. It indicates that perhaps the number of teeth preserved needed to be taken into consideration when selecting which individuals to include in the calculation of the true prevalence.

6.4.3 Intra-period sex comparison

The association between sex and the prevalence of dental enamel hypoplasia was further tested by assessing the impact of sex within each time period. In the Roman population, there were a total of 112 males and 69 females. Of the males, 62 had dental enamel hypoplasia, a prevalence of 64.6%. Of the females, 42 had enamel defects, a prevalence of 70.0%. The slightly greater prevalence associated with Roman females was not determined to be significant by Pearson's Chi-squared test ($p > 0.05$). The early medieval population was similarly determined to have no association between sex and the prevalence rate of dental enamel hypoplasia. There were 135 individuals of both males and females. Of the males, 27 were found to have evidence of dental enamel hypoplasia, a prevalence of 23.1%. The females had a similar prevalence of 28.8%, representing 36 individuals with the condition. This difference was not significant in Pearson's Chi-squared test ($p > 0.05$), though it is worth noting that in both periods, females had a slightly higher prevalence of the condition than males. As seen above when comparing those of undetermined sex with males and females, there was a significant association between individuals who could not be assigned a sex and lower prevalence rates of dental enamel hypoplasia. In the Roman individuals of undetermined sex the true prevalence was 45.8% (27/59), and Pearson's Chi-squared test resulted in an indication of significance ($p < 0.05$). The same was seen in the early medieval population: 9 cases of dental enamel hypoplasia were recorded in those of undetermined sex (12.5%), and Pearson's Chi-squared test for association determined this difference was significant ($p < 0.05$).

6.4.4 Inter-period sex comparison

The prevalence of dental enamel hypoplasia was compared in each sex across the time periods to assess whether sex affected the response to the change. The males exhibited a significant decrease in the prevalence of the condition between the Roman and early medieval periods, the same as seen in the full study sample. In Roman males, 62 were recorded as having dental enamel hypoplasia (64.6%), whereas only 27 early medieval males were seen with it (23.1%). This decrease was found to be significant by Pearson's Chi-squared test ($p < 0.05$). In females the same pattern was seen: 42 Roman females had enamel defects (70.0%), compared to 36 early medieval females (28.8%), a difference which was deemed significant ($p < 0.05$). The post hoc adjusted standardised residuals (6.1 in males, 5.3 in females; Table 6.4.4) show that the association between time period and prevalence of enamel defects was stronger in the males, similar to the pattern seen with cribra orbitalia, indicating that sex influenced the response to the societal changes. There were sufficient individuals of undetermined sex to perform the Pearson's Chi-squared test comparing the prevalence of the condition between the Roman and early medieval periods. In the Romans, the prevalence was 45.8%, compared to 12.5% in the early medieval population, and the association of this decrease with the time period was deemed to be significant ($p < 0.05$). The adjusted standardised residual of 4.2 shows that this change was not of the same magnitude as the decrease in either males or females.

Period	Sex	Total individuals (T)	Number of individuals with skeletal element (S)	Number of individuals with condition (N)	Crude prevalence (N/T)	True prevalence (N/S)
Roman	Male	112	96	62	55.4%	64.6%
	Female	69	60	42	60.9%	70.0%
	Undet.	82	59	27	32.9%	45.8%
Early medieval	Male	135	117	27	20.0%	23.1%
	Female	135	125	36	26.7%	28.8%
	Undet.	123	72	9	7.3%	12.5%
All	Male	247	213	89	36.0%	41.8%
	Female	204	185	78	38.2%	42.2%
	Undet.	205	131	36	17.6%	27.5%

Table 6.4.3: The number of individuals of each sex with dental enamel hypoplasia, from the full dataset and in each time period.

Sex	Period	DEH	Observed	Expected	Adjusted residual
Male	Roman	Present	62	40	6.1
		Absent	34	56	-6.1
	Early medieval	Present	27	49	-6.1
		Absent	90	68	6.1
Female	Roman	Present	42	25	5.3
		Absent	18	35	-5.3
	Early medieval	Present	36	53	-5.3
		Absent	89	72	5.3

Undetermined sex	Roman	Present	27	16	4.2
		Absent	32	43	-4.2
	Early medieval	Present	9	20	-4.2
		Absent	63	52	4.2

Table 6.4.4: The contingency tables used in the Chi-squared test for association for the inter-period comparison of sex, with associated post hoc adjusted residual scores.

6.4.5 Inter-age category comparison

The individuals were then divided by their age at death category, to test the possibility of an association between developing dental enamel hypoplasia during childhood stress, and adult life span. Across the specific age categories the prevalence of dental enamel hypoplasia was very similar, ranging from 37.4% in the Mature Adult category, to 43.6% in the Young Adult category. The Adult category, for those who could not be more specifically aged, had a lower prevalence of 29.8% (Table 6.4.5). Overall, the variation in the prevalence of dental enamel hypoplasia across the age categories was not determined to be significant by Pearson's Chi-squared test ($p > 0.05$).

6.4.6 Intra-period age category comparison

The populations from each period were then separately subjected to the same comparison between age categories to further investigate the factors influencing the development of dental enamel hypoplasia. From the Roman period assemblage, an interesting pattern emerged. The greatest prevalence of dental enamel hypoplasia was found in the Young Adult category (78.8%), with a steady decline in prevalence as the age at death increased. In the Young Middle Adult category, the prevalence rate was 69.2%, in the Old Middle Adult category it was 65.6%, and in the Mature Adult category it was lower again at 53.1%. The Adult category had the lowest prevalence of dental enamel hypoplasia at 41.5%. These differences in the true prevalence of the condition between age categories were much greater than those found when considering both time periods together. However when performing Pearson's Chi-squared test, this association was found not to be significant ($p > 0.05$). The early medieval population did not exhibit the same pattern of dental enamel hypoplasia decreasing as age at death increased: the greatest prevalence (28.8%) was found in the Mature Adult category, followed by Young Adult (24.6%), Young Middle Adult (23.2%, and Old Middle Adult (19.5%). As seen in the Roman population, the Adult category presented the smallest prevalence (14.6%), and this lower prevalence in the poorly preserved skeletons was similar to that seen in the individuals of undetermined sex, supporting the conclusion that the method used to determine which individuals were labelled as having recordable dentition needs further consideration. The variation in the prevalence of dental enamel hypoplasia between each age category of the early medieval period assemblage was not determined to be significant by Pearson's Chi-squared test ($p > 0.05$). It is therefore shown that the overall decrease in the prevalence of dental enamel hypoplasia between the Roman and early medieval period was not due to differing age profiles in each population, but rather was seen within and between each age category.

Period	Age at death	Total individuals (T)	Number of individuals with skeletal element (S)	Number of individuals with condition (N)	Crude prevalence (N/T)	True prevalence (N/S)
Roman	YA 18-25	39	33	26	66.7%	78.8%
	YMA 26-35	68	65	45	66.2%	69.2%
	OMA 36-45	39	32	21	53.8%	65.6%
	MA 46+	39	32	17	43.6%	53.1%
	A 18+	78	53	22	28.2%	41.5%
Early medieval	YA 18-25	64	61	15	23.4%	24.6%
	YMA 26-35	120	112	26	21.7%	23.2%
	OMA 36-45	48	41	8	16.7%	19.5%
	MA 46+	63	59	17	27.0%	28.8%
	A 18+	98	41	6	6.1%	14.6%
All	YA 18-25	103	94	41	39.8%	43.6%
	YMA 26-35	188	177	71	37.8%	40.1%
	OMA 36-45	87	73	29	33.3%	39.7%
	MA 46+	102	91	34	33.3%	37.4%
	A 18+	176	94	28	15.9%	29.8%

Table 6.4.5: The number of individuals with dental enamel hypoplasia in each age category, from the full dataset and in each time period.

6.4.7 Settlement type comparison

In the individuals from the Roman period, the impact of settlement type on the likelihood of developing dental enamel hypoplasia was also investigated. The majority of individuals were excavated from cemeteries associated with urban settlements, with 221 individuals from these environments compared to just 42 from rural contexts. The prevalence of dental enamel hypoplasia was found to be greater in the urban assemblage, as 117 individuals were recorded as having the condition, a prevalence of 65.7%, in contrast to the 14 individuals (37.8%) from the rural cemeteries having the condition (Table 6.4.6). The association between the urban environment and the greater number of people affected by dental enamel hypoplasia was determined to be significant by Pearson's Chi-squared test ($p < 0.05$).

Settlement type	Total individuals (T)	Number of individuals with skeletal element (S)	Number with condition (N)	Crude prevalence (N/T)	True prevalence (N/S)
Urban	221	178	117	52.9%	65.7%
Rural	42	37	14	33.3%	37.8%

Table 6.4.6: Number of individuals with dental enamel hypoplasia from the urban and rural cemeteries of the Roman period.

6.4.8 Summary of the findings for dental enamel hypoplasia

In summary, dental enamel hypoplasia was found to be much more prevalent in the Roman period, affecting more than half of the Roman period individuals included in this study. As was the case with cribra orbitalia, sex and age at death were not connected to the prevalence of dental enamel hypoplasia, but in contrast settlement type did influence the condition.

6.5 Rickets

Among the collated dataset of 656 individuals, eight were noted as having rickets, or bowing in the long bones which was not specifically described as rickets but was not attributed to any other condition or taphonomic factor. The true prevalence for this condition was calculated as the number of individuals with either recorded bowing or named rickets out of the number of individuals with the long bones of at least two limbs preserved well enough that rachitic characteristics could be seen on reconstruction. A total of 100 individuals were recovered without any long bones, or in such a fragmented state that they could not be reconstructed well enough for assessment of bowing and epiphyseal fraying, so the true prevalence of the condition was 1.4% (Table 6.5.1).

6.5.1 Inter-period comparison

The presence of rickets was compared between the time periods to assess whether the changes in society affected the prevalence of the condition. Only two of the Roman period assemblage of 263 individuals were determined to have rickets, a true prevalence of 0.8%. This was lower than the true prevalence among the early medieval assemblage, where six of the 393 had rickets (1.9%). This difference was indicated to be significant by Pearson's Chi-squared test ($p < 0.05$), but the number of cases was too small for the test to be considered valid. Therefore, while the lower prevalence of rickets in the Roman period was contrary to the pattern established with cribra orbitalia and dental enamel hypoplasia, it must be noted that no comments on the significance of the lower prevalence in the Roman period can be made. It should also be noted that all six cases among the early medieval assemblage came from the Burnby Lane cemetery in Pocklington, and so differences in osteological analysis may have impacted this result.

Period	Total individuals (T)	Number of individuals with skeletal element (S)	Number of individuals with condition (N)	Crude prevalence (N/T)	True prevalence (N/S)
Roman	263	240	2	0.8%	0.8%
Early medieval	393	316	6	1.5%	1.9%
All	656	556	8	1.2%	1.4%

Table 6.5.1: The number of individuals with rickets, and the condition's prevalence, from the full dataset and in each time period.

6.5.2 Inter-sex comparison

When comparing the prevalence of the condition between the sexes from the full dataset, it was seen that rickets was more common in the males. Of the 247 males, six were determined to be rachitic, giving a true prevalence of 2.5% (Table 6.5.2). In comparison, only one female individual showed evidence of the condition out of a total 204 females (0.5%). Only one individual of undetermined sex was found to have evidence of rickets (0.8%). Pearson's Chi-squared test indicated that the greater prevalence of rickets associated with males was statistically significant ($p < 0.05$), though the test was not valid due to the low number of cases involved. The greater prevalence of rickets in males matches the greater (though not significantly so) prevalence of cribra orbitalia in males, and is in contrast with the greater (also not significantly so) prevalence of dental enamel hypoplasia in females.

6.5.3 Intra-period sex comparison

The two Roman cases of rickets were in one male and one individual of undetermined sex, giving a true prevalence from among the 112 males of 0.9%, 1.6% prevalence among the 82 individuals of undetermined sex, and 0% prevalence among the females. From the total early medieval assemblage, there were 135 males, of which five were determined to have rickets, a true prevalence of 3.8%. There were also 135 females, with a single case of rickets (0.8%), and the differing prevalences were indicated to be significant by Pearson's Chi-square test ($p < 0.05$), though the test was not valid due to the small numbers involved. As the early medieval cases of rickets were found on one site, it was more likely that the difference between the sexes was not an artefact of compiling sites with different sex ratios. In fact, the Burnby Lane site had a total of 30 individuals, 12 males and 11 females. The true prevalence of rickets at this site alone was 41.7% for males, compared to just 9.1% for females, and the disparity was indicated to be significant by Pearson's Chi-squared test ($p < 0.05$), though the test was invalid due to the small number of cases involved. Overall it was seen that sex appeared to be associated with the development of rickets in childhood at the Burnby Lane site, though the association could not be confidently labelled as such due to the low number of cases.

6.5.4 Inter-period sex comparison

For both sexes, it was seen that the occurrence of rickets increased from the Roman to the early medieval period, from 0.9% to 3.8% in males and 0% to 0.8% in females, as it did for the population overall. However, as already discussed, the number of cases was too small to perform statistical analyses, and no conclusions could be drawn about the changes in the health of either sex across the time periods.

Period	**Sex**	**Total individuals (T)**	**Number of individuals with skeletal element (S)**	**Number of individuals with condition (N)**	**Crude prevalence (N/T)**	**True prevalence (N/S)**
Roman	Male	112	111	1	0.9%	0.9%
	Female	69	67	0	0%	0%
	Undet.	82	62	1	1.2%	1.6%
Early medieval	Male	135	130	5	3.7%	3.8%
	Female	135	127	1	0.7%	0.8%
	Undet.	123	59	0	0%	0%
All	Male	247	241	6	2.4%	2.5%
	Female	204	194	1	0.5%	0.5%

Period	Sex	Total individuals (T)	Number of individuals with skeletal element (S)	Number of individuals with condition (N)	Crude prevalence (N/T)	True prevalence (N/S)
	Undet.	205	121	1	0.5%	0.8%

Table 6.5.2: The number of individuals of each sex with rickets, from the full dataset and in each time period.

6.5.5 Inter-age category comparison

The small number of identified cases of rickets made the consideration of an association between an individual developing the condition as a child and their age at death somewhat difficult, as seen with all other factors. Of the eight individuals with the condition, four were assigned to the Mature Adult category (4.0%), two to the Young Middle Adult category (1.2%), one to the Old Middle Adult category (1.2%), and one to the Adult category (0.8%). It is interesting to note that rickets was most commonly seen in the Mature Adult category, despite that category being one of the less frequent among the dataset (Table 6.5.3). The greater prevalence in the Mature Adult category was calculated to be significant by Pearson's Chi-squared test ($p < 0.05$), but the small number of cases made the test invalid.

6.5.6 Intra-period age category comparison

The two Roman cases of rickets were an individual assigned to the Old Middle Adult category, making the true prevalence of the condition within the age category 2.5%, and an individual in the non-specific adult category, the prevalence being 1.6%. The distribution of cases between the age categories was not found to be significant ($p > 0.05$). The early medieval cases were distributed with four in the Mature Adult category (6.6%), and two in the Young Middle Adult category (1.9%). Therefore two-thirds of the early medieval cases of rickets were in individuals assigned to the Mature Adult category, an association which was determined to be significant by Pearson's Chi-squared test ($p < 0.05$), though as with the other tests performed on the prevalence of rickets, the number of cases was too small to validate the test.

Period	Age at death	Total individuals (T)	Number of individuals with skeletal element (S)	Number of individuals with condition (N)	Crude prevalence (N/T)	True prevalence (N/S)
Roman	YA 18-25	39	33	0	0%	0%
	YMA 26-35	68	67	0	0%	0%

Period	Age at death	Total individuals (T)	Number of individuals with skeletal element (S)	Number of individuals with condition (N)	Crude prevalence (N/T)	True prevalence (N/S)
	OMA 36-45	39	39	1	2.6%	2.6%
	MA 46+	39	38	0	0%	0%
	A 18+	79	63	1	1.3%	1.6%
Early medieval	YA 18-25	64	50	0	0%	0%
	YMA 26-35	120	103	2	1.7%	1.9%
	OMA 36-45	48	44	0	0%	0%
	MA 46+	63	61	4	6.3%	6.6%
	A 18+	98	58	0	0%	0%
All	YA 18-25	103	83	0	0%	0%
	YMA 26-35	188	170	2	1.1%	1.2%
	OMA 36-45	87	83	1	1.1%	1.2%
	MA 46+	102	99	4	3.9%	4.0%
	A 18+	176	121	1	0.6%	0.8%

Table 6.5.3: The number of individuals with rickets in each age category, from the full dataset and in each time period.

6.5.7 Settlement type comparison

No comparison between settlement types could be made for rickets as only two individuals from the Roman period had the condition. They were from Bainesse and Hungate, which were both urban sites, but the lack of cases from rural sites was likely a reflection of the smaller sample size and not indicative of any health consequences experienced as a result of the type of settlement people lived in.

6.5.8 Summary of the findings for rickets

Overall, the study of rickets was of little use when determining the effects of the Roman-early medieval transition as poor preservation and several lacklustre osteological reports meant few cases were identified, so no patterns could be established. It can however be noted that within the Pocklington Burnby Lane site where the majority of the cases were found, rickets was seen to more often affect males, and those who died as older adults.

6.6 Stature

The final piece of data collected from the original reports on the case study sites was stature. In total, 211 individuals were preserved well enough to have one of the necessary long bones measured, comprising 113 males, 89 females, and nine individuals of undetermined sex. Those nine were discounted from this work because the Trotter equations for the calculation of stature differ depending on sex, so the reported stature for those nine individuals could not be relied upon to represent the individual's height in life or be directly comparable to either the males or the females. For both time periods combined, the mean stature in the 113 males was 170.6 cm, ranging from 158.0 cm to 188.2 cm. The mean stature in the 89 females was 160.7 cm, ranging from 143.7 cm to 177.0 cm (Table 6.6.1). The Kolmogorov-Smirnov test for normality confirmed that the measurements of stature in males and females were normally distributed, and so t-tests could be performed. Comparing males and females was not necessary for this indicator of stress as it was with those discussed previously, because females of all populations tend towards a shorter stature than their male counterparts (Roser et al. 2013). For this reason, it is also standard practice to report the mean stature of males and females separately, which will be done in this work.

6.6.1 Inter-period comparison

Comparing mean stature across the Roman and early medieval periods revealed that the population's average height changed over time (Figure 6.6.1). From the total group of 112 Roman males, 61 were able to be measured for stature, with the mean height being 168.0 cm, ranging from 158.0 cm to 188.2 cm. In contrast, 52 of the group of 135 early medieval males were able to have a long bone measured, giving a mean stature of 173.6 cm, almost 6 cm taller than that of the Roman males, with the range of stature from 159.0 cm to 187.0 cm. Comparing the Roman and early medieval males by an independent samples t-test confirmed that the difference in stature was significant ($p < 0.05$). Similarly, of the 69 Roman females, 37 were preserved well enough for calculation of stature, ranging from 143.7 cm to 168.0 cm, and giving a mean height of 156.6 cm. Of the early medieval females, stature could be calculated for 52 of the total 135 individuals, ranging from 147 cm to 177 cm, and the mean stature was 163.5 cm, just under 7 cm taller than that of the Roman females. The independent samples t-test confirmed that this difference was also significant ($p < 0.05$). The comparison of the change in stature over time between males and females revealed that there was a slightly greater increase in stature in the females; mean stature in the early medieval males was 5.6 cm taller than that of Roman males, whereas mean stature in the early medieval females was 6.9 cm taller than that of Roman females. In addition to this it was seen that the difference between mean stature for males and females in the Roman period was 11.4 cm, in comparison to 10.1 cm when making the same comparison for the early medieval population, indicating that females may have been more subject to growth delay in the Roman period.

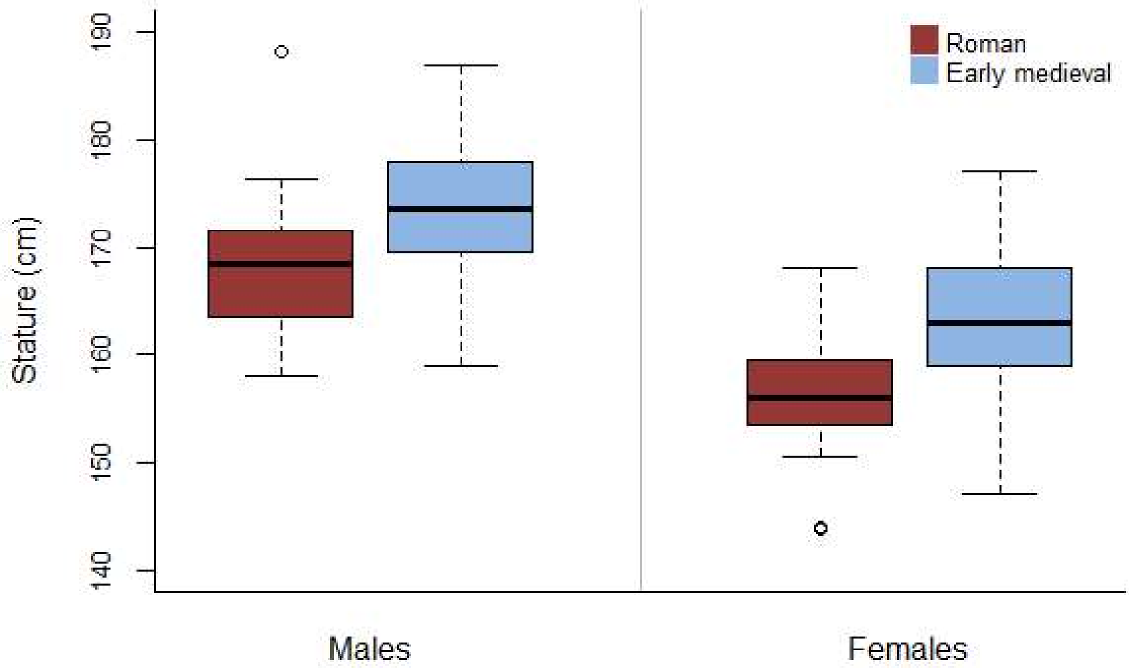


Figure 6.6.1: Boxplot showing the mean, interquartile range and 1.5x interquartile range in estimated stature for males and females of each time period.

Period	Sex	Total individuals	Number of individuals with skeletal element	Mean stature (cm)
Roman	Male	112	61	168.0
	Female	69	37	156.6
Early medieval	Male	135	52	173.6
	Female	135	52	163.5
All	Male	247	113	170.6
	Female	204	89	160.7

Table 6.6.1: The mean stature for all males and females within each time period and in the total study sample.

6.6.2 Inter-age category comparison

The mean stature of males and females within each assigned age-at-death category was compared to determine whether growth delay in childhood had an effect on adult longevity. In all males, there was a slight dip and subsequent rise in mean stature with increasing age at death; Young Adults and Young Middle Adults were very similar with mean statures of 170.5 cm and 170.6 cm respectively, Old Middle Adults were the shortest at 167.6 cm, and Mature Adults tallest at 172.2 cm. Only six male individuals who could not be assigned a specific age category due to poor preservation were preserved well enough to allow the calculation of stature, giving a mean value of 170.0 cm, closest to that of the Young Adults and Young Middle Adults (Table 6.6.2). The variation in stature across age categories in males was not determined to be significant by a one-way ANOVA test ($p > 0.05$). In all females there was a slight decrease in mean stature across the increasing age-at-death categories. Young Adults were tallest, with a mean stature of 163.5 cm, the mean stature for Young Middle Adults was 159.9 cm, it slightly increased to 160.2 cm for Old Middle Adults, and decreased again to 159.7 cm in Mature Adults. Only three individuals from the Adult category could have their stature calculated, with the mean being 163.0 cm, closest to that of the Young Adults. In females, the variation in mean stature across the age categories was also not found to be significant when subject to a one-way ANOVA test ($p > 0.05$), demonstrating that overall, mean living stature and age at death were not related.

6.6.3 Intra-period age category comparison

The possibility that growth delay may have impacted age at death in only one time period was then interrogated (Figures 6.6.2 and 6.6.3). In the Roman males there was little difference between the specific age categories, presenting mean statures of 168.5 cm in Young Adults, 167.8 cm in Young Middle Adults, 166.1 cm in Old Middle Adults and 168.6 cm in Mature Adults. The non-specific Adult category had a slightly greater mean stature, at 170.0 cm. However, this difference was not deemed to be significant by a one-way ANOVA ($p > 0.05$), and Tukey's HSD test did not determine there to be any significance in the individual differences between Adults and the other age categories when considered separately from one another. Considering the males of the early medieval period, it was seen that the range of mean stature across the assigned age categories was slightly greater than in Roman males. The greatest mean stature was seen in the Mature Adult category, at 174.8 cm, compared to the shortest seen in the Old Middle Adult category at 170.2cm. The mean statures for the Young Adult and Young Middle Adult categories were 172.2 cm and 174.3 cm respectively. No individuals assigned to the Adult category were preserved well enough for stature estimation. The one-way ANOVA performed on the stature of early medieval males did not reveal any significant difference between the age categories ($p > 0.05$).

Among the females of the Roman period, slightly more variation in the mean stature across the age categories was seen in comparison to the males. The Young Adults were shortest, at 154.7 cm on average. Mean stature then increased, at 158.0 cm in Young Middle Adults. The Old Middle Adult and Mature Adult categories had lower mean stature again, at 156.2 cm and 156.1 cm respectively. No Roman females from the Adult category were able to be measured for stature estimation. Assessing this variation by one-way ANOVA determined that there was no significant relationship between the stature of Roman females and their age at death ($p > 0.05$). From the early medieval females, the Young Adult category had the greatest mean stature, at 166.5 cm, closely followed by the Old Middle Adult category, at 166.1 cm. The Mature Adult and Adult categories also had very similar mean statures, at 163.9 cm and 163.0 cm respectively. Finally, Young Middle Adults had the shortest mean stature of 161.0 cm. The one-way ANOVA did not deem there to be any significance in the variation of mean stature across the age categories ($p > 0.05$).

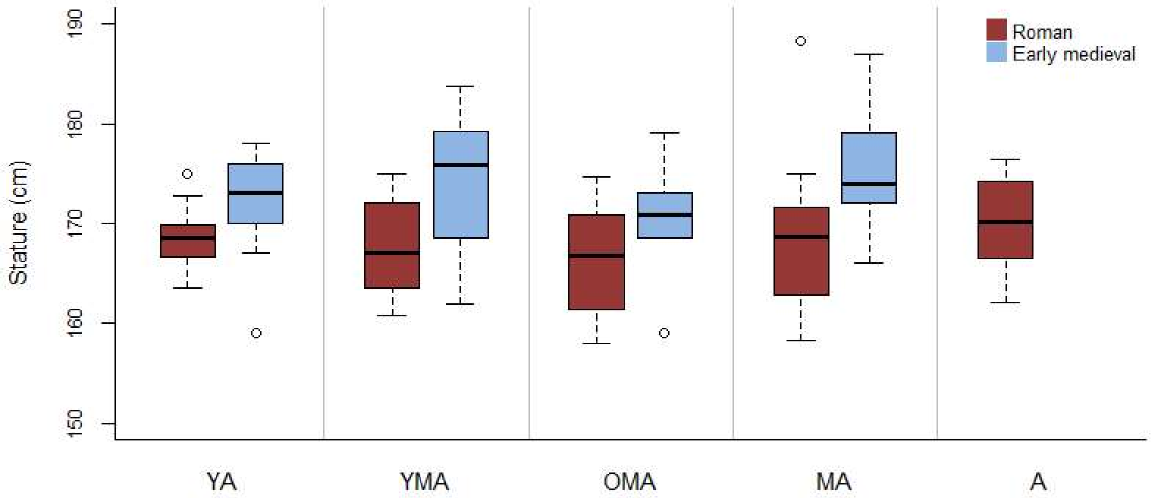


Figure 6.6.2: Boxplot showing the mean, interquartile range and 1.5x interquartile range in estimated stature for the males of each age category, separated by time period.

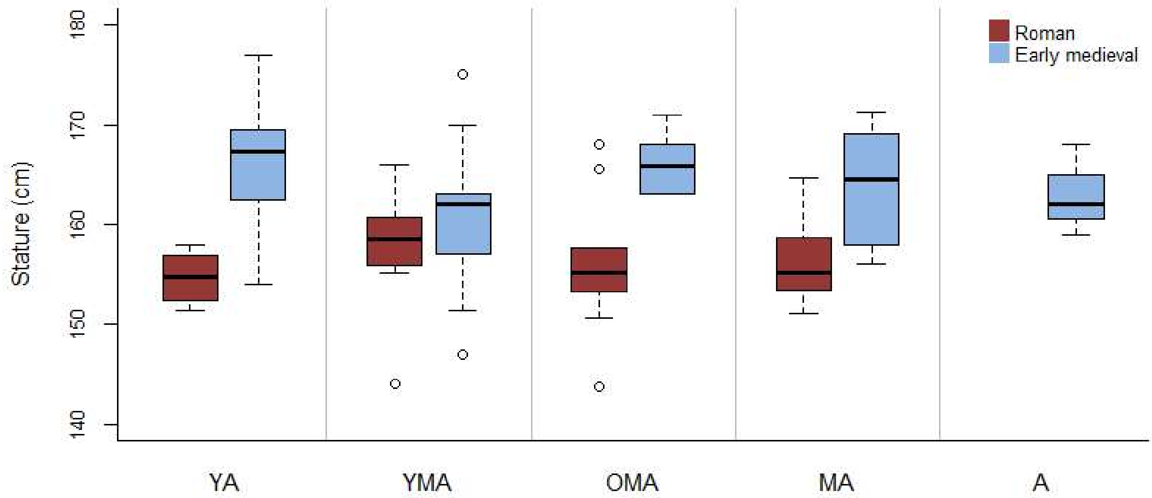


Figure 6.6.3: Boxplot showing the mean, interquartile range and 1.5x interquartile range in estimated stature for the females of each age category, separated by time period.

Period	Sex	Age at death	Total individuals	Number of individuals with skeletal element	Mean stature (cm)
Roman	Male	YA 18-25	16	10	168.5
		YMA 26-35	39	21	167.8
		OMA 36-45	21	11	166.1
		MA 46+	21	13	168.6
		A 18+	15	6	170.0
	Female	YA 18-25	7	4	154.7
		YMA 26-35	22	12	158.0
		OMA 36-45	15	9	156.2
		MA 46+	18	12	156.1
		A 18+	7	0	-
Early medieval	Male	YA 18-25	21	12	172.2
		YMA 26-35	50	16	174.3
		OMA 36-45	22	6	170.2
		MA 46+	30	18	174.8
		A 18+	12	0	-
	Female	YA 18-25	26	12	166.5
		YMA 26-35	53	21	161.0
		OMA 36-45	18	6	166.1
		MA 46+	28	10	163.9
		A 18+	10	3	163.0
All	Male	YA 18-25	37	22	170.5
		YMA 26-35	89	37	170.6
		OMA 36-45	43	17	167.6

Period	Sex	Age at death	Total individuals	Number of individuals with skeletal element	Mean stature (cm)
		MA 46+	51	31	172.2
		A 18+	27	6	170.0
	Female	YA 18-25	33	16	163.5
		YMA 26-35	75	33	159.9
		OMA 36-45	33	15	160.2
		MA 46+	46	22	159.7
		A 18+	17	3	163.0

Table 6.6.2: The mean stature of males and females in each age category, from the full dataset and in each time period.

6.6.4 Settlement type comparison

Considering the context in which the populations were found, it was seen that 87 males were from urban environments, compared to 25 from rural environments. From the urban group of males, 41 could have stature estimated, and the mean was calculated as 167.3 cm. Among the rural male group mean stature was slightly greater; 20 individuals had stature estimated, the mean value 169.5 cm (Table 6.6.3). When assessed by an individual samples t-test, it was found this difference was not statistically significant ($p > 0.05$). Among the females, 56 were from urban cemeteries, 26 of whom had estimated statures with a mean of 155.9 cm. A total of 13 females were from rural contexts, with stature estimated for 11 of them, giving a mean value of 158.2 cm, slightly taller than the urban females. This was also found not to be a statistically significant difference by t-test ($p > 0.05$). Overall it was seen that mean stature was slightly greater in rural areas for both males and females, though the statistical significance to support this is lacking.

Settlement type	Sex	Total individuals	Number of individuals with skeletal element	Mean stature (cm)
Urban	Male	87	41	167.3
	Female	56	26	155.9
Rural	Male	25	20	169.5

Settlement type	Sex	Total individuals	Number of individuals with skeletal element	Mean stature (cm)
	Female	13	11	158.2

Table 6.6.3: Mean stature in males and females from urban and rural sites.

6.6.5 Summary of the findings for stature

In summary, it has been shown that the typical stature of those from the Roman period in northern England was shorter than that of their successors in both males and females. This difference was not found to be influenced by age at death, and had only a slight link to settlement type during the Roman period.

6.7 Summary of the results from the compilation of literature

Overall, the consideration of cribra orbitalia, dental enamel hypoplasia, rickets and stature among the case study sites has strongly indicated that those living during the Roman period in northern England experienced a greater degree of childhood stress than their early medieval successors. The prevalence of cribra orbitalia and dental enamel hypoplasia was greater among the Roman period individuals, and this was not associated with sex or age at death. The settlement type had some effect on the distribution of the conditions, but regardless, they were always more common in the Roman period populations. The estimation of stature also indicated greater stress in the Roman period, manifesting as delayed growth and shorter mean stature in both males and females as compared to those of the early medieval period. Although rickets was more prevalent in the early medieval period, contradicting the higher load of skeletal indicators of stress in the Roman period, it was too rarely diagnosed to be considered a true indicator of the effect that the loss of Roman rule in Britain had on the population’s health.

Chapter 7: Results from the study of the vertebral neural canal

In this chapter the results of the measurement of the vertebral neural canal are presented. As discussed in section 3.5, the vertebral neural canal can preserve evidence of childhood growth delay due to physiological stress, which can be revealed through the measurement of the transverse and anterior-posterior diameters as according to the protocol described in section 4.5.2. The following analyses the transverse and anterior-posterior diameters, comparing them between the Roman and early medieval populations to identify any evidence of changes to growth delay. The vertebral neural canal measurements are then compared to stature and vertebral body height to determine the relationships between these different measures of growth delay, and also to each of the pathologies discussed in the previous chapter to establish whether there is any correspondence between growth delay in the vertebral neural canal and childhood stress as indicated by the skeletal pathologies. A total of 86 individuals from eight sites were included in the programme of measurement: 40 Roman individuals and 46 early medieval individuals (Table 7.0.1). The sites were selected based on accessibility of the skeletal collections, and the individuals within each collection were chosen based on preservation. The Roman group comprised 23 males, 15 females, and two individuals of undetermined sex, whereas the early medieval group comprised 21 males, 24 females, and one individual of undetermined sex. Before any analysis of the growth delay in the vertebral neural canal was performed, the measurements of the diameters of the vertebral neural canal were compared by sex, to ensure that no sex based variation in size, as seen in stature (section 6.6), could influence the results based on the differing sex ratios. However, sex was not found to affect the vertebral neural canal, as elaborated upon in section 7.1.2, so the comparison of the time periods was conducted with individuals of all assigned sexes pooled together despite the number of females being much lower in the Roman group. The inter-period comparison is reported first, as it was in each section of the previous chapter, to maintain a standard order for the reporting of analyses throughout the work.

Site	Period	Total	Sex			Age				
			M	F	U	YA	YMA	OMA	MA	A
Bainesse	R	21	15	5	1	1	10	5	3	2
	EM	2	-	2	-	-	2	-	-	-
Cataractonium	R	5	3	1	1	-	1	3	1	-
Dalton Parlours	R	2	1	1	-	-	1	1	-	-
	EM	1	-	1	-	-	1	-	-	-

Healam Bridge	R	3	1	2	-	-	-	2	1	-
	EM	1	1	-	-	-	-	1	-	-
Pocklington Burnby Lane	EM	13	5	8	-	1	4	3	5	-
Sewerby	EM	12	6	6	-	-	5	3	2	2
Wattle Syke	R	9	3	6	-	1	3	-	5	-
	EM	1	1	-	-	-	-	-	1	-
West Heslerton	EM	16	8	7	1	3	5	2	1	5
Total	R	40	23	15	2	2	15	11	10	2
	EM	46	21	24	1	4	17	9	9	7
	All	86	44	39	3	6	32	20	19	9

Table 7.0.1: The demographic distribution of the individuals from each site included in the group which had VNC measurements taken. Sex = male (M), female (F), or undetermined (U). Age = Young Adult (YA), Young Middle Adult (YMA), Old Middle Adult (OMA), Mature Adult (MA), and Adult (A).

7.1: Analysis of the vertebral neural canal measurements

The vertebral columns of the 86 individuals assessed were not uniformly preserved along their length, nor were the vertebrae equally identifiable, so different numbers of measurements were taken for each vertebra (Table 7.1.1). In all cases, more measurements were taken of the transverse diameter than the anterior-posterior diameter (Figure 7.1.1) due to the typical fragmentation pattern, in which the spinous process and vertebral arch broke off more often than both of the pedicles. The most identifiable vertebrae, namely the C1 (atlas) and C2 (axis), and the first and last vertebrae of each segment and their immediate neighbours, were also more likely to be measured, as any measurement of a vertebra which could not be confidently identified may have skewed the dataset, so many well preserved vertebrae were excluded as they could not be placed within the spine. This resulted in a general decrease in numbers of measurements more distally, until the middle of the thoracic segment when numbers started to increase again. The greatest numbers of measurements were in cervical vertebrae, and least in the central thoracic vertebrae, with C2 having the most and T6 the least overall.

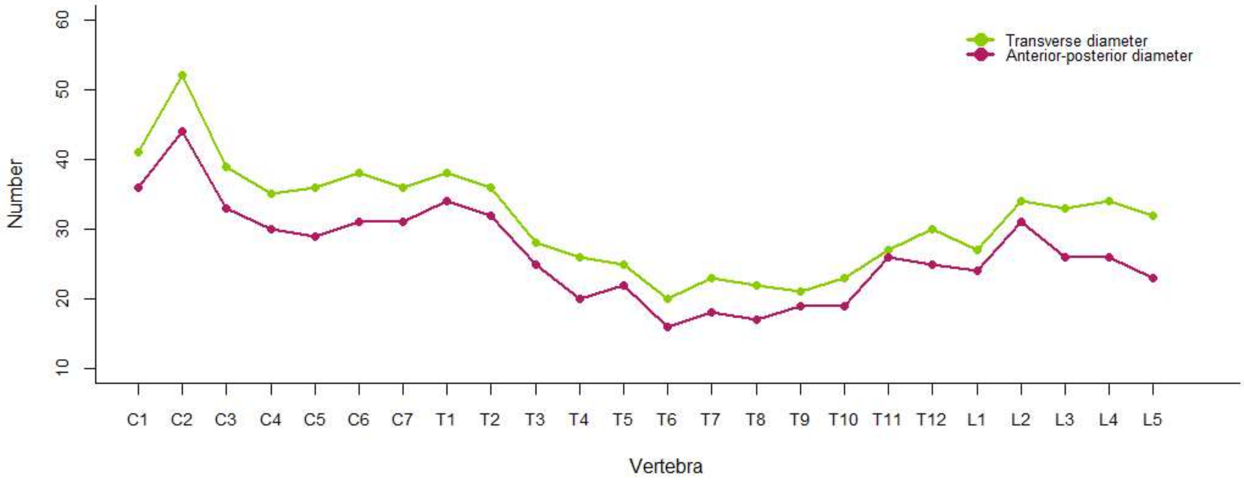


Figure 7.1.1: The total number of measurements of both the TR and AP diameters in each vertebra.

As may be expected, the breadth of the range of values for both the transverse and anterior-posterior diameters generally varied depending on the number of measurements taken. The range was also generally narrower in the anterior-posterior diameter. Overall, the mean diameters followed the expected pattern (as seen in Masharawi and Salame, 2011; Tatarek, 2005); the transverse diameter was greatest in C1, sharply decreased in C2, saw a slight overall rise C2-6, decreased steadily from C7 to T4, then remained approximately equal in T4-T8 with the lowest value in T7, increased steadily in T9-L1, stayed approximately equal in L1-L4, and then increased sharply again in L5, which was the second largest value overall (Figure 7.1.2). The mean anterior-posterior diameter was also greatest in C1, sharply decreased to C2 which was the second greatest overall value, decreased slightly again in C3, steadily increased a very small amount from C3 to L1, decreased slightly again in L1-L3 and increased in L4-L5 (Figure 7.1.3).

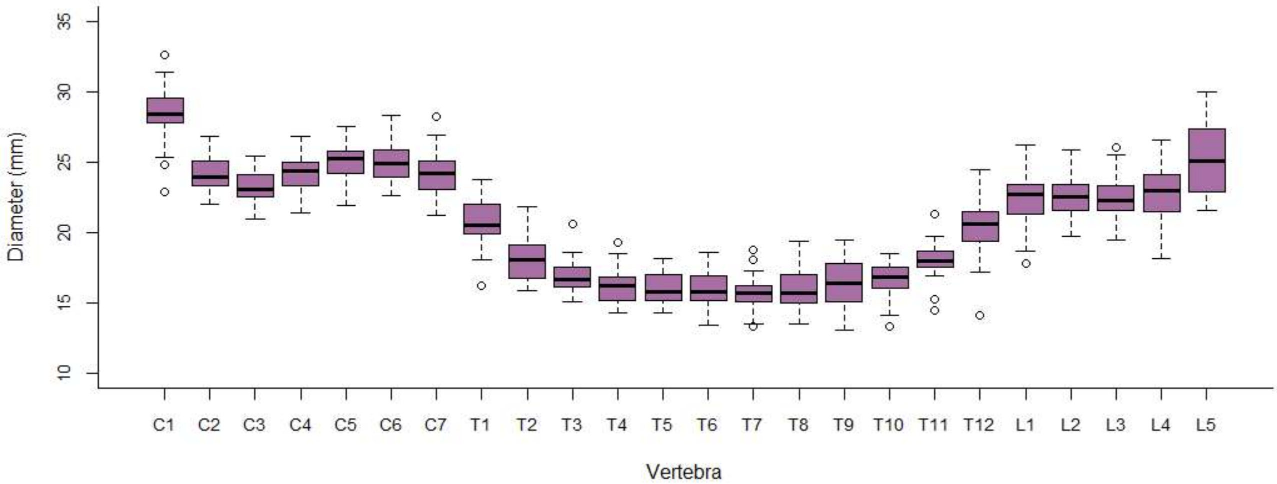


Figure 7.1.2: Boxplots showing the mean, interquartile range, and 1.5x interquartile range of measurements of the transverse diameter of the VNC for each vertebra in the full dataset.

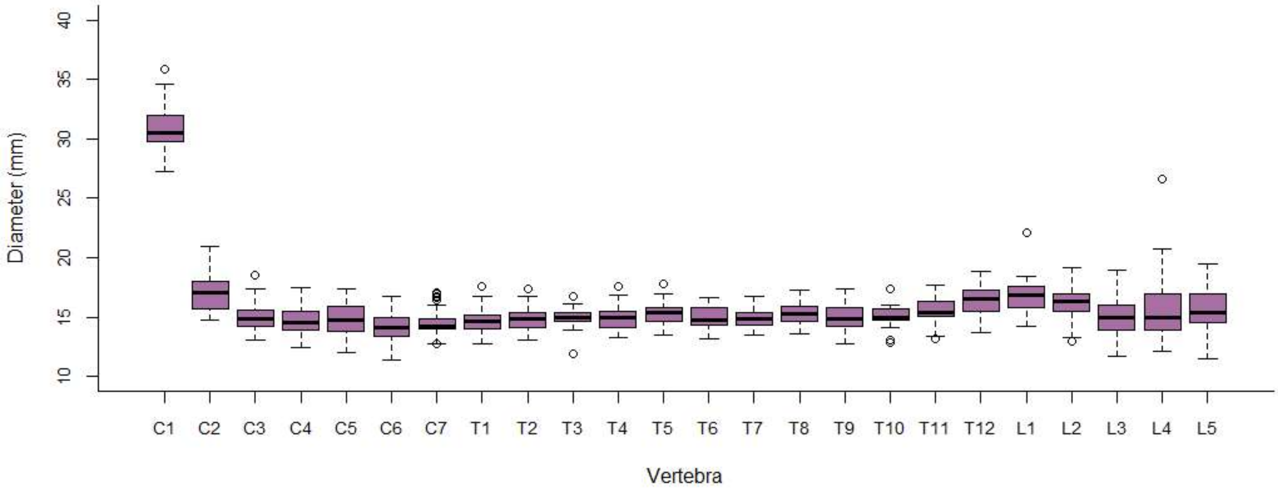


Figure 7.1.3: Boxplots showing the mean, interquartile range, and 1.5x interquartile range of measurements of the anterior-posterior diameter of the VNC for each vertebra in the full dataset.

7.1.1 Inter-period comparison

The assemblage for the vertebral neural canal study comprised similar numbers of Roman and early medieval individuals: 40 and 46, respectively. The transverse and anterior-posterior diameter measurements were compared between the Roman and early medieval populations for each vertebra and measurement type. In the transverse diameter, the means differed very slightly in each of the vertebrae between the Roman and early medieval periods, though neither period consistently had the larger mean (Table 7.1.1, Figure 7.1.4). When this was assessed by independent samples t-test, there was no significant difference in the measurements between Roman and early medieval individuals in any of the vertebrae ($p > 0.05$ in all vertebrae). This proved that broadly, the transverse diameter of the vertebral neural canal did not show any signs of growth delay differing between the periods, despite the differences shown in the pathology and stature in the previous chapter.

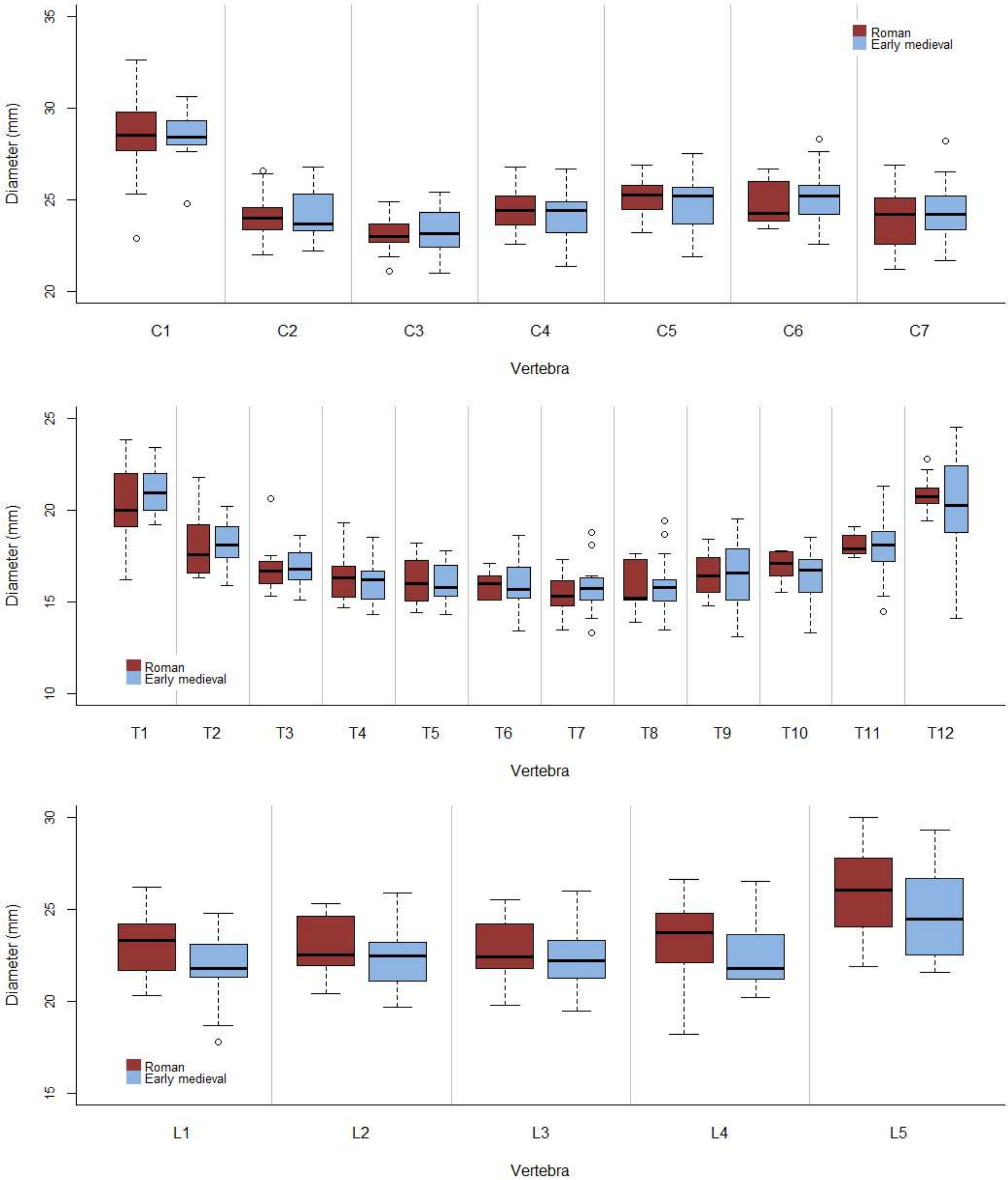


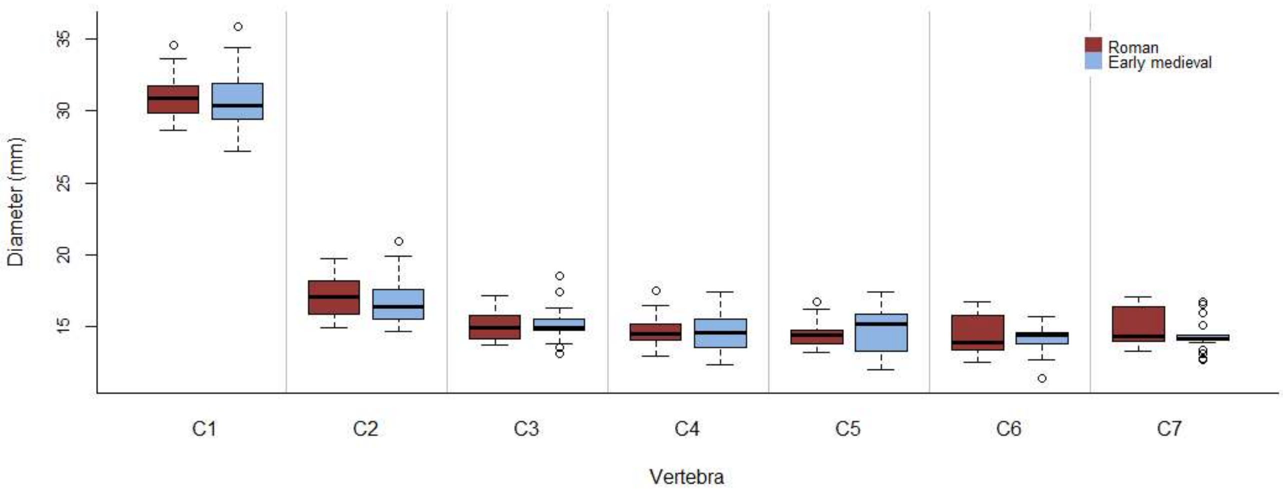
Figure 7.1.4: Boxplots comparing the mean, interquartile range and 1.5x interquartile range of the measurements of the transverse diameter of the VNC, in Roman and early medieval populations. The top graph shows cervical vertebrae, middle thoracic and bottom lumbar.

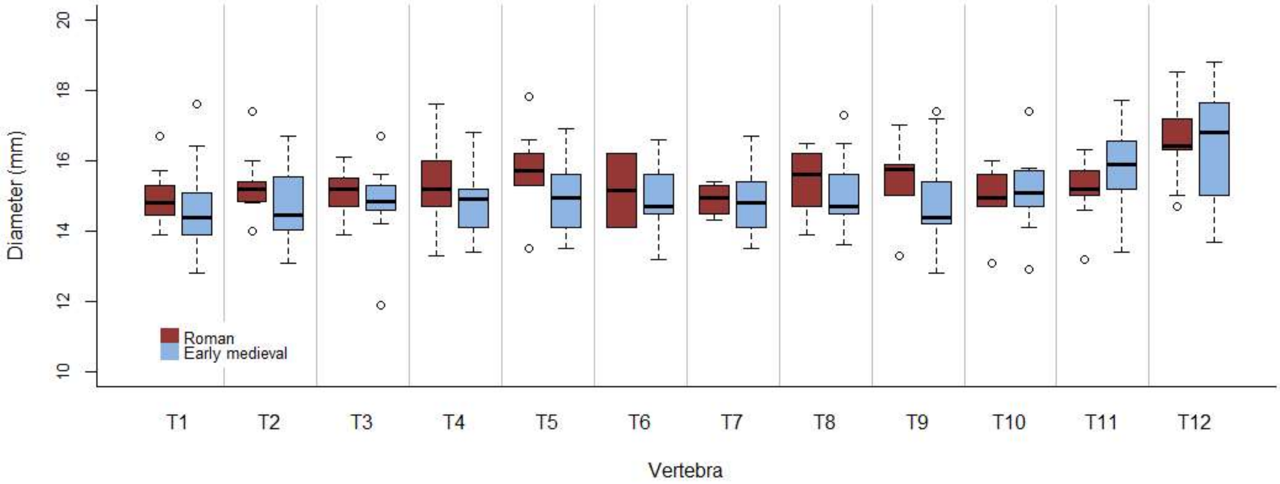
Vertebra	Roman		Early medieval		All	
	N	TR mean	N	TR mean	N	TR mean
C1	25	28.6	16	28.5	41	28.6
C2	27	24.1	25	24.3	52	24.2
C3	17	23.2	22	23.2	39	23.2
C4	16	24.4	19	24.2	35	24.3
C5	18	25.1	18	24.9	36	25.0
C6	16	24.8	22	25.1	38	25.0
C7	13	23.9	23	24.3	36	24.2
T1	14	20.3	24	21.0	38	20.7
T2	14	18.0	22	18.2	36	18.1
T3	10	16.9	18	16.9	28	16.9
T4	11	16.4	15	16.1	26	16.2
T5	8	16.2	17	16.0	25	16.0
T6	5	15.9	15	16.0	20	16.0
T7	7	15.4	16	16.0	23	15.8
T8	7	15.9	15	16.0	22	16.0
T9	7	16.5	14	16.5	21	16.5
T10	7	17.0	16	16.5	23	16.6
T11	11	18.1	16	18.0	27	18.0
T12	12	20.9	18	20.3	30	20.6
L1	10	23.2	17	21.8	27	22.3
L2	12	23.0	22	22.2	34	22.5
L3	14	22.7	19	22.3	33	22.5
L4	16	23.4	18	22.5	34	22.9

Vertebra	Roman		Early medieval		All	
	N	TR mean	N	TR mean	N	TR mean
L5	12	25.9	20	24.7	32	25.2

Table 7.1.1: The number (N) of measurements taken, and the mean transverse diameter of each vertebra in each period separately and the full dataset.

The anterior-posterior diameter also varied slightly between the periods, though again whether a period had a smaller or larger mean was not consistent between the vertebrae. The means were not significantly different when subject to independent samples t-tests between the Roman and early medieval populations in most vertebrae ($p > 0.05$). The sole exception to this was the L4 vertebra, where the mean anterior-posterior diameter was 17.1 mm from 13 Roman individuals, compared to a mean of 14.6 mm from 13 early medieval individuals (Figure 7.1.5; Table 7.1.2). This difference was found to be significant by an independent samples t-test ($p < 0.05$). On examining this result more closely, it became clear that the mean value was skewed high in the Roman population due to the high outlier in the individual from Grave 15 (G15) from Bainesse. Once this individual was removed from the analysis, the difference between the two periods was no longer statistically significant ($p > 0.05$). Hence, the results of the vertebral neural canal analysis have shown no difference in growth delay between the Roman and the early medieval period.





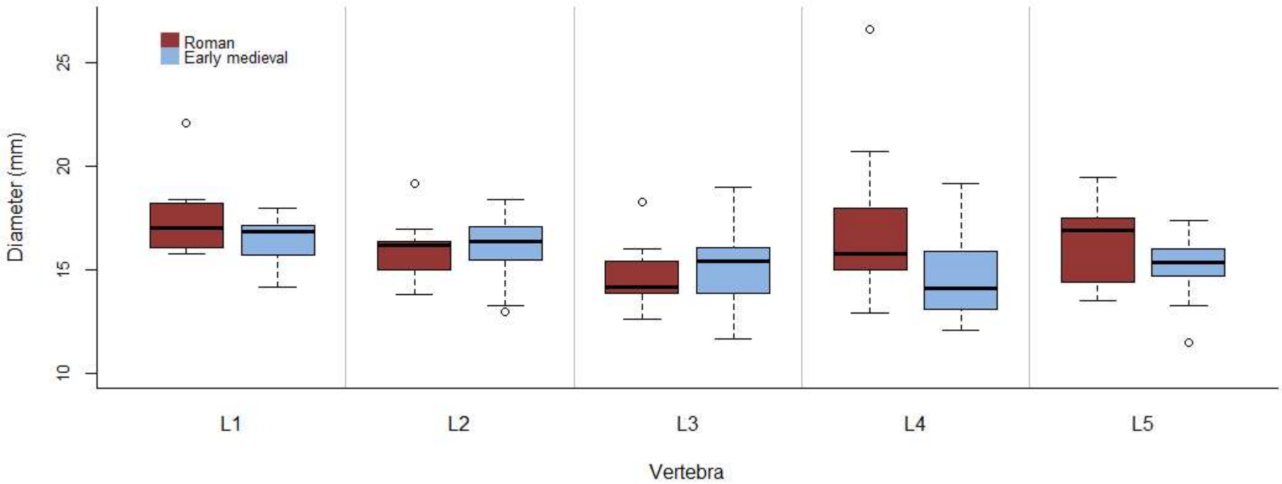


Figure 7.1.5: Boxplots comparing the mean, interquartile range and 1.5x interquartile range of the measurements of the anterior-posterior diameter of the VNC, in Roman and early medieval populations. The top graph shows cervical vertebrae, middle thoracic and bottom lumbar.

Vertebra	Roman		Early medieval		All	
	N	AP mean	N	AP mean	N	AP mean
C1	20	31.0	16	30.7	36	30.9
C2	24	17.1	20	16.8	44	17.0
C3	16	15.1	17	15.2	33	15.1
C4	16	14.7	14	14.7	30	14.7
C5	13	14.6	16	14.8	29	14.7
C6	13	14.5	18	14.1	31	14.3
C7	10	14.9	21	14.4	31	14.6

Vertebra	Roman		Early medieval		All	
	N	AP mean	N	AP mean	N	AP mean
T1	11	14.9	23	14.6	34	14.7
T2	12	15.3	20	14.7	32	14.9
T3	9	15.1	16	14.9	25	14.9
T4	7	15.4	13	14.8	20	15.0
T5	8	15.7	14	15.0	22	15.3
T6	2	15.2	14	14.9	16	14.9
T7	4	14.9	14	14.9	18	14.9
T8	6	15.4	11	15.2	17	15.2
T9	6	15.5	13	14.8	19	15.0
T10	6	14.9	13	15.1	19	15.0
T11	11	15.2	15	15.8	26	15.6
T12	10	16.5	15	16.4	25	16.4
L1	8	17.6	16	16.5	24	16.8
L2	9	16.0	22	16.2	31	16.1
L3	12	14.6	14	15.3	26	15.0
L4	13	17.1*	13	14.6*	26	15.8
L5	9	16.1	14	15.3	23	15.6

Table 7.1.2: The number (N) of measurements taken, and the mean anterior-posterior diameter of each vertebra in each period separately and the full dataset. Pairs of symbols (*) in the same row indicate significance.

7.1.2 Inter-sex comparison

As stated above, the comparison of the sexes was performed before the comparison of the time periods. However, for the sake of keeping all analyses in a standard order throughout this work, it is discussed here, subsequent to the comparison of the time periods.

There were a total of 44 males, 39 females, and three individuals of undetermined sex among the group of skeletons included in the study of the vertebral neural canal (Table 7.0.1). The mean values of the transverse diameter were generally slightly greater in males than females, except in the thoracic vertebrae, and those in the individuals of undetermined sex varied inconsistently between vertebrae in comparison to both males and females (Table 7.1.3). Comparing the males and females with independent samples t-tests found no significant difference in the mean values of the transverse diameter ($p > 0.05$), except in C3, where the male mean of 23.6mm was deemed to be significantly greater than the female mean of 22.8mm ($p < 0.05$). The variation in the transverse diameter was then compared between all three sex categories by a one-way ANOVA, which also found no significant association between vertebral neural canal size and sex in the majority of vertebrae ($p > 0.05$), with the exception of C3 ($p < 0.05$).

Vertebra	**Male**		**Female**		**Undetermined**	
	N	TR mean	N	TR mean	N	TR mean
C1	22	28.5	17	28.5	2	29.3
C2	31	24.3	20	23.9	1	24.6
C3	18	23.6*	21	22.8*	0	-
C4	17	24.6	18	23.9	0	-
C5	19	25.3	17	24.6	0	-
C6	21	25.1	17	24.7	0	-
C7	18	24.3	18	24.1	0	-
T1	17	20.7	21	20.7	0	-
T2	19	18.1	17	18.1	0	-
T3	13	16.8	15	17.0	0	-
T4	12	16.2	14	16.2	0	-
T5	11	16.0	14	16.1	0	-
T6	8	16.2	12	15.8	0	-
T7	11	15.6	12	16.0	0	-
T8	9	15.4	13	16.3	0	-
T9	10	16.1	11	16.8	0	-

Vertebra	Male		Female		Undetermined	
	N	TR mean	N	TR mean	N	TR mean
T10	11	16.7	12	16.6	0	-
T11	12	17.8	14	18.1	1	19.1
T12	14	20.9	15	20.0	1	21.0
L1	14	22.9	13	21.7	0	-
L2	16	23.0	18	22.1	0	-
L3	14	22.9	18	22.2	1	22.2
L4	16	23.3	17	22.6	1	21.8
L5	14	25.4	17	25.1	1	22.9

Table 7.1.3: The number (N) of measurements taken, and the mean transverse diameter of each vertebra separated by sex. Pairs of symbols (*) in the same row indicate significance.

In the anterior-posterior diameter, no sex had consistently greater or smaller means across the vertebrae, and any difference in means was small (Table 7.1.4). Comparing the measurements for each vertebra in males and females only by independent samples t-tests found no significant difference in the anterior-posterior means for most vertebrae ($p > 0.05$), with the exception of C6 and 7, and L2. In both C6 and C7, the anterior-posterior diameter was greater in males, with means of 14.7 mm and 15.0 mm respectively, compared to 13.7 mm and 14.1 mm respectively in females, both of which were deemed significant by the t-test ($p < 0.05$ in both cases). In L2 however, the mean anterior-posterior diameter was greater in females, at 16.6 mm compared to 15.5 mm in the males, which was deemed significant by the t-test ($p < 0.05$). When comparing each vertebra by one-way ANOVA in order to include those of undetermined sex, it was found that there was no significant difference between the sexes in most vertebrae ($p > 0.05$), with the same exceptions of C6 and 7, and L2. Overall it was found that while some measurements of certain vertebrae showed differentiation between males and females, there was no consistent pattern as to which sex had the greater measurement, and out of the 48 possible measurements (two diameters per vertebra for 24 vertebrae), 44 presented no difference. This lack of sex-based size difference was supported by Watts (2011) and Clark et al. (1986), who also found no difference between the sexes in their populations, which is why the decision was made not to separate males and females in the further analysis of the vertebral neural canal.

Vertebra	Male		Female		Undetermined	
	N	AP mean	N	AP mean	N	AP mean
C1	20	31.2	14	30.4	2	30.8
C2	28	17.2	15	16.6	1	18.2
C3	17	15.1	16	15.1	0	-
C4	12	14.6	18	14.8	0	-
C5	16	14.9	13	14.4	0	-
C6	17	14.7*	14	13.7*	0	-
C7	16	14.0*	15	14.1*	0	-
T1	17	15.0	17	14.5	0	-
T2	17	15.3	15	14.6	0	-
T3	12	14.7	13	15.1	0	-
T4	9	15.0	11	15.0	0	-
T5	9	15.3	13	15.2	0	-
T6	4	15.1	12	14.9	0	-
T7	8	14.9	10	14.9	0	-
T8	5	15.0	12	15.4	0	-
T9	8	14.7	11	15.2	0	-
T10	7	14.7	12	15.2	0	-
T11	12	15.4	14	15.8	0	-
T12	13	16.6	11	16.3	1	16.1
L1	13	16.6	11	17.1	0	-
L2	13	15.5*	18	16.6*	0	-
L3	11	14.9	14	15.2	1	12.3
L4	13	16.3	12	15.6	1	12.8

Vertebra	Male		Female		Undetermined	
	N	AP mean	N	AP mean	N	AP mean
L5	7	15.6	15	15.7	1	14.7

Table 7.1.4: The number (N) of measurements taken, and the mean anterior-posterior diameter of each vertebra separated by sex. Pairs of symbols (*) in the same row indicate significance.

7.1.3 Intra-period sex comparison

The individuals of the vertebral neural canal dataset were then divided by sex within the time period groups to ensure that the differing sex ratios in each period – 1.5:1 males to females in the Roman sample and 1:1.1 males to females in the early medieval – did not mask any sex-based difference in the combined assemblage. The Roman population comprised 23 males, 15 females, and two individuals of undetermined sex. In the transverse diameter, the mean was generally slightly larger in males in the cervical and lumbar vertebrae, and in the females in the thoracic vertebrae (Table 7.1.5). When comparing the males and females with independent samples t-tests, it was clear that these slight differences did not represent significant variance based on sex in most vertebrae ($p > 0.05$). In the only exception, T8, the male mean of 15.3 mm was found to be significantly smaller than the female mean of 17.6 ($p < 0.05$), and the Levene's test for homogeneity of variance was passed ($p > 0.05$), however, this comparison was performed between five males and only two females, so does not fully represent this measurement in the population as a whole. The early medieval population comprised 21 males, 24 females, and one individual of undetermined sex. Measurements of the transverse diameter appeared slightly larger in males than females in most vertebrae, though in T8, 9 and 11 the mean was larger in the females (Table 7.1.5). When the transverse diameter was compared between males and females by independent samples t-tests, no difference was found between the means in all vertebrae ($p > 0.05$). Overall it has been shown that sex had no effect on the transverse diameter of the vertebral neural canal.

Vertebra	Roman				Early medieval			
	Male		Female		Male		Female	
	N	TR mean	N	TR mean	N	TR mean	N	TR mean
C1	15	28.2	8	29.2	7	29.2	9	28.0
C2	18	24.1	8	23.9	13	24.6	12	24.0
C3	10	23.4	7	22.8	8	23.8	14	22.8
C4	10	24.6	6	24.0	7	24.6	12	23.9

Vertebra	Roman				Early medieval			
	Male		Female		Male		Female	
	N	TR mean	N	TR mean	N	TR mean	N	TR mean
C5	12	25.2	6	24.9	7	25.6	11	24.5
C6	11	24.9	5	24.4	10	25.3	12	24.9
C7	9	24.2	4	23.4	9	24.3	14	24.4
T1	7	19.7	7	20.8	10	21.4	14	20.7
T2	10	17.8	4	18.6	9	18.5	13	18.0
T3	7	16.5	3	17.9	6	17.1	12	16.8
T4	8	16.1	3	17.3	4	16.6	11	15.9
T5	6	15.8	2	17.3	5	16.3	12	15.9
T6	4	15.7	1	17.1	4	16.7	11	15.7
T7	6	15.1	1	17.3	5	16.1	11	15.9
T8	5	15.3*	2	17.6*	4	15.6	11	16.1
T9	6	16.3	1	17.8	4	15.9	10	16.7
T10	6	16.8	1	17.8	5	16.5	11	16.5
T11	8	18.0	3	18.4	4	17.5	11	18.1
T12	9	20.8	3	21.2	5	21.1	12	20.0
L1	8	23.0	2	24.0	6	22.7	11	21.3
L2	8	23.6	4	21.9	8	22.4	14	22.1
L3	8	23.2	6	22.1	6	22.6	12	22.2
L4	11	23.6	5	22.9	5	22.6	12	22.5
L5	7	25.5	5	26.5	7	25.3	12	24.5

Table 7.1.5: The number (N) of measurements taken, and the mean transverse diameter of each vertebra separated by sex and time period. Pairs of symbols (*) in the same row indicate significance.

Considering the anterior-posterior diameter in the Roman population (Table 7.1.6), the size was greater in the females than the males in most vertebrae, with several exceptions in each category of vertebrae. Testing this statistically, the anterior-posterior diameters of all vertebrae except L1 were determined not to differ significantly in males and females by independent samples t-tests ($p > 0.05$). In L1, the female measurement of 22.1 mm was found to be significantly greater than the male mean of 16.9 mm ($p < 0.05$). However, there was only one Roman female L1 measured in the anterior-posterior diameter, Bainesse G239, and the result of 22.1 mm was the largest of all L1 transverse measurements from the entire population, the next greatest being 18.4 mm, implying that either this measurement was incorrectly recorded, or there was a morphological variant present in that vertebra which put it outside of the normal range, and therefore it cannot be used to indicate a difference based on sex. This has shown that overall in the Roman sample, the vertebral neural canal dimensions were not influenced by the sex of the individual, and therefore the unequal ratio of males to females did not impact the picture of Roman growth delay in the vertebral neural canal. In the measurements of the anterior-posterior diameter for the early medieval population, there was again no consistency in which sex had the greater mean value, though most cervical vertebrae were larger in the males, and most thoracic and lumbar were larger in the females (Table 7.1.6). Independent samples t-tests were performed again for the anterior-posterior diameter, and found no significant difference between the means for males and females ($p > 0.05$) in any vertebra. As in the Roman population, and in the full sample, sex did not affect the growth of the vertebral neural canal in the study population from the early medieval period, confirming that the differing sex ratios in each time period did not impact the comparisons drawn between measurements of the vertebral neural canal.

Vertebra	**Roman**				**Early medieval**			
	Male		**Female**		Male		**Female**	
	N	AP mean	N	AP mean	N	AP mean	N	AP mean
C1	12	30.9	6	31.2	8	31.6	8	29.7
C2	17	17.1	6	17.1	11	17.3	9	16.3
C3	10	14.9	6	15.3	7	15.5	10	15.0
C4	9	14.7	7	14.9	3	14.3	11	14.7
C5	10	14.8	3	14.1	6	15.2	10	14.8
C6	9	15.0	4	13.4	8	14.4	10	13.9
C7	7	15.4	3	13.7	9	14.7	12	14.3
T1	7	15.0	4	14.9	10	14.9	13	14.4

Vertebra	Roman				Early medieval			
	Male		**Female**		Male		**Female**	
	N	AP mean	N	AP mean	N	AP mean	N	AP mean
T2	8	15.4	4	15.1	9	15.2	11	14.4
T3	6	14.9	3	15.5	6	14.6	10	15.0
T4	5	15.5	2	15.1	4	14.3	9	14.9
T5	6	15.7	2	15.8	3	14.6	11	15.1
T6	1	14.1	1	16.2	3	15.4	11	14.8
T7	4	14.9	0	-	4	14.9	10	14.9
T8	4	15.0	2	16.2	1	14.7	10	15.2
T9	5	15.4	1	15.8	3	13.6	10	15.1
T10	5	14.7	1	15.6	2	14.7	11	15.2
T11	8	15.0*	3	15.9	4	16.1*	11	15.7
T12	8	16.5	2	16.8	5	16.7	9	16.3
L1	7	16.9*	1	22.1*‡	6	16.3	10	16.6‡
L2	5	15.3	4	16.9	8	15.7	14	16.5
L3	7	14.8	5	14.3	4	14.9	9	15.8
L4	8	17.6	5	16.2	5	14.2	7	15.1
L5	4	15.7	5	16.5	3	15.3	10	15.3

Table 7.1.6: The number (N) of measurements taken, and the mean anterior-posterior diameter of each vertebra separated by sex and time period. Pairs of symbols (*, ‡) in the same row indicate significance.

7.1.4 Inter-period sex comparison

The dimensions of the vertebral neural canal were compared within each sex across the time periods, to fulfil the objective of uncovering sex-based variation in the overall response to the collapse of Roman control in Britain. Of the 44 males, 23 were from Roman contexts, and 21 from early medieval. The mean transverse diameter was generally slightly higher in the early medieval males from C1 to T8, and generally higher in the Roman males in T9 to L5 (Table 7.1.5). However the difference between the periods was not found to be significant by independent samples t-test for any of the vertebrae ($p > 0.05$). There were 39 females in total, 15 from the Roman period and 24 from the early medieval. The mean transverse diameters were generally similar in each period in the cervical vertebrae, and slightly higher in the Roman female population for the thoracic and lumbar vertebrae (Table 7.1.5). However these differences were determined to be insignificant by independent samples t-tests ($p > 0.05$) in all vertebrae.

For the majority of vertebrae, the comparison by t-test showed there was no significant difference in the mean anterior-posterior diameter between the Roman and early medieval males ($p > 0.05$), with the exception of T11, in which the Roman mean of 15.0 mm was found to be significantly lower than the early medieval mean of 16.1 mm ($p < 0.05$). It can therefore be concluded that overall, the vertebral neural canal size did not change in males between the Roman and early medieval periods because the majority of measurements across each diameter and all vertebrae presented no difference between the periods. In the females, the t-tests also showed that the anterior-posterior diameter did not change significantly over time in most vertebrae, with the exception of L1, which had a measurement of 22.1 mm in the Roman and a mean of 16.6 mm in the early medieval population. As has been discussed, that value of 22.1 mm was obtained from a single individual, Bainesse G239, and was an outlier much greater than the next largest value, so it is unlikely that it represented an actual change in the diameter over time. In summary, the dimensions of the vertebral neural canal did not change in response to the societal transition in either sex, meaning no inferences could be made as to whether sex-based resilience and ability to adapt to change existed in the study population.

7.1.5 Inter-age category comparison

The individuals included in the study of the vertebral neural canal were not evenly distributed between the age-at-death categories defined in section 4.2. Among the full assemblage, there were six individuals assigned to the Young Adult category, 32 to Young Middle Adult, 20 to Old Middle Adult, 19 to Mature Adult, and nine to the non-specific Adult category as they were not preserved well enough to estimate their age-at-death more precisely (Table 7.0.1). The vertebral neural canal dimensions were compared between these categories to determine whether stress in childhood affecting adult longevity could be seen in the growth delay of the vertebral neural canal. In the transverse diameter, the highest and lowest values were not confined to age categories across the vertebrae, instead the variation in the means was distributed differently over the age categories in each vertebra (Table 7.1.7). All five age categories were compared by one-way ANOVA, which showed there was no variance between the mean values depending on age at death, for any vertebra ($p > 0.05$). The test was then performed only on the four specific categories, i.e. excluding the Adult category, to check that the non-specific category had not obscured any connection. The results again showed no link between the transverse diameter and age-at-death in all vertebrae ($p > 0.05$).

Vertebra	YA		YMA		OMA		MA		A	
	N	TR mean	N	TR mean	N	TR mean	N	TR mean	N	TR mean
C1	2	29.0	16	28.5	11	28.7	10	28.6	2	27.8
C2	3	23.9	23	24.0	12	24.0	9	24.8	5	24.2
C3	4	23.3	16	22.9	8	23.2	6	23.8	5	23.2
C4	4	24.8	15	23.9	8	24.5	4	24.5	4	24.3
C5	4	25.8	16	24.8	8	25.1	5	25.4	3	24.3
C6	4	26.4	16	24.7	6	24.9	8	25.1	4	24.4
C7	3	25.8	12	24.1	9	24.2	8	23.9	4	23.8
T1	3	21.1	15	21.2	8	20.5	8	19.8	4	20.8
T2	2	18.7	15	18.5	10	17.7	6	17.9	3	18.1
T3	3	14.4	13	16.9	6	16.2	4	17.1	2	18.0
T4	3	16.7	13	16.5	6	15.2	3	16.5	1	16.6
T5	4	16.8	13	16.2	4	15.0	3	15.8	1	16.0
T6	3	17.3	11	15.9	4	14.9	1	17.1	1	15.7
T7	4	17.1	12	15.7	5	14.7	1	17.3	1	15.9
T8	4	16.8	9	15.9	6	15.4	2	16.4	1	16.0
T9	4	17.3	9	16.4	6	16.1	1	15.9	1	16.7
T10	2	17.0	12	16.8	6	16.2	2	16.8	1	17.0
T11	5	18.6	12	18.1	8	17.7	1	17.9	1	16.9
T12	4	20.9	16	20.6	8	20.6	1	19.9	1	19.0
L1	4	22.4	15	22.3	7	22.4	0	-	1	21.5
L2	5	21.9	15	22.3	7	22.4	6	23.7	1	21.7
L3	5	22.0	16	22.5	7	22.1	5	23.3	0	-
L4	5	23.1	13	22.9	8	22.2	7	23.8	1	20.9

Vertebra	YA		YMA		OMA		MA		A	
	N	TR mean	N	TR mean	N	TR mean	N	TR mean	N	TR mean
L5	3	26.9	14	25.0	9	24.4	4	26.7	2	23.8

Table 7.1.7: The number (N) of measurements taken, and the mean transverse diameter of each vertebra separated by assigned age-at-death category.

Similarly, in the anterior-posterior diameter, the age categories with the highest and lowest mean values changed with each vertebra, and no consistent pattern of growth delay was seen in any age group (Table 7.1.8). The comparison of all five categories via the one-way ANOVA did not show any variance in vertebral neural canal size between the age-at-death categories for any vertebra ($p > 0.05$). When testing the relationship between the four specific age categories, most vertebrae were also deemed to have no relationship between anterior-posterior diameter variance and age ($p > 0.05$), however L4 was indicated to have such a relationship ($p < 0.05$). On closer investigation by Tukey's HSD test, it was seen that the anterior-posterior diameter in the Young Adult category was significantly greater than that of the Old Middle Adult category ($p < 0.05$). Examining the data of the individuals, it became clear that the greater mean value in the Young Adult category was due to the very high outlier in G15 from Bainesse mentioned earlier, and therefore it is argued that there is no relationship between anterior-posterior diameter and age-at-death in L4. On the whole, there was no link found between either dimension of the vertebral neural canal and an individual's longevity in adulthood.

Vertebra	YA		YMA		OMA		MA		A	
	N	AP mean	N	AP mean	N	AP mean	N	AP mean	N	AP mean
C1	2	30.4	14	31.3	8	30.6	10	30.8	2	30.0
C2	3	16.4	31	17.1	12	16.9	4	17.3	4	16.8
C3	4	15.1	14	15.0	7	14.8	4	15.5	4	15.8
C4	4	14.4	12	14.7	7	14.3	4	14.8	3	16.0
C5	4	14.2	14	15.0	5	14.5	4	14.8	2	14.3
C6	4	13.7	12	14.7	5	13.9	6	14.0	4	14.5
C7	3	14.2	11	14.4	6	14.5	7	15.3	4	14.2
T1	3	14.5	14	14.5	9	14.8	5	15.3	3	14.
T2	2	15.8	14	14.7	9	15.2	4	15.1	3	5

T3	2	15.6	13	14.8	6	14.6	2	15.9	2	15.4
T4	2	15.8	10	14.9	4	14.7	3	15.3	1	14.1
T5	3	15.1	11	15.2	4	15.0	3	15.9	1	14.9
T6	3	15.6	9	14.7	2	14.8	1	16.2	1	14.2
T7	3	15.5	11	14.7	3	14.9	0	-	1	15.4
T8	3	15.8	7	14.9	5	15.1	1	16.5	1	15.5
T9	3	15.3	8	15.0	6	15.2	1	12.8	1	14.6
T10	2	15.1	11	14.9	4	15.2	1	15.0	1	15.8
T11	5	16.2	11	15.3	8	15.7	1	15.1	1	15.1
T12	4	16.8	13	16.5	6	16.4	1	16.4	1	14.5
L1	4	16.9	13	16.5	6	17.6	0	-	1	16.1
L2	5	17.1	14	15.8	7	16.1	4	16.1	1	17.1
L3	4	15.8	13	14.8	6	15.0	3	14.7	0	-
L4	4	19.6*	10	15.4	7	14.2*	4	16.3	1	14.1
L5	0	-	10	15.1	8	16.2	4	15.6	1	15.6

Table 7.1.8: The number (N) of measurements taken, and the mean anterior-posterior diameter of each vertebra separated by assigned age-at-death category. Pairs of symbols (*) in the same row indicate significance.

7.1.6 Intra-period age category comparison

The potential for association between age-at-death and delayed growth in the vertebral neural canal was then tested in the Roman and early medieval populations separately. The Roman group comprised two Young Adults, 15 Young Middle Adults, 11 Old Middle Adults, 10 Mature Adults, and two individuals in the non-specific Adult category. Comparing the mean transverse diameter between these groups showed a range of about two or three millimetres for all vertebrae, but no age category was consistently at the higher or lower end of the range across the vertebrae. Assessing the variance of each vertebra between the four specific age categories by a one-way ANOVA test showed that while there was no significant difference in mean transverse diameter in most vertebrae between the ages ($p > 0.05$), the variance between the age categories in T1, 4 and 5, and L2 and 5, was deemed to be significant ($p < 0.05$). Performing the Tukey's HSD test on these vertebrae to investigate the relationships between specific categories showed several cases of significant variance in transverse diameter between two age categories. In T1, the Young Middle Adult mean diameter of 22.1 mm was significantly larger than the 18.6 mm seen in the Mature Adult category ($p < 0.05$). In T4, the Young Middle Adult category was again the largest, at 18.0 mm compared to the significantly smaller mean of 15.4 mm in the Old Middle Adult category ($p < 0.05$). In T5, the Young Middle Adult mean diameter (18.2 mm) was again significantly larger than both those of Old Middle Adult (15.2 mm, $p < 0.05$) and Mature Adult (15.8 mm, $p < 0.05$). For L2, the mean transverse diameter in Old Middle Adults (21.9 mm) was significantly smaller than both that of the Young Middle Adult (24.4 mm, $p < 0.05$), and the Mature Adult (24.1 mm, $p < 0.05$) categories. Finally, in L5, the Old Middle Adult mean value was again lower than that of Mature Adult, at 24.3 mm compared to 28.1 mm ($p < 0.05$). Combined, these results present a tentative pattern of larger vertebral neural canals in those who died at a younger age, though this was not seen across all vertebrae.

In the early medieval group, there were four Young Adults, 17 Young Middle Adults, nine Old Middle Adults, nine Mature Adults, and seven in the non-specific Adult category. In the transverse diameter, similarly to the Roman population, the range of means was approximately two to three millimetres in each vertebra, with little consistent pattern in which age categories had the highest or lowest values. It was seen that in several thoracic vertebrae, the smallest means were generally in the Old Middle Adult category, but the measurements were all from one individual, so may only indicate that that individual has particularly small vertebrae. Conducting the one-way ANOVA test for all four specific age categories demonstrated that there was no variance in the measurements of the transverse diameter between the age categories for all vertebrae ($p > 0.05$).

Examining the mean anterior-posterior diameter in the Roman group also found inconsistent variance between the age categories, with many having two or fewer measurements per vertebra. The comparison of the four specific age categories by one-way ANOVA also showed no relationship between vertebral neural canal size and age-at-death in the majority of vertebrae ($p > 0.05$), except T1, 3 and 5 ($p < 0.05$). T3 could not be further investigated by Tukey's HSD test as there was only one individual in the Mature Adult category, but it was performed for both T1 and 5. In T1, the mean anterior-posterior diameter in Young Middle Adults, 15.8 mm, was significantly larger than that of Old Middle Adults (14.5 mm, $p < 0.05$). In T5, the anterior-posterior diameter was significantly larger in the Young Middle Adult category (16.8 mm) than both the Old Middle Adult (14.8 mm) and Mature Adult (15.9 mm) categories ($p < 0.05$). This analysis has shown that some individuals who died in early adulthood in the Roman period had larger vertebral neural canals than those who outlived them, in both the anterior-posterior and transverse diameters. However, it must be noted that this pattern was restricted to a few vertebrae, and the categories were very small, generally with two to five individuals in each per vertebra. Therefore, while the pattern revealed is intriguing, the sample size means it cannot be said to be representative of the population as a whole.

Likewise, when comparing the anterior-posterior diameter across the age categories for the early medieval population, the means ranged by up to four millimetres, but there was no consistent relationship between any age category and the highest or lowest values. Performing the one-way ANOVA confirmed that there was no relationship between the mean values and age at death in most vertebrae ($p > 0.05$), the exceptions being T2 and L4 ($p < 0.05$). In T2, the mean anterior-posterior diameter of 14.1 mm in the Young Middle Adult category was determined by Tukey's HSD test to be significantly smaller than the mean from the Old Middle Adult category (16.0 mm, $p < 0.05$). In L4, the Young Adult mean (18.5 mm) was significantly greater than those of the Old Middle Adult (13.8 mm) and Mature Adult categories (13.8 mm, $p < 0.05$). However, the larger mean diameter in the Young Adult category is again due to that high outlier in Bainesse G15 (section 7.1.1), and therefore does not indicate an actual difference on the population level. Overall, in the early medieval population there was very little association seen between age-at-death and vertebral neural canal size, with the only significant variation seen in one diameter of one vertebra, between only two age categories, with no other relationships in other vertebrae to support it.

7.1.7 Settlement type comparison

The final analysis of environmental effects which may have delayed growth in the vertebral neural canal was the comparison of the individuals from the Roman urban and Roman rural sites. This comparison was not performed in the early medieval assemblage as all sites within the study area in this period were rural in character. Among the 40 Roman individuals included in the study of the vertebral neural canal, 28 were from three urban sites – Bainesse, *Cataractonium*, and Healam Bridge – and 12 were from two rural sites – Dalton Parlours and Wattle Syke. Although this distribution was uneven, there were comparatively fewer rural individuals in the full assemblage so the small number is a reasonable representation of the full assemblage. In the transverse diameter, there were no measurements taken in T6, 7 and 8, from the rural population (Table 7.1.9). Assessing the transverse diameter of each measured vertebra found that the mean was generally slightly greater in the rural assemblage than the urban. However, comparing the means between settlement types by independent samples t-tests found that there was no significant difference in the mean diameter between the two groups in most vertebrae ($p > 0.05$), except L5, where the mean in the urban population was significantly smaller than that of the rural population, at 24.7 mm compared to 27.6 mm ($p < 0.05$).

The pattern seen in the anterior-posterior diameter was similar, with no measurements of T6, 7 and 8 from the rural population, and slightly greater mean values in the rural population. Again, no significant difference was seen in the mean diameter of the majority of vertebrae when subject to t-test ($p > 0.05$). The exception was C2, in which the mean diameter of 17.4 mm in the urban population was determined to be significantly greater than that of 15.7 mm in the rural population, the opposite relationship to that seen in the transverse diameter of L5. The general lack of difference in size between the urban and rural assemblages, and the opposing differences in the transverse diameter of L5 and the anterior-posterior diameter of C2 suggest that the growth and final size of the vertebral neural canal was not affected by the type of settlement in which an individual lived.

Vertebra	Transverse				Anterior-posterior			
	Urban		**Rural**		Urban		**Rural**	
	N	Mean	N	Mean	N	Mean	N	Mean
C1	18	28.6	7	28.7	15	31.1	5	30.9
C2	21	24.1	6	24.1	20	17.4*	4	15.7*
C3	13	23.0	4	23.7	12	15.2	4	14.6
C4	12	24.3	4	24.9	12	14.9	4	14.4
C5	13	25.0	5	25.3	10	14.6	3	14.7
C6	11	24.6	5	25.1	9	14.4	4	14.6
C7	9	23.9	4	24.0	6	14.7	4	15.3
T1	10	20.2	4	20.3	9	14.8	2	15.8
T2	11	17.9	3	18.7	10	15.1	2	16.1
T3	9	17.0	1	16.6	8	14.9	1	16.1
T4	8	16.1	3	17.2	4	15.1	3	15.7
T5	6	15.9	2	17.0	6	15.4	2	16.6
T6	5	15.9	0	-	2	15.2	0	-
T7	7	15.4	0	-	4	14.9	0	-
T8	7	15.9	0	-	6	15.4	0	-
T9	6	16.2	1	18.4	5	15.1	1	17.0
T10	5	16.8	2	17.4	4	14.6	2	15.5
T11	9	18.1	2	17.9	9	15.2	2	15.3
T12	9	20.7	3	21.3	8	16.5	2	16.7
L1	8	22.9	2	24.7	7	17.6	1	17.4
L2	7	22.6	5	23.5	6	15.9	3	16.2
L3	9	22.8	5	22.7	8	14.7	4	14.5

Vertebra	Transverse				Anterior-posterior			
	Urban		**Rural**		Urban		**Rural**	
	N	Mean	N	Mean	N	Mean	N	Mean
L4	10	23.4	6	23.3	8	17.4	5	16.4
L5	7	24.7*	5	27.6*	5	15.9	4	16.4

Table 7.1.9: The number (N) of measurements taken, and the mean transverse and anterior-posterior diameter of each vertebra in the urban and rural sites. Pairs of symbols (*) in the same row indicate significance.

7.1.8 Summary of the results from analysis of the vertebral neural canal

The study of the vertebral neural canal in a subset of the total case study population found a surprising lack of variation overall. The strong indications of childhood stress in the Roman period from the pathology and stature discussed in the previous chapter indicated that the same stress would be visible as growth delay in the vertebral neural canal, but this was not the case. In both the transverse and anterior-posterior diameters, any variation was found to be inconsistent between vertebrae, and insignificant between period, sex, age at death and settlement type. Therefore, the vertebral neural canal does not seem to be as sensitive to negative environmental influences as the other indicators of stress examined in this work.

7.2 Comparison of measures of growth delay

Four measures of growth delay were assessed in the course of this study: stature, transverse diameter, anterior-posterior diameter, and the vertebral body height. These measures were compared to each other in order to evaluate whether delay in one measure correlated with delay in the others, or whether they did not respond in the same way to stress.

7.2.1 Correlation between the transverse and anterior-posterior diameters

The relationship between transverse and anterior-posterior values was assessed across all vertebrae with Pearson's correlation coefficient and linear regression, in order to determine whether smaller size in one diameter was directly related to smaller size in the other, whether this was caused by growth delay or an individual's genetics. The correlation was positive in all vertebrae, but not particularly strong (Table 7.2.1). It was seen that there were significant ($p < 0.05$) positive linear relationships in one third of vertebrae, namely C2 and 5, and L5, which had moderate positive correlations ($0.3 < r < 0.5$), and T6, 8 and 9, and L3-4, which had strong positive correlations ($0.5 < r < 0.9$). There were also moderate positive linear relationships in T3-

5, 7, 10 and 12, and L1, which were not found to be statistically significant ($p > 0.05$), and several weak positive correlations ($0 < r < 0.3$) in C1, 3, 4, 6 and 7, T1, 2 and 11, and L2, which were also not significant ($p > 0.05$). Examining the statistically significant positive correlations further with a linear regression model showed that in the vertebrae with strong correlations between the two vertebral neural canal diameters, variation in one predicted 30-44% of the variation in the other. In those vertebrae with moderate correlations, variation in one diameter predicted 10-21% of variation in the other. It was therefore determined that the transverse and anterior-posterior diameters of vertebrae were related to each other, with greater size in one making greater size in the other more likely, but that the majority of the variation was dependent on other variables. Potentially, this consistent but moderate relationship would have been stronger with more individuals included, and better preservation of vertebrae. Alternatively, the correlation may only be moderate due to the different growth patterns in the two diameters: the anterior-posterior diameter ceases growth in early childhood and the transverse diameter continues growing into adolescence so has a greater length of time for size to diverge from that of the anterior-posterior diameter.

Vertebra	N	r	p	R^2
C1	35	0.262	0.13	0.069
C2	43	0.316	0.04*	0.100
C3	32	0.184	0.31	0.034
C4	29	0.185	0.34	0.034
C5	29	0.374	0.05*	0.140
C6	31	0.207	0.26	0.043
C7	31	0.151	0.42	0.023
T1	33	0.295	0.10	0.087
T2	32	0.267	0.14	0.071
T3	25	0.340	0.10	0.115
T4	20	0.413	0.07	0.171
T5	22	0.408	0.06	0.091
T6	16	0.587	0.02*	0.345
T7	18	0.434	0.07	0.188
T8	17	0.584	0.01*	0.341

Vertebra	N	r	p	R^2
T9	19	0.574	0.01*	0.329
T10	19	0.429	0.07	0.184
T11	26	0.114	0.58	0.013
T12	25	0.309	0.13	0.095
L1	24	0.325	0.12	0.105
L2	31	0.046	0.81	0.002
L3	26	0.548	0.004*	0.300
L4	26	0.667	0.001*	0.444
L5	23	0.459	0.03*	0.210

Table 7.2.1: Number of individuals included (N), Pearson's correlation coefficient (r), P value indicating significance of r not being 0, and the coefficient of determination (R^2) for each vertebra when the TR and AP diameters were compared. Symbols (*) flag significant p values.

7.2.2 Correlation between the transverse diameter and vertebral body height

Vertebral body height contributes directly to an individual's living stature, as it determines the length of the spine and therefore the length of the torso. The relationship between body height and transverse diameter was examined with Pearson's correlation coefficient to determine whether size in one was associated with size in the other. There was a generally positive correlation, though it was weak and inconsistent (Table 7.2.2). In four vertebrae, a significant relationship ($p < 0.05$) was found; T10 and 12, and L3 presented strong positive correlations ($0.5 < r < 0.9$) in which greater body height was associated with greater transverse diameter, and L4 had a similar moderate positive correlation ($0.3 < r < 0.5$). Testing these significant results with linear regression models showed that variation in the transverse diameter explained 52% of variation in vertebral body height for T10 and 12, 27% for L3 and 24% for L4. There were also several vertebrae in which there was a positive correlation which was not found to be significant ($p > 0.05$), including a weak relationship ($0 < r < 0.3$) in C3 and 5, and T2-4 and 9, a moderate relationship in C4, T11 and L2, and a strong relationship in T6 and L1. However, there was also uncertainty in the relationship between transverse diameter and vertebral body height, because there were negative correlations in seven vertebrae, indicating that greater size in one dimension was linked to smaller size in the other. Though all were statistically insignificant ($p > 0.05$), weak negative correlations ($-0.3 < r < 0$) were found in C6 and 7, and T1 and 7, a moderate negative correlation ($-0.5 < r < -0.3$) was found in T5, and strong negative correlations were found in T8 and L5 ($-0.9 < r < -0.5$). In summary, while four vertebrae had a definite link between greater transverse diameter and greater body height, supported by the 11 vertebrae with positive relationships that were not significant, seven of the 22 vertebrae (not counting C1 and C2 as vertebral body height measurements cannot be taken in these vertebrae) did not follow this trend, and therefore called into question the validity of support given by the insignificant positive correlations.

Vertebra	N	r	p	R^2
C3	24	0.266	0.21	0.071
C4	19	0.405	0.09	0.164
C5	21	0.058	0.80	0.003
C6	19	-0.084	0.73	0.007
C7	18	-0.091	0.72	0.008
T1	16	-0.003	0.99	0.000
T2	11	0.232	0.49	0.054
T3	10	0.235	0.51	0.055
T4	13	0.248	0.41	0.062
T5	7	-0.314	0.49	0.099
T6	3	0.540	0.64	0.291
T7	9	-0.039	0.92	0.002
T8	6	-0.563	0.25	0.317
T9	8	0.121	0.78	0.015
T10	9	0.720	0.03*	0.519
T11	9	0.482	0.19	0.232
T12	10	0.718	0.02*	0.516
L1	10	0.543	0.11	0.295
L2	11	0.417	0.20	0.174
L3	15	0.516	0.05*	0.267
L4	17	0.487	0.05*	0.237

Vertebra	N	r	p	R^2
L5	12	-0.547	0.07	0.299

Table 7.2.2: Number of individuals included (N), Pearson's correlation coefficient (r), P value indicating significance of r not being 0, and the coefficient of determination (R^2) for each vertebra when the TR diameter was compared to vertebral body height. Symbols (*) flag significant p values.

7.2.3 Correlation between the anterior-posterior diameter and vertebral body height

A similar comparison was performed with the anterior-posterior diameter and vertebral body height, to ascertain whether the two diameters had different relationships with body height as they were not consistently strongly related to each other. The comparison could only be conducted in 21 vertebrae, as C1 and C2 do not have measurable vertebral bodies, and T6 only had both body height and anterior-posterior measurements in two individuals thereby creating a perfect yet unreliable correlation. There was not a clear pattern in the correlation, with great variation between strong positive and negative relationships (Table 7.2.3). Only one correlation was judged to be significant in this test, with T11 found to have a significant strong negative correlation ($-0.9 < r < -0.5$, $p < 0.05$), though the linear regression model demonstrated that only 46% of the variation in the anterior-posterior diameter could be explained by the vertebral body height, clearly indicating the presence of other influences. There were also several negative correlations which were not statistically significant ($p > 0.05$), including weak relationships in T10 and L2, and moderate relationships in C3 and T8 and 9. In all other vertebrae, there were positive correlations which were not statistically significant. In C4, 5 and 7, T1, 3-5, 7 and 12 and L1 and 3-5 there were weak positive correlations, a moderate positive correlation was found in C6, and a strong positive correlation was found in T2. Similarly to the comparison of vertebral body height with the transverse diameter, there was no consistent relationship between the vertebral body height and anterior-posterior diameter, so it cannot be said that the two measures were associated. The degree of variation in the correlations was greater than the variation seen when comparing body height with transverse diameter, indicating that growth in body height and anterior-posterior diameter is affected very differently, and may be related to the early fixation of anterior-posterior diameter in comparison to both transverse diameter and stature.

Vertebra	N	r	p	R^2
C3	20	-0.333	0.15	0.111
C4	17	0.019	0.94	0.000
C5	19	0.261	0.28	0.068
C6	19	0.410	0.08	0.168

Vertebra	N	r	p	R^2
C7	16	0.251	0.35	0.063
T1	15	0.043	0.88	0.002
T2	11	0.540	0.09	0.291
T3	9	0.187	0.63	0.035
T4	11	0.191	0.57	0.036
T5	6	0.226	0.67	0.051
T6	2	-	-	-
T7	9	0.205	0.60	0.042
T8	6	-0.471	0.35	0.222
T9	8	-0.352	0.39	0.124
T10	7	-0.289	0.53	0.084
T11	9	-0.678	0.05*	0.460
T12	10	0.234	0.52	0.055
L1	10	0.235	0.51	0.055
L2	10	-0.145	0.69	0.021
L3	13	0.223	0.47	0.050
L4	14	0.211	0.47	0.044
L5	9	0.018	0.96	0.000

Table 7.2.3: Number of individuals included (N), Pearson's correlation coefficient (r), P value indicating significance of r not being 0, and the coefficient of determination (R^2) for each vertebra when the AP diameter was compared to vertebral body height. Symbols (*) flag significant p values.

7.2.4 Correlation between stature and the transverse diameter

It was originally expected that stature would be correlated with both the transverse and anterior-posterior diameters, because both are affected by growth delay, though the lack of evidence for growth delay in the vertebral neural canal introduced an amount of uncertainty. The Pearson's correlation coefficient was therefore calculated for both diameters of each vertebra paired with stature to test for a linear relationship between the measures. Comparing the transverse diameter of each vertebra with the stature of the individual did not find a statistically significant relationship in any vertebra ($p > 0.05$), and the linear regression models indicated that very little of the variation in the transverse diameter was explained by the individual's stature. The majority of vertebrae had a weak positive correlation (Table 7.2.4), with Pearson's correlation coefficient (r) between 0 and 0.3, a moderate positive correlation was found in T6 and 12, and L2-5 ($0.3 < r < 0.5$), and in T1, 8 and 11, there was a weak negative correlation ($-0.3 < r < 0$). Among the 86 individuals of the vertebral neural canal study, it was therefore seen that stature and transverse diameter were largely independent of each other, though potentially a larger sample size would have indicated significance in the moderate correlations.

Vertebra	N	r	P	R^2
C1	23	0.028	0.90	0.001
C2	28	0.199	0.31	0.039
C3	21	0.183	0.43	0.033
C4	22	0.162	0.47	0.026
C5	21	0.060	0.80	0.004
C6	18	0.178	0.48	0.032
C7	19	0.219	0.37	0.048
T1	20	-0.031	0.90	0.001
T2	20	0.012	0.96	0.000
T3	16	0.079	0.77	0.006
T4	17	0.181	0.49	0.033
T5	15	0.237	0.39	0.056
T6	11	0.409	0.21	0.167
T7	14	0.112	0.70	0.013
T8	15	-0.173	0.54	0.030
T9	14	0.039	0.89	0.002
T10	16	0.126	0.64	0.016
T11	18	-0.014	0.96	0.000

Vertebra	N	r	P	R^2
T12	20	0.340	0.14	0.115
L1	18	0.289	0.25	0.084
L2	22	0.363	0.10	0.132
L3	22	0.346	0.12	0.120
L4	19	0.401	0.09	0.161
L5	20	0.397	0.08	0.158

Table 7.2.4: Number of individuals included (N), Pearson's correlation coefficient (r), P value indicating significance of r not being 0, and the coefficient of determination (R^2) for each vertebra when the TR diameter was compared with stature.

7.2.5 Correlation between stature and the transverse diameter in each time period

The comparison between stature and the vertebral neural canal was then drawn in the populations from each time period separately, to ascertain whether the weak relationship changed in either or both periods. Pearson's correlation coefficient was calculated for the diameter of each vertebrae paired with stature in order to assess the strength of the correlation (Table 7.2.5). In the Roman period group, none of the correlations, whether positive or negative, were found to be statistically significant ($p > 0.05$). Only L2 had a strong positive correlation between stature and the transverse diameter ($0.5 < r < 0.9$), though the linear regression model showed only 34.8% of variation in the transverse diameter to be explained by stature. There were also moderate positive correlations in C3, 4 and 7, T6, and L3 and 4 ($0.3 < r < 0.5$), and weak positive correlations in C2,5 and 6, T4 and 5, and L5 ($0 < r < 0.3$). In addition, there were strong negative correlations in T7 and 8 ($-0.9 < r < -0.5$), which were demonstrated by the linear regression models to explain 43.5% and 41.8% of variation respectively. There was also a moderate negative correlation in T11 ($-0.5 < r< -0.3$), and weak negative correlations in C1, T1-3, 9-10 and 12, and L1 ($-0.3 < r < 0$). The variation across the spine shows that the relationship between the transverse diameter and stature was weak and unclear overall in the Roman period, in the same manner as in the full study population.

Repeating this analysis in the early medieval period individuals yielded results more strongly suggesting a relationship than those in either the Roman period population or the full population of both time periods. In the transverse diameter, there were statistically significant ($p < 0.05$) strong positive correlations in T12 and L4 and 5. Linear regression models found that in T12, almost half (47.8%) of the variation could be explained by stature, and this figure was even greater in L4 and 5, at 72.7% and 67.5% respectively. The remaining vertebrae did not have significant correlations ($p > 0.05$). There was a strong positive correlation between stature and transverse diameter in C5 and 6, T3,4 and 12, and L1, 4 and 5. A moderate positive correlation was present in C1 and 2, T5-7, and L2 and 3, and weak positive correlations were present in C3, 4 and 7, and T1, 2 and 8-11. While the majority of these relationships were not deemed statistically significant, they were positive in all vertebrae, thereby supporting those in which they were significant and strengthening the overall picture of greater transverse diameters in the individuals with greater stature in the early medieval period population.

Vertebra	**Roman**				**Early medieval**			
	N	r	P	R^2	N	r	P	R^2
C1	18	-0.085	0.74	0.007	5	0.468	0.43	0.219
C2	19	0.140	0.57	0.020	9	0.383	0.31	0.147
C3	13	0.364	0.22	0.132	8	0.132	0.76	0.017
C4	13	0.338	0.26	0.114	9	0.147	0.71	0.022
C5	15	0.016	0.95	0.000	6	0.738	0.09	0.544
C6	12	0.152	0.64	0.023	6	0.535	0.27	0.286
C7	12	0.310	0.33	0.096	7	0.121	0.80	0.015
T1	13	-0.042	0.89	0.002	7	0.040	0.93	0.002
T2	12	-0.057	0.86	0.003	8	0.243	0.56	0.059
T3	9	-0.039	0.92	0.002	7	0.712	0.07	0.507
T4	10	0.175	0.63	0.031	7	0.562	0.19	0.316
T5	7	0.013	0.98	0.000	8	0.407	0.32	0.166
T6	4	0.400	0.60	0.160	7	0.486	0.27	0.236
T7	6	-0.660	0.15	0.435	8	0.416	0.31	0.173
T8	7	-0.646	0.12	0.418	8	0.166	0.70	0.027
T9	6	-0.055	0.92	0.003	8	0.093	0.83	0.009
T10	7	-0.288	0.53	0.083	9	0.264	0.49	0.070
T11	10	-0.375	0.29	0.141	8	0.203	0.63	0.041
T12	11	-0.122	0.72	0.015	9	0.691	0.04*	0.478

Vertebra	Roman				Early medieval			
	N	r	P	R^2	N	r	P	R^2
L1	9	-0.021	0.96	0.000	9	0.610	0.08	0.372
L2	10	0.590	0.07	0.348	12	0.375	0.23	0.140
L3	11	0.428	0.19	0.183	11	0.370	0.26	0.137
L4	13	0.382	0.20	0.146	6	0.853	0.03*	0.727
L5	12	0.178	0.58	0.032	8	0.822	0.01*	0.675

Table 7.2.5: Number of individuals included (N), Pearson's correlation coefficient (r), P value indicating significance of r not being 0, and the coefficient of determination (R^2) for each vertebra when the TR diameter was compared with stature in the populations from each period. Symbols (*) flag significant p values.

7.2.6 Correlation between stature and the anterior-posterior diameter

As stated, it was expected that stature would correlate to both diameters of the vertebral neural canal, and it was therefore surprising when it did not in the transverse diameter. A similar result was seen when comparing the anterior-posterior diameter to stature with Pearson's correlation coefficient, though there were more vertebrae presenting negative correlations (Table 7.2.6). There was only one relationship which bordered on significance ($p = 0.05$), a strong positive correlation ($0.5 < r < 0.9$) in C7, though the linear regression model found that only 26.2% of the variance in the anterior-posterior diameter could be explained by stature. In all other vertebrae the correlations found were statistically insignificant ($p > 0.05$). There was a weak positive correlation ($0 < r < 0.3$) in C2-4, T1, 9 and 12, and L3-5, and moderate positive correlations in C1, 5 and 6, and T2 and 4-6 ($0.3 < r < 0.5$). There were also negative relationships in many vertebrae: weak negative correlations ($-0.3 < r < 0$), where anterior-posterior diameter decreased as stature increased, were found in T7, 8, 10 and 11, and L1 and 2, and one moderate negative correlation between anterior-posterior diameter and stature, in T3 ($-0.5 < r < -0.3$). In summary, the lack of correlation between stature and vertebral neural canal size in this sample population was maintained in the anterior-posterior diameter, with no significant linear relationships with stature for any vertebra, and variation in positive and negative correlations.

Vertebra	N	r	P	R^2
C1	18	0.367	0.13	0.134
C2	26	0.218	0.29	0.047

Vertebra	N	r	P	R^2
C3	17	0.049	0.85	0.002
C4	18	0.142	0.57	0.020
C5	16	0.334	0.21	0.112
C6	15	0.452	0.09	0.204
C7	15	0.512	0.05 *	0.262
T1	19	0.154	0.53	0.024
T2	17	0.396	0.12	0.157
T3	15	-0.315	0.25	0.099
T4	14	0.358	0.21	0.128
T5	15	0.332	0.23	0.007
T6	9	0.306	0.42	0.094
T7	10	-0.011	0.98	0.000
T8	12	-0.069	0.83	0.005
T9	14	0.126	0.67	0.016
T10	15	-0.047	0.87	0.002
T11	18	-0.118	0.64	0.014
T12	15	0.104	0.71	0.011
L1	15	-0.217	0.44	0.047
L2	20	-0.210	0.38	0.044
L3	20	0.112	0.64	0.013
L4	17	0.294	0.25	0.087
L5	16	0.288	0.28	0.083

Table 7.2.6: Number of individuals included (N), Pearson's correlation coefficient (r), P value indicating significance of r not being 0, and the coefficient of determination (R^2) for each vertebra when the AP diameter was compared with stature. Symbols (*) flag significant p values.

7.2.7 Correlation between stature and the anterior-posterior diameter in each time period

The same comparison was then performed in the Roman and early medieval populations separately, to determine whether the growth delay seen in stature in the Roman population affected the relationship with the anterior-posterior diameter of the vertebral neural canal. Similar confusion to that in the transverse diameter was present when comparing stature to the anterior-posterior diameter of each vertebra in the Roman period (Table 7.2.7). There was one very strong positive correlation in T7 ($0.9 < r < 1.0$) though there were only three individuals included in this test which likely affected the result, and strong positive correlations in C6 and 7, and T2, 4 and 5, though linear regression found that stature only explained 26.5-41.1% of variation in the anterior-posterior diameter of these vertebrae. Moderate positive correlations were seen in T1 and 9, and L3, and weak positive correlations in C4 and 5, and L4 and 5. There were also several negative correlations; strong in T11 and L1, moderate in C2, T8 and L2, and weak in C1 and 3, and T3, 10 and 12. T6 was not included in these calculations as only two individuals had measurements for both stature and anterior-posterior diameter, and therefore the correlation could not be assessed. In all vertebrae, the anterior-posterior diameter was not found to have a statistically significant relationship to stature ($p > 0.05$), and the variance in positive and negative correlations suggested again that there was little relationship between the two measures in the Roman period.

In the population from the early medieval period, the correlation with stature was positive in the majority of vertebrae, with strong positive correlations in C1-3 and 5-7, T2, and L4 and 5, moderate positive correlations in C4 and T6, 11 and 12, and weak positive correlations in T4, 5, 8 and 10, and L1. Only the strong positive correlation in C2 was determined to be statistically significant ($p < 0.05$), and performing linear regression for this vertebra found 68.7% of variation in the anterior-posterior diameter to be explained by stature, showing that while other factors were involved, the major influence was stature. There were contrasting negative correlations in the other vertebrae; moderate in T3 and weak in T1, 7 and 9 and L2 and 3, though none of these were statistically significant ($p > 0.05$). The mixed response in the anterior-posterior diameter was reminiscent of that seen in both the Roman population and the full study sample, and supports the inference that the anterior-posterior diameter was less likely to be affected by environmental conditions due to its short growth period, as it had an even more unclear relationship to stature than the transverse diameter.

Vertebra	**Roman**				**Early medieval**			
	N	r	P	R^2	N	r	P	R^2
C1	13	-0.076	0.81	0.006	5	0.784	0.12	0.614
C2	17	-0.306	0.23	0.094	9	0.829	0.006*	0.687

Vertebra	Roman				Early medieval			
	N	r	P	R^2	N	r	P	R^2
C3	11	-0.084	0.81	0.007	6	0.534	0.28	0.285
C4	12	0.016	0.96	0.000	6	0.409	0.42	0.167
C5	10	0.091	0.80	0.008	6	0.669	0.15	0.448
C6	9	0.515	0.16	0.265	6	0.575	0.23	0.330
C7	9	0.641	0.06	0.411	6	0.591	0.22	0.349
T1	11	0.470	0.15	0.221	8	-0.086	0.84	0.007
T2	10	0.529	0.12	0.280	7	0.604	0.15	0.365
T3	8	-0.023	0.96	0.001	7	-0.349	0.44	0.122
T4	7	0.517	0.24	0.267	7	0.256	0.58	0.066
T5	7	0.597	0.16	0.356	8	0.093	0.83	0.007
T6	2	-	-	-	7	0.418	0.35	0.175
T7	3	0.996	0.06	0.992	7	-0.225	0.63	0.051
T8	6	-0.402	0.43	0.161	6	0.189	0.72	0.036
T9	6	0.402	0.43	0.161	8	-0.060	0.89	0.004
T10	6	-0.232	0.66	0.054	9	0.061	0.88	0.004
T11	10	-0.628	0.05	0.395	8	0.314	0.45	0.099
T12	9	-0.277	0.47	0.077	6	0.490	0.32	0.240
L1	7	-0.551	0.20	0.304	8	0.143	0.74	0.020
L2	8	-0.369	0.37	0.136	12	-0.125	0.70	0.016
L3	10	0.320	0.37	0.102	10	-0.122	0.74	0.015
L4	11	0.200	0.56	0.040	6	0.747	0.09	0.558
L5	9	0.195	0.61	0.038	7	0.558	0.19	0.311

Table 7.2.7: Number of individuals included (N), Pearson's correlation coefficient (r), P value indicating significance of r not being 0, and the coefficient of determination (R^2) for each vertebra when the AP diameter was compared with stature in the populations of either time period. Symbols (*) flag significant p values.

7.2.8 Correlation between stature and vertebral body height

As vertebral body height directly contributes to an individual's stature, it was expected that the two would be correlated in all vertebrae. The relationship was tested in order to assess whether this was true in the study population. Pearson's correlation coefficient was considered strong in many more vertebrae compared to the comparison of the vertebral neural canal with stature, or the vertebral neural canal with vertebral body height. The correlation was deemed significant ($p < 0.05$) in 7 vertebrae, namely C3,4 and 7, T1 and 3, and L2, in which the correlation was strong ($0.5 < r < 0.9$), and T5, in which the correlation was very strong ($0.9 < r < 1.0$). Linear regression models for these vertebrae found that 41.8-92.7% of variation in vertebral body height was predicted by stature, showing how closely related these two measures are. In most other vertebrae, the correlation between the individual's stature and vertebral body height was positive but not statistically significant ($p > 0.05$); the relationship was weak in T7, and L3 and 5 ($0 < r < 0.3$), moderate in C5, T2 and 9-11, and L1 and 4 ($0.3 < r < 0.5$), and strong in C6 and T4, 8 and 12. In addition to these predicted results, there was a weak negative correlation between stature and vertebral body height in L5, though it was not statistically significant and only 12 individuals were included in the test. Overall, the expected relationship was present wherein an individual with greater stature would also present greater vertebral body height (Table 7.2.8). Though this was not deemed statistically significant in most vertebrae, the small sample size may have caused this, and a larger group could have more robustly assessed the link between vertebral body height and stature in the case study area.

Vertebra	N	r	p	R^2
C3	13	0.685	0.01*	0.469
C4	13	0.669	0.01*	0.448
C5	12	0.446	0.15	0.199
C6	9	0.647	0.06	0.419
C7	12	0.647	0.02*	0.418
T1	12	0.743	0.01*	0.551
T2	7	0.442	0.32	0.195
T3	9	0.819	0.01*	0.671
T4	9	0.586	0.10	0.343
T5	4	0.963	0.04*	0.927

Vertebra	N	r	p	R^2
T6	2	-	-	-
T7	8	0.244	0.56	0.060
T8	4	0.835	0.17	0.697
T9	6	0.468	0.35	0.219
T10	8	0.311	0.45	0.096
T11	8	0.370	0.37	0.137
T12	7	0.640	0.12	0.409
L1	9	0.390	0.30	0.152
L2	10	0.688	0.03*	0.474
L3	15	0.178	0.53	0.032
L4	16	0.349	0.19	0.121
L5	12	-0.115	0.72	0.013

Table 7.2.8: Number of individuals included (N), Pearson's correlation coefficient (r), P value indicating significance of r not being 0, and the coefficient of determination (R^2) for each vertebra when the stature was compared to vertebral body height. Symbols (*) flag significant p values.

7.2.9 Summary of the comparison of measures of growth delay

Comparing the four different measures of growth and their potential delay did not find clear relationships between the variables as would have been expected. The two measures of the vertebral neural canal, as well as stature and the vertebral body height were the most related pairs with moderate correlations and statistical significance in several vertebrae, understandably so given the transverse and anterior-posterior diameters are physically connected, and vertebral body height is a contributor to a person's overall stature. However, any comparisons between the measures of height and the measures of diameter were inconclusive, finding great variation in the direction and strength of the correlations, and creating a picture of generally unconnected measures which were more likely to be related by chance on the occasions when it did happen. While it is likely that the small sample size obscured the connections of these measures, it is also considered that these measures may not be subject to growth delay in the same ways, because the clear delay in stature was not matched in the vertebral neural canal.

7.3 Correspondence of the vertebral neural canal size with the presence of pathology

In order to examine the relationship between the vertebral neural canal dimensions and known episodes of childhood stress, the diameters of the vertebral neural canal were compared to the skeletal pathology reported in the published and grey literature on the case study sites, and discussed in the previous chapter. It was originally expected that childhood stress experienced by an individual would manifest in more than one way in their skeleton, and therefore the presence of pathology would be associated with growth delay in the vertebral neural canal, but the lack of visible growth delay in analyses so far has tempered those expectations.

7.3.1 Correspondence of vertebral neural canal size with the presence of cribra orbitalia

The presence of cribra orbitalia, which forms in childhood (section 3.1.2), was compared to the vertebral neural canal dimensions to determine whether childhood stress as indicated by cribra orbitalia was also visible as growth delay in the vertebral neural canal. From the 86 individuals included in the study of the vertebral neural canal, 10 had neither eye orbit preserved for assessment of cribra orbitalia, and so were discounted from the comparison with the vertebral neural canal. Of the remaining 76, 48 did not have cribra orbitalia and 28 did, a true prevalence of 36.8%, which was much higher than the true prevalence seen in the total study assemblage of 18.6% (68/365), indicating that the sites included in the vertebral neural canal study either had characteristics which negatively impacted the populations' health more so than other case study sites, or that the skeletal preservation better allowed identification of the condition. An independent samples t-test was performed for the measurements of each vertebra between the groups of individuals which had the condition and did not have it. In the transverse dimension, the mean diameter was generally greater in the group without cribra orbitalia (Table 7.3.1). The t-tests showed that this difference in the means between the group with the condition and the group without was not statistically significant in 14 vertebrae, including C1-7, T1, and L2-5 ($p > 0.05$). However, in the other 10 vertebrae, namely T2-10 and L1, the mean transverse diameter was confirmed to be significantly greater in the group without cribra orbitalia ($p < 0.05$). While in some previous comparisons, significant variance in diameter of one vertebra was dismissed as happenstance, the same could not be said of significant variance in two-fifths of vertebrae, where all were in agreement that the group of individuals without cribra orbitalia had the greater mean diameters. This implied that, while it was limited to the thoracic spine, childhood stress as indicated by the presence of cribra orbitalia was also visible in the form of growth delay in the transverse diameter of the vertebral neural canal.

The anterior-posterior dimension did not support this picture however, as the mean diameter was generally very similar between the groups with and without cribra orbitalia, and this was confirmed by independent samples t-tests, which found no significant difference between the groups for almost all vertebrae ($p > 0.05$). The sole exception was C1, which had a significantly greater mean anterior-posterior diameter in the group without cribra orbitalia ($p < 0.05$). The implication overall was that the anterior-posterior diameter did not tend to react to childhood stress that would result in cribra orbitalia, but that it was possible in the transverse diameter, especially in the thoracic vertebrae where the variation in size was narrower. For the study population, it was clear that the consideration of multiple potential indicators of childhood stress was able to uncover those individuals who suffered more intensely.

Vertebra	**Transverse**				**Anterior-posterior**			
	CO present		**CO absent**		CO present		**CO absent**	
	N	Mean	N	Mean	N	Mean	N	Mean
C1	20	28.4	17	28.4	16	30.2*	17	31.6*
C2	21	24.1	27	24.2	17	16.8	24	17.2
C3	12	23.2	22	23.0	10	15.0	19	15.2
C4	13	24.1	19	24.2	12	14.7	16	14.6
C5	11	24.5	21	25.1	9	14.5	17	14.7
C6	12	24.7	21	25.0	9	14.1	19	14.1
C7	13	23.8	19	24.7	11	14.8	16	14.3
T1	13	20.5	21	20.8	12	14.6	20	14.8
T2	12	17.4*	22	18.4*	10	15.0	20	15.0
T3	8	15.9*	17	17.3*	8	14.8	14	14.9
T4	6	15.0*	17	16.5*	6	14.5	11	15.4
T5	9	15.0*	14	16.7*	9	15.0	12	15.4
T6	6	15.0*	12	16.4*	6	14.9	9	14.9
T7	9	14.8*	12	16.5*	8	14.8	8	14.8
T8	10	15.0*	12	16.8*	8	15.3	9	15.2
T9	8	15.2*	13	17.3*	8	14.8	11	15.2
T10	10	15.9*	12	17.1*	9	14.9	10	15.2
T11	10	17.6	16	18.3	10	15.4	16	15.7

Vertebra	Transverse				Anterior-posterior			
	CO present		**CO absent**		CO present		**CO absent**	
	N	Mean	N	Mean	N	Mean	N	Mean
T12	10	19.8	18	20.7	9	16.6	14	16.2
L1	10	21.2*	16	22.8*	10	16.8	13	16.9
L2	10	21.9	21	22.8	9	16.1	19	16.1
L3	11	22.2	18	22.8	10	15.5	13	14.9
L4	10	22.9	20	23.1	9	17.2	13	15.6
L5	7	24.9	21	25.1	5	15.6	14	15.7

Table 7.3.1: The number (N) of measurements taken, and the mean transverse and anterior-posterior diameter of each vertebra in those individuals who did and did not have cribra orbitalia. Pairs of symbols (*) in the same row indicate significance.

7.3.2 Correspondence of vertebral neural canal size with the presence of cribra orbitalia in each time period

Due to the differing prevalence of cribra orbitalia between the time periods, the comparison of the vertebral neural canal dimensions with the presence of the condition was tested in each period separately to ascertain the strength of the connection. From the group of 41 Roman-period individuals included in the study of the vertebral neural canal, four were discounted as they did not have the necessary preservation in either orbit for assessment, 16 had cribra orbitalia, and 21 did not. The true prevalence was therefore calculated as 43.2%, much greater than the true prevalence of 31.8% (48/151) seen in the full Roman assemblage for this study. Among the 45 early medieval period individuals included in the study of the vertebral neural canal, six were discounted from this comparison as they did not have either orbit preserved to the necessary standard for the assessment of cribra orbitalia, and of the 39 remaining, 12 had cribra orbitalia and 27 did not. The true prevalence of the condition therefore, was 30.8%, which was again much greater than than in the full population, 9.3% (20/214).

Comparing the measurements of the transverse dimension for each vertebrae in the Roman individuals found that the mean diameter was generally very similar in the cervical and lumbar vertebrae, and slightly greater in those without cribra orbitalia in the thoracic vertebrae (Table 7.3.2). When assessing the variance by independent samples t-tests, it was shown that the differences between the means were not statistically significant in most vertebrae ($p > 0.05$), except T5 and T9, where the mean diameters in those without cribra orbitalia (17.1 mm and 17.4 mm respectively) were significantly greater than those with the condition (15.2 mm and 15.3 mm respectively, $p < 0.05$). This lack of differentiation between those Roman individuals who did and did not develop cribra orbitalia in childhood was unexpected when compared to the strong differentiation in the assemblage as a whole. Comparing the transverse measurements in the early medieval individuals showed an overall increase in the mean diameter between those who had cribra orbitalia and those who did not. The greater diameter in those without the condition was confirmed by independent samples t-tests to be significant in T3-10, and L1 and 2 ($p < 0.05$), though it was not significant in all other vertebrae ($p > 0.05$). This was the anticipated result, as it mirrors that in the full assemblage, with the majority of the thoracic and the upper lumbar region presenting significant growth delay in individuals with cribra orbitalia.

Vertebra	**Roman**				**Early medieval**			
	CO present		**CO absent**		CO present		**CO absent**	
	N	TR mean	N	TR mean	N	TR mean	N	TR mean
C1	12	28.4	10	28.4	8	28.4	7	28.3
C2	11	24.1	14	24.1	10	24.1	13	24.4
C3	7	23.5	8	22.7	5	22.7	14	23.2
C4	8	24.3	7	24.4	5	23.7	12	24.1
C5	7	24.8	9	25.1	4	24.0	12	25.2
C6	6	24.7	8	24.7	6	24.7	13	25.1
C7	5	23.8	6	24.5	8	23.8	13	24.7
T1	5	20.3	8	20.5	8	20.7	13	20.9
T2	4	17.1	10	18.4	8	17.5	12	18.4
T3	3	16.2	6	17.4	5	15.7*	11	17.3*
T4	2	15.3	8	16.8	4	14.8*	9	16.3*
T5	4	15.2*	4	17.1*	5	14.9*	10	16.5*
T6	2	16.1	3	15.8	4	14.4*	9	16.6*
T7	4	15.1	3	15.9	5	14.6*	9	16.7*
T8	4	15.4	3	16.6	6	14.8*	9	16.8*
T9	3	15.3*	4	17.4*	5	15.1*	9	17.3*

Vertebra	Roman				Early medieval			
	CO present		**CO absent**		CO present		**CO absent**	
	N	TR mean	N	TR mean	N	TR mean	N	TR mean
T10	4	16.5	3	17.5	6	15.5*	9	16.9*
T11	6	18.2	5	18.0	4	16.6	11	18.4
T12	6	20.8	6	21.0	4	18.4	12	20.6
L1	5	22.3	5	24.2	5	20.2*	11	22.2*
L2	5	22.8	5	23.8	5	21.0*	16	22.5*
L3	6	23.0	6	23.0	5	21.2	12	22.6
L4	6	23.7	9	23.4	4	21.6	11	22.9
L5	3	25.3	8	25.9	4	24.6	13	24.7

Table 7.3.2: The number (N) of measurements taken, and the mean transverse diameter of each vertebra in those individuals who did and did not have cribra orbitalia in the Roman and early medieval populations. Pairs of symbols (*) in the same row indicate significance.

Considering the anterior-posterior diameter in the Roman population, it was found that the two groups again had very similarly sized vertebral neural canals in all vertebrae (Table 7.3.3), and the lack of difference in all vertebrae was confirmed by t-test ($p > 0.05$). This was not an unexpected result as, in contrast to the transverse diameter, the anterior-posterior diameter did not show any great difference between those with the condition and those without in the full assemblage, which was reflected in the Roman group. In the early medieval population, the results of the comparison of the anterior-posterior diameter between those with and without cribra orbitalia were also much the same as those in the full assemblage, with very similar mean diameters and no statistically significant difference in any vertebra ($p > 0.05$). Overall, it can be seen that the measurement of the anterior-posterior diameter does not tend to differ based on the presence or absence of cribra orbitalia as an indicator of childhood stress, but such differences may be visible in the transverse diameter, particularly in the thoracic region of the spine. It must be noted that with such small groups – commonly around three measurements per category in the Roman population, and around six for the early medieval – any relationship seen between variables may not be representative of the entire case study assemblage, and the statistical tests may not produce robust results.

Vertebra	Roman				Early medieval			
	CO present		**CO absent**		CO present		**CO absent**	
	N	AP mean	N	AP mean	N	AP mean	N	AP mean
C1	9	30.6	9	31.6	7	29.8	8	31.5
C2	10	17.2	13	17.0	7	16.2	11	17.3
C3	5	15.4	9	15.1	5	14.6	10	15.3
C4	7	14.9	8	14.6	5	14.3	8	14.7
C5	5	14.2	7	14.7	4	14.9	10	14.6
C6	4	14.0	8	14.4	5	14.2	11	13.9
C7	4	14.4	4	15.2	7	15.0	12	14.0
T1	4	14.6	7	15.1	8	14.6	13	14.7
T2	4	14.9	8	15.5	6	15.1	12	14.7
T3	3	14.8	5	15.0	5	14.8	9	14.9
T4	2	14.3	4	16.1	4	14.6	7	14.9
T5	4	15.3	4	16.1	5	14.8	8	15.0
T6	2	15.2	0	-	4	14.8	9	14.9
T7	3	14.8	1	15.2	5	14.8	7	14.8
T8	4	15.7	2	14.9	4	14.8	7	15.3
T9	3	15.5	3	15.4	5	14.3	8	15.1
T10	4	14.6	2	15.5	5	15.2	8	15.1
T11	6	14.9	5	15.7	4	16.3	11	15.7
T12	6	16.2	4	17.0	3	17.5	10	15.9
L1	5	16.5	3	19.3	5	17.1	10	16.1
L2	4	15.6	3	15.9	5	16.5	16	16.1
L3	5	15.2	5	14.3	5	15.8	8	15.3

Vertebra	Roman				Early medieval			
	CO present		**CO absent**		CO present		**CO absent**	
	N	AP mean	N	AP mean	N	AP mean	N	AP mean
L4	5	18.6	7	16.2	4	15.5	6	14.9
L5	2	15.3	6	16.7	3	15.8	8	15.0

Table 7.3.3: The number (N) of measurements taken, and the mean anterior-posterior diameter of each vertebra in those individuals who did and did not have cribra orbitalia in the Roman and early medieval populations.

7.3.3 Correspondence of vertebral neural canal size with the presence of dental enamel hypoplasia

Dental enamel hypoplasia, which forms during tooth crown development in children under five (section 3.2.1), was the next pathology to be compared to the vertebral neural canal size in order to determine the relationships between conditions that developed at different ages. From the 86 individuals selected for the vertebral neural canal study, four did not have dentition preserved for the assessment of dental enamel hypoplasia and were discounted from the comparison of vertebral neural canal size with the presence of the condition, 27 individuals presented enamel defects in at least one tooth, and 55 did not show any evidence of enamel hypoplasia. Therefore, the true prevalence of dental enamel hypoplasia in the vertebral neural canal study population was 32.9%, which was slightly lower than that of 38.4% (203/529) found in the full assemblage for this study. Comparing the transverse diameter between those with dental enamel hypoplasia and those without found that the mean was generally slightly larger in the group without the condition (Table 7.3.4), but when applying the independent samples t-test, it was determined that the difference was not significant in any vertebra ($p > 0.05$).

A similar picture was seen in the anterior-posterior diameter: comparing the mean diameters for each vertebrae found they were usually slightly larger in the group without dental enamel hypoplasia, but the difference was not statistically significant by t-test in most vertebrae ($p > 0.05$). The exception was T11, where the mean of 15.0 mm in those with dental enamel hypoplasia was determined to be significantly smaller than the mean of 15.9 mm in those without the condition ($p < 0.05$). In contrast to cribra orbitalia, it was therefore seen that no link existed between dental enamel hypoplasia as a result and indicator of childhood stress, and growth delay in either dimension of the vertebral neural canal.

Vertebra	Transverse				Anterior-posterior			
	DEH present		**DEH absent**		DEH present		**DEH absent**	
	N	Mean	N	Mean	N	Mean	N	Mean

C1	16	28.3	24	28.7	16	30.7	20	31.0
C2	20	23.9	31	24.3	18	17.0	25	17.0
C3	15	23.1	24	23.2	13	15.0	20	15.2
C4	12	24.3	22	24.3	10	14.5	19	14.8
C5	14	25.0	21	25.1	10	14.3	19	14.9
C6	13	24.7	25	25.1	9	14.4	22	14.2
C7	11	23.5	25	24.5	9	14.2	22	14.7
T1	11	20.5	27	20.8	9	14.2	25	14.9
T2	11	18.0	25	18.2	10	14.4	22	15.2
T3	11	16.7	17	17.0	10	15.2	15	14.8
T4	10	16.1	16	16.3	7	14.3	13	15.3
T5	10	15.7	15	16.2	9	15.0	13	15.4
T6	9	16.0	11	16.0	6	14.7	10	15.1
T7	11	15.6	12	16.0	9	15.0	9	14.8
T8	8	15.8	14	16.1	8	14.9	9	15.5
T9	9	16.4	12	16.5	8	14.8	11	15.1
T10	9	16.9	13	16.3	8	14.9	11	15.1
T11	10	18.3	17	17.9	10	15.0*	16	15.9*
T12	11	20.3	18	20.5	10	15.9	14	16.7
L1	8	21.9	18	22.4	7	16.6	16	17.0
L2	11	22.5	20	22.5	10	15.9	18	16.1
L3	12	22.8	19	22.4	10	14.7	15	15.1
L4	11	23.2	21	22.8	8	16.9	16	15.5
L5	11	25.0	20	25.1	8	15.5	14	15.7

Table 7.3.4: The number (N) of measurements taken, and the mean transverse and anterior-posterior diameter of each vertebra in those individuals who did and did not have dental enamel hypoplasia.

7.3.4 Correspondence of vertebral neural canal size with the presence of dental enamel hypoplasia in each time period

Due to the much greater prevalence of dental enamel hypoplasia in the Roman period among the full assemblage, the diameters of the vertebral neural canal were then compared to the presence of the condition in Roman and early medieval individuals separately, in order to uncover any correlation masked by the differing prevalence in each period. Of the 41 Roman period individuals included in the study of the vertebral neural canal, two did not have dentition preserved for analysis and were discounted from the comparison with the vertebral neural canal, 19 had the condition and 20 did not. The true prevalence was 48.7%, lower than that of 60.9% (131/215) seen in the total Roman population for this study. The early medieval assemblage of 45 individuals comprised two without preserved dentition, who were discounted from comparison with the vertebral neural canal, eight with dental enamel hypoplasia, and 35 without. The true prevalence of the condition in the vertebral neural canal study group was therefore 18.6%, slightly lower than that of 22.9% (72/314) seen in the whole early medieval study sample.

In comparing the transverse dimension between those with and without dental enamel hypoplasia from the Roman group, the mean diameters were very similar in most vertebrae (Table 7.3.5), and the independent samples t-test found no significant difference between the means in all vertebrae ($p > 0.05$) except T6. In T6, the mean transverse diameter was greater in those with dental enamel hypoplasia, at 16.5 mm, compared to 15.1 mm in those without the condition, and this difference was deemed significant by t-test ($p < 0.05$). It was unexpected to see that those with the pathological condition displayed less evidence of growth delay than those without, but it must be noted that this comparison was made between only five individuals total, and therefore cannot be said to reliably represent the full population, or indeed the response of the entire spine. In the early medieval population, the comparison of the mean transverse diameters found that they were usually slightly greater in those without dental enamel hypoplasia, although this was not found to be significant in most vertebrae when assessed by independent samples t-tests ($p > 0.05$). The only vertebra determined to have significant variance in the mean transverse diameter between the groups was C5 ($p < 0.05$), where the mean was 23.3 mm in those with dental enamel hypoplasia, and 25.3 mm in those without. Therefore, in contrast to the comparison with cribra orbitalia, there was very little difference in growth delay in the transverse diameter based on the presence or absence of dental enamel hypoplasia in either time period,as was also seen in the combined sample.

Vertebra	Roman				Early medieval			
	DEH present		**DEH absent**		DEH present		**DEH absent**	
	N	TR mean	N	TR mean	N	TR mean	N	TR mean
C1	14	28.2	10	29.1	2	29.3	14	28.4
C2	15	24.0	11	24.2	5	23.8	20	24.4
C3	11	23.3	6	23.0	4	22.6	18	23.3
C4	8	24.5	7	24.5	4	24.0	15	24.2
C5	11	25.4	6	24.7	3	23.3*	15	25.3*
C6	9	24.9	7	24.6	4	24.2	18	25.3
C7	8	23.6	5	24.5	3	23.1	20	24.5
T1	6	20.1	8	20.3	5	20.9	19	21.0
T2	6	17.8	8	18.2	5	18.2	17	18.2
T3	5	16.5	5	17.4	6	16.9	12	16.9
T4	4	15.6	7	16.9	6	16.5	9	15.8
T5	4	15.6	4	16.8	6	15.9	11	16.1
T6	3	16.5*	2	15.1*	6	15.7	9	16.2
T7	5	15.5	2	15.3	6	15.7	10	16.1
T8	4	15.9	3	16.0	4	15.7	11	16.1
T9	4	16.0	3	17.1	5	16.8	9	16.4
T10	4	16.9	3	17.0	5	17.0	10	16.1
T11	6	18.2	5	17.9	4	18.3	12	17.9
T12	6	20.9	6	20.8	5	19.6	12	20.3
L1	5	22.6	5	23.8	3	20.6	13	21.8
L2	6	23.0	5	23.6	5	21.9	15	22.2
L3	7	23.2	6	22.7	5	22.1	13	22.3

Vertebra	Roman				Early medieval			
	DEH present		**DEH absent**		DEH present		**DEH absent**	
	N	TR mean	N	TR mean	N	TR mean	N	TR mean
L4	7	24.3	8	22.8	4	21.2	13	22.8
L5	6	25.8	6	26.0	5	24.0	14	24.7

Table 7.3.5: The number (N) of measurements taken, and the mean transverse diameter of each vertebra in those individuals who did and did not have dental enamel hypoplasia in the Roman and early medieval populations. Pairs of symbols (*) in the same row indicate significance.

Considering the anterior-posterior dimension for the Roman assemblage, it was seen that the mean diameter was generally slightly smaller in those with dental enamel hypoplasia compared to those without the condition (Table 7.3.6), but these differences were not statistically significant in any vertebra when assessed by t-test ($p > 0.05$). Similarly, in the early medieval population the mean anterior-posterior diameter was generally slightly greater in the group without dental enamel hypoplasia. This variance was not found to be significant by t-test in most vertebrae ($p > 0.05$). The only vertebrae with statistically significant difference ($p < 0.05$) in the mean anterior-posterior diameter were T2 and T4; in both, the mean diameter in those without dental enamel hypoplasia (15.1 mm and 15.2 mm respectively) was greater than that in those with enamel defects (13.7 mm and 14.1 mm respectively). While there is slight indication that dental enamel hypoplasia as a manifestation of childhood stress was associated with narrower anterior-posterior diameter indicating the same for the early medieval population, this was not the case in the majority of vertebrae. On balance, there was not a clear connection between the presence of dental enamel hypoplasia and growth delay in either dimension of the vertebral neural canal, in both time periods and in the combined assemblage.

Vertebra	Roman				Early medieval			
	DEH present		**DEH absent**		DEH present		**DEH absent**	
	N	AP mean	N	AP mean	N	AP mean	N	AP mean
C1	13	30.6	7	31.8	3	31.3	13	30.5
C2	13	17.0	10	17.4	5	17.1	15	16.8
C3	10	14.9	6	15.4	3	15.6	14	15.1
C4	8	14.5	7	15.1	2	14.6	12	14.7

Vertebra	Roman				Early medieval			
	DEH present		**DEH absent**		DEH present		**DEH absent**	
	N	AP mean	N	AP mean	N	AP mean	N	AP mean
C5	7	14.6	6	14.6	3	13.6	13	15.1
C6	6	14.5	7	14.4	3	14.0	15	14.1
C7	6	14.6	4	15.4	3	13.5	18	14.6
T1	4	14.6	7	15.1	5	13.9	18	14.8
T2	5	15.2	7	15.4	5	13.7*	15	15.1*
T3	5	15.4	4	14.6	5	14.9	11	14.9
T4	2	15.0	5	15.5	5	14.1*	8	15.2*
T5	4	15.9	4	15.6	5	14.3	9	15.4
T6	1	16.2	1	14.1	5	14.3	9	15.2
T7	3	15.1	1	14.3	6	14.9	8	14.9
T8	4	15.1	2	16.1	4	14.8	7	15.4
T9	3	15.0	3	15.9	5	14.7	8	14.8
T10	3	14.5	3	15.3	5	15.2	8	15.1
T11	6	15.0	5	15.5	4	15.1	11	16.1
T12	6	16.4	4	16.8	4	15.2	10	16.7
L1	4	17.2	4	18.0	3	15.9	12	16.6
L2	5	16.0	3	15.1	5	15.9	15	16.3
L3	6	14.7	5	14.4	4	14.9	10	15.4
L4	5	18.8	7	16.1	3	13.6	9	15.1
L5	4	15.9	5	16.3	4	15.0	9	15.3

Table 7.3.6: The number (N) of measurements taken, and the mean anterior-posterior diameter of each vertebra in those individuals who did and did not have dental enamel hypoplasia in the Roman and early medieval populations.

7.3.5 Correspondence of vertebral neural canal size with the presence of rickets

Despite the low number of cases, the vertebral neural canal size was compared between those individuals who were determined to have rickets and those that did not, for consistency between the pathological conditions. The comparison was not drawn in each period individually. In total, there were just four cases of rickets among the group of 86 individuals included in the study of the vertebral neural canal, and two individuals who were poorly preserved and could not be assessed for rickets, who were therefore discounted from the following analysis. The true prevalence of the condition was therefore 4.8%, much higher than that of 1.4% seen in the total population (8/556) due to the inclusion of the skeletal assemblage from the Burnby Lane site in the vertebral neural canal study, which had six of the eight cases of rickets seen in the full study assemblage.

In the transverse diameter, the mean was generally slightly greater in the individuals who did not have rickets (Table 7.3.7), but this was only found to be statistically significant ($p < 0.05$) by independent samples t-test in T7, where the measurement in the rachitic individual was 13.5 mm in comparison to the mean of 15.8 mm in those without the condition. The rachitic group had only one or two individuals measured for comparison in the majority of vertebrae, who may not have been representative in their vertebral neural canal measurements of all those with the condition, and so no conclusion about the relationship between rickets and growth in the vertebral neural canal can be drawn.

In the anterior-posterior diameter, the mean was generally slightly smaller in those who did not have rickets, though there were several vertebrae in which the rachitic individuals had the smaller mean measurements. However, these differences were not found to be statistically significant ($p > 0.05$) by the independent samples t-tests in the majority of vertebrae. The differences in the means were found to be significant ($p < 0.05$) in six vertebrae, including C2-5, where the anterior-posterior diameter was significantly greater in the rachitic individuals, and T10 and 11, where the anterior-posterior diameter was significantly smaller in those with rickets. However, the greater measurements in rachitic individuals in C3-5 were in fact from just one individual, Skeleton 108 from Burnby Lane, and therefore could not be said to represent the wider population. Similarly, the smaller measurements in T10 and 11 were from one individual, G197A from Bainesse, and therefore also could not be said to represent the wider population. This individual was also the only one in the rachitic group to provide a measurement for the transverse diameter in T7, so the significant difference in this vertebra may have been due to general small size in this individual. Overall, there was no consistent link present between the anterior-posterior diameter and the development of rickets during childhood, in part due to the small sample size as very few cases of rickets were identified from the study population. In addition to the transverse diameter, this has revealed no relationship between growth delay in the vertebral neural canal and childhood stress manifesting in rickets. While the lack of difference may stem from the small number of cases, it may also corroborate the lack of difference seen in vertebral neural canal size with the presence or absence of dental enamel hypoplasia.

Vertebra	Transverse				Anterior-posterior			
	Rickets present		**Rickets absent**		Rickets present		**Rickets absent**	
	N	Mean	N	Mean	N	Mean	N	Mean
C1	3	28.4	37	28.6	4	31.3	31	30.7
C2	4	24.2	47	24.2	4	18.5*	39	16.8*
C3	2	24.5	36	23.2	1	17.4*	32	15.1*
C4	3	25.0	31	24.2	1	17.4*	28	14.5*
C5	2	25.2	33	25.0	1	17.4*	27	14.6*
C6	2	24.8	35	25.0	0	-	30	14.3
C7	2	22.1*	33	24.4*	2	15.4	28	15.6
T1	2	19.1	35	20.8	1	13.9	32	14.8
T2	2	17.9	33	18.2	1	15.0	30	15.0
T3	1	16.0	26	16.9	1	15.0	23	14.9
T4	1	15.2	24	16.2	1	15.2	18	14.9
T5	1	14.4	23	16.1	1	15.3	20	15.2
T6	0	-	19	15.8	0	-	15	14.9
T7	1	13.5	21	15.8	1	15.4	17	14.9
T8	2	14.5	19	16.0	1	15.3	15	15.2
T9	2	15.4	18	16.5	2	14.3	16	15.1
T10	2	16.0	20	16.6	1	13.1*	17	15.2*
T11	1	17.5	24	18.0	1	13.2*	24	15.6*
T12	1	20.6	27	20.4	1	15.0	22	16.5
L1	1	21.4	25	22.3	1	18.0	22	16.8
L2	2	21.5	31	22.5	2	15.9	28	16.2
L3	2	21.6	29	22.5	2	14.3	22	15.1

Vertebra	Transverse				Anterior-posterior			
	Rickets present		**Rickets absent**		Rickets present		**Rickets absent**	
	N	Mean	N	Mean	N	Mean	N	Mean
L4	1	24.1	31	22.9	1	15.0	23	16.0
L5	1	26.2	29	25.1	1	17.1	20	15.5

Table 7.3.7: The number (N) of measurements taken, and the mean transverse and anterior-posterior diameter of each vertebra in those individuals who did and did not have rickets.

7.3.6 Summary of the correspondence of vertebral neural canal size with the presence of pathology

This analysis has shown that the presence of pathology as indicators of childhood stress was not always related to growth and its delay in the vertebral neural canal. Analysis of the transverse diameter revealed a strong connection between smaller mean diameters and the presence of cribra orbitalia, but no difference in diameter when comparing presence and absence of dental enamel hypoplasia or rickets. By contrast, the anterior-posterior diameter was found to be unrelated to the presence of all three pathologies. This was not the anticipated result, as the pathologies and the measurements of the vertebral neural canal are all considered indicators of stress, and might therefore be expected to co-occur. However, in this study population the vertebral neural canal has been shown not to be related to any variable, including stature and time period, in the expected ways, so the lack of correspondence with pathology is not opposed with these other results.

7.4 Summary of the study of the vertebral neural canal

Overall, the vertebral neural canal was not found to differ particularly between groups defined by many conditions, including time period, cemetery location, other measures of growth delay, and other indicators of stress, all of which were strongly connected as seen in the previous chapter. The sole exception was the correspondence of growth delay in the transverse diameter with the presence of cribra orbitalia. The general lack of variance was particularly the case when considering the anterior-posterior diameter, with difference seen more often in the transverse diameter of individual vertebrae even when unsupported by the others. It is therefore suggested that the vertebral neural canal was affected by childhood stress in a different way to the other indicators included in this study, perhaps due to the intensity or duration of episodes of stress having a greater physiological effect on certain parts of the body compared to others, supported by the greater variance in the transverse diameter, which has a longer growth period and therefore more opportunity to be affected by poor health. It may also be the case that too few individuals were included in the study of the vertebral neural canal, and that with a larger population the individuals who experienced growth delay may have been identifiable among the natural variation in size.

Chapter 8: Discussion

The Roman-early medieval transition and its effect on population health is a topic which has been attracting increased interest in recent years, with several osteoarchaeological studies being published focusing on Italy and Croatia (Šlaus et al., 2011; Šlaus, 2008; Belcastro et al., 2007; Salvadei et al., 2001; Manzi et al., 1999). In Britain, comparative studies of Roman and early medieval skeletal assemblages have focused on southern England, where there is a greater wealth of excavated cemeteries and better preservation of the skeletal material (Griffin, 2017; Walther, 2017; Klingle, 2012). The area north of the approximate line between the mouths of the Humber and Ribble rivers was separated by more than just geographical distance from the more southerly regions of England during the Roman and early medieval periods. In contrast to southern England, with its short crossing to the continent, network of towns and rich villa complexes, and few forts, northern England was one of the most remote reaches of the Roman Empire at its greatest extent, and played host to thousands of legionaries and auxiliary troops. These soldiers were responsible for the control of the region, but also took part in uprisings both for and against various people in positions of power (Mattingly, 2007). Many of the larger settlements in northern England were reliant on the presence of the army, being primarily composed of traders needing the soldiers' custom to earn a living, so could not sustain themselves beyond the end of the 4th century when the units were recalled to the continent (Evans, 1984). Towns and markets also could not survive without the Roman administration responsible for collecting taxes and providing the coinage necessary to maintain the coin-based economy, and so were slowly abandoned, falling into disrepair (Fleming, 2011). Small village and farmstead settlements, with little to no social stratification characterised the centuries immediately following the Imperial withdrawal, with greatly reduced trade and much more reliance on the production of resources within the community (Hamerow, 2012). Migrants from the continent included men, women and children, who are shown by aDNA and isotopic analyses to have integrated with the local populations in many areas (Gretzinger et al., 2022; Leggett, 2021; Montgomery et al., 2005). The transition from a central authority to local organisation on a very small scale bore numerous differences, such that the typical daily lifestyle was unrecognisable within a few decades.

From the results presented in this thesis we have seen that in northern England there was a difference in childhood health between the Roman and early medieval periods. The indicators of stress examined were mostly non-specific, and so could have been caused by any number of environmental influences, but even the conditions with specific aetiologies could have been triggered by a range of different factors. On the basis of this evidence it is not possible to identify the precise experience responsible for a lesion in an individual, but the broader patterns across the region revealed by the compilation of smaller sites show the bigger picture of stress and health in this dynamic period. Considering each skeletal manifestation of stress in turn, this chapter will explore palaeopathology and its intersection with what life was like for the people of northern England during the 3rd-7th centuries. It will delve into the experiences produced by Roman rule and its subsequent loss, and their relation to the divide in the health profiles of the case study populations. The results from northern England will be compared to those from across Britain and on the continent, to place the study area explored in this thesis in the context of wider Roman and early medieval society. Additionally, the methods used in this thesis will be considered in turn to determine their strengths and limitations for the insight they gave into the experiences of the case study populations.

8.1 Cribra orbitalia

As reviewed in section 3.1, cribra orbitalia is a condition generally accepted to be caused by anaemia. The deficiency of iron leads to overproduction of red blood cells and expansion of the diploë, in turn causing pressure atrophy of the outer table in thin bone such as that of the eye orbits, creating the characteristic pitted surface (Brickley, 2018; Oxenham and Cavill, 2010). Anaemia, a clinically low concentration of haemoglobin, can vary in aetiology, with causes including genetic conditions and iron deficiency, which can arise as a result of dietary deficiencies or serious illness (Brickley and Mays, 2019). The following will consider the differences in lifestyle, settlements, climate and migration between the Roman and early medieval periods, as well as the methods used to analyse cribra orbitalia in this thesis, to determine the likely cause of the decrease in prevalence after the decline of Roman control in Britain.

8.1.1 Lifestyle in the Roman and early medieval periods

To begin with, cribra orbitalia can be reflective of dietary deficiencies including iron, vitamins A and B_{12}, and folate, all of which are essential for normal production and function of red blood cells (Fishman et al., 2000). Iron is most plentiful in red meats, pulses and leafy green vegetables (NIH, 2024a), vitamin A is found in dairy products, fish and yellow vegetables (NIH, 2023), vitamin B_{12} in meat and fish, dairy and eggs (NIH, 2024b), and folate from leafy greens and pulses (NIH, 2022). Hence, the importance of a varied diet inclusive of a range of vegetables and animal products in order to prevent the development of anaemia. With the greater prevalence of cribra orbitalia in the assemblage from the Roman period, it could be inferred that there was not access to a sufficient variety of foods. The indication from cribra orbitalia of a nutritionally poor diet supports the conclusion of Erdkamp and Holleran's work on diet in the Roman period (2018); that the majority of the urban poor would have been reliant on cereals, with pulses, eggs, dairy and vegetables as occasional supplements depending on what could be transported into the town from the local area. The rural poor, while still reliant on cereals, likely had access to vegetables, eggs and dairy, and meat as they could hunt and forage, keep small vegetable gardens and occasionally rear animals. The dependence of diet upon location may offer an explanation for the slightly greater prevalence of cribra orbitalia found in the urban individuals compared to the rural individuals of the Roman study population, though the small sample size hindered the possibility of statistical testing. Isotopic studies of diet in Roman Britain have shown that terrestrial and sometimes marine protein were components of the typical diet (Chenery et al., 2010; Fuller et al., 2006; Richards et al., 1998), including in York (Müldner and Richards, 2007). While these foods were eaten, it may not have been in sufficient amounts to maintain iron levels in the body, or perhaps deficiencies in vitamins A and B_{12} from a lack of fish and dairy in the diet were more contributory to the development of cribra orbitalia.

It is also interesting to note that there was no difference in the prevalence of cribra orbitalia between males and females of the Roman period case study population, despite Roman cultural practices wherein female diet was nutritionally poorer and therefore more likely to cause iron or other vitamin deficiencies, as seen in isotopic studies of diet, and by the consistently lower rates of gout, dental disease and caries in female skeletons from Romano-British assemblages (Fuller et al., 2006; Allason-Jones, 2005, 41; Prowse et al., 2005; Roberts and Cox; 2003, 134-5). Of course, the study of gendered differences in diet through skeletal remains can only be conducted on adult individuals, so it is not clear whether female children also received a poorer diet than their male counterparts. Through the historic record it is known that Imperial and private schemes to provide for children's needs in Italian cities tended to include fewer girls, and allocated less to them than boys (Erdkamp and Holleran, 2018, 286), which may indicate the general attitude towards male and female subadults, but it is not certain that this attitude persisted in Romanised Britain. Several theories spring from the similar prevalence of cribra orbitalia in males and females: that there was less cultural influence on male and female children's diets in northern England than elsewhere in the empire, that the greater resilience of females to stress (Stinson, 1985) was able to compensate for their iron deficient diet, or that diet was so poor for everyone that it masked any differences between groups, though the osteological evidence from the case study populations cannot be used to distinguish between these options.

The early medieval population from this study, while presenting a much lower prevalence of cribra orbitalia, was still afflicted by the condition. In the case that the condition was caused by an insufficiency in iron intake, the low prevalence indicates that the diet at the time was generally sufficient to maintain iron levels in the blood for most individuals, but not all. The major difference in food provision between the Roman and early medieval periods was the intensive farming and production of massive surplus to be taken in tax during the Roman period, and used to provision the army both within Britain and on the continent (Mattingley, 2007, 511). The early medieval period saw no such pressures, with little social or economic complexity, no coinage, and no industrial production of goods (James, 2013, 73-76). The lessened demand for grain meant more land could be used as pasture for animals to provide dairy products and meat (Gerrard, 2013, 101), and so the typical diet could be expected to have been more plentiful and nutritionally complete, if less varied due to the decrease in trade across the continent. However, the few isotopic studies which have been conducted on 5th and 6th-century populations have shown even lower contributions of animal and marine protein to the diet than in Romano-British populations (Fox, 2019; Privat et al., 2002), counteracting this theory and suggesting that the cause of the difference in prevalence of cribra orbitalia between the periods in this thesis was not dietary in nature.

8.1.2 The influence of settlements on cribra orbitalia

As well as nutritional deficiencies, anaemia can also develop as a result of chronic disease, the risk of which varies depending on how hygienic the living environment is. The mechanism of this varies, including direct destruction of red blood cells by pathogens, loss of red blood cells through haemorrhage, and compromised nutrient absorption due to intestinal damage or diarrhoeal diseases (Grauer, 2019). The high levels of cribra orbitalia found in the Roman population may therefore be indicative of a greater disease burden, which was likely a result of the settlements in which people lived. In the towns or communities associated with military installations, living conditions would have been crowded and unhygienic despite the provision of water and sewage systems. Evidence for poor hygiene in Roman towns has been discovered by many excavations, including in York, which uncovered remains of grain pests and rats in storage areas, and human parasites including intestinal worms, fleas and lice in riverside areas and wells (Kenward et al. 1986). Intestinal parasites are especially likely to contribute to the development of iron deficiency, as they hinder nutrient uptake, and some species such as hookworms can also cause haemorrhage through direct damage (Loukas et al., 2016).

Osteoarchaeological studies of Roman populations both within York and elsewhere in Britain have noted the presence of infectious diseases such as tuberculosis and leprosy, as well as infections without a diagnosable cause (McIntyre, 2012; Lewis, 2011; Roberts and Cox, 2003). Roberts and Cox found the prevalence of these infections to be much greater in comparison to that found in Iron Age populations. These studies also note an increase in the prevalence of cribra orbitalia over the same time frame. These were likely related to the greater movement of people seen in urban areas in comparison to the countryside, as people moved to towns to find jobs, whether they came from a nearby rural settlement or the other side of the continent, and the constant contact with people from new areas would have been facilitated the transmission of pathogens which had not been encountered before (Mascie-Taylor and Krzyżanowska, 2017). Mitchell (2017) found an increase in parasitic infection from the Iron Age to the Roman period across the Empire, stretching from sites in Britain to the Middle East, demonstrating the impact of increasingly densely populated towns and the unhygienic realities of sharing baths, toilets and fresh water supplies.

However, it cannot be assumed that the risk of disease was the only hazard of urban living in the Roman period. Instead it must be considered that many factors of Roman settlements were contributing to iron deficiency anaemia, with lead poisoning a possible contender in addition to disease. Lead exposure was common in the Roman period as it was used in everyday objects like water pipes, pottery, cooking vessels and coins, as well as being added directly to food as a sweetener or preservative (Nriagu, 1983; Waldron, 1973). Furthermore, in the areas of North Yorkshire where it is a natural resource, proximity to the mining and smelting industries would have led people to accumulate high levels of lead in their bodies (Tylecote, 1964). Once lead starts accumulating in the body it prevents proper enzymatic function, disrupting many processes including the synthesis of haeme – a component of haemoglobin - and increasing the destruction of red blood cells, thereby inducing iron deficiency anaemia (WHO, 2010). Children are known to be particularly vulnerable to the cumulative effects of lead poisoning, as they absorb lead much more readily through the digestive tract, retaining around 40% of the lead intake (Ziegler et al., 1978), as opposed to the approximately 10% retention in adults (Hursh and Suomela, 1968). Greater dental lead concentration has been found to correlate with greater prevalence of cribra orbitalia in continental Roman populations (Moore et al., 2021), further supporting the theory that there may be an aetiological link, though osteological reports rarely suggest lead poisoning as an alternative cause of anaemia when discussing identified cases of cribra orbitalia. The difference in lead exposure between Roman and early medieval populations in Britain was illustrated by Budd and colleagues (2004), who analysed skeletons dating from the Neolithic period through to the late medieval period from a variety of locations around Britain, determining that lead concentration peaked dramatically in the Roman individuals before falling again, only reaching a similar level once again in the later medieval (12th-16th century) population. This difference in lead exposure may explain the greater prevalence of cribra orbitalia in the Roman populations studied in this thesis.

Cribra orbitalia is not solely related to urban living in the case of the Roman study populations. Indeed, while the prevalence of cribra orbitalia is slightly greater in the urban group, at 33.6% in comparison to 23.1% in the rural group of cemeteries, this difference is not statistically significant, and the prevalence in the rural Roman population is still much greater than that of 9.3% seen in the early medieval population (section 6.3.11). Additionally, cribra orbitalia is still present in the early medieval population, despite the lack of urban environments, so further causative factors must be involved. The villages of the early medieval period were small, and typically housed between 50 and 100 people. Most villages were poorly provisioned, with little management of either fresh- or wastewater (Hamerow, 2012), a benefit when considering the avoidance of lead poisoning from drinking water, but running the risk of the spread of disease and parasites through contact with sewage. This risk may have contributed to the presence of cribra orbitalia in the early medieval case study population, indicating that while life may have been healthier overall than in the preceding centuries, there were, nonetheless, episodes of ill health for individuals.

8.1.3 The influence of migration on cribra orbitalia

Another factor which could explain the difference in prevalence of cribra orbitalia between the Roman and early medieval people of the case study population is migration. In the Roman period, movement between Britain and the continent was more common than the early medieval period, with a particular influx of military into the north. Comparing the results of this thesis with the prevalence of cribra orbitalia seen in other studies of Romano-British populations, the prevalence in northern England was unusually high. It was 31.8%, compared to 16.9% in Roberts and Cox's (2003) work compiling data from around the British Isles. It is also, surprisingly greater than seen in studies focusing on Roman York, where the true prevalence of cribra orbitalia was found to be 12.8% in the assemblage compiled from multiple Roman cemeteries by McIntyre (2014), and 16.2% in the Trentholme Drive cemetery by Peck (2009). This indicates that some of the case study sites from outside York included in this thesis had unusually large numbers of cases and influenced the final calculation of prevalence (Figure 8.1). The overall prevalence of cribra orbitalia in the Roman period seen in this thesis was also generally greater than that seen in skeletal assemblages from southern England, where prevalences of 5-20% are common (for example Walther, 2017; Klingle, 2012; Pitts and Griffin, 2012), and prevalences between 20% and 30% are more infrequent (for example Keefe et al., 2015; Rohnbogner, 2015; Bonsall, 2013). Since northern England had a greater military presence than the south due to the ever-present threat from the tribes of Scotland, the influence of the military may be responsible for the difference seen between the findings of this study, where health improved after the collapse of Roman control, to those which saw negligible or negative change in more southerly populations (Griffin, 2017; Klingle, 2012). The prevalence of cribra orbitalia in the early medieval case study population is at the lower end of the range seen in populations from southern England, where osteological studies commonly find the prevalence of cribra orbitalia to be between 7% and 25% (for example Walther, 2017; Klingle, 2012; Egging Dinwiddy, 2011; Roberts and Cox, 2003), indicating that the factor which caused the divide between the north and south in the Roman period was no longer at play.

At its greatest, the Roman army in Britain numbered over 40 thousand, or around an eighth of the whole of the Imperial force (Fleming, 2011, 2). These people had origins across the empire, from modern Germany and France to North Africa and the Balkans (Mattingly, 2007, 169; 181). The enormous variety in early life experiences adds untold complications to the regional study of skeletal pathology. The Roman model of creating auxiliary units from newly conquered populations and sending them to new regions (Mattingly, 2007, 167) could explain the poor health in the Roman period populations of northern England. Those who died in places with a heavy military presence like York and Catterick may have grown up elsewhere in the empire under the shadow of ongoing colonisation, and therefore could have been more likely to experience the poor diet and unsanitary conditions which can lead to iron deficiency anaemia and cribra orbitalia than their contemporaries who were not drafted and remained in their region of origin. This suggests that people who had stressful childhoods were perhaps more likely to be drafted into the Roman army and sent to northern Britain than those who were better off in their respective home regions.

It is also possible that the greater prevalence in the Roman population may have had a genetic root. There are two hereditary forms of anaemia which are most common around the Mediterranean and in Africa; thalassaemia and sickle cell anaemia (Brickley and Mays, 2019). Both are capable of triggering the development of cribra orbitalia, so it is possible that the greater movement between the Mediterranean, North Africa and Britain in the Roman period resulted in a greater number of people in Britain who had a genetic predisposition to developing cribrotic lesions due to these conditions, in comparison to the early medieval population which had less influx from these areas and a lower prevalence of cribra orbitalia. In the original osteological report for *Cataractonium* and Bainesse (Speed and Holst, 2019), four individuals were identified as possibly having African ancestry on the basis of facial characteristics (SK12996, SK13328, SK13342 and SK20957), and isotopic studies on the Roman remains from Scorton found that most individuals likely originated from central or eastern Europe (Eckardt et al., 2015), but only one of these individuals – SK13342 from Bainesse – had cribra orbitalia. Isotopic analysis only identifies the individuals who migrated themselves, and not their descendants who may have inherited any genetic predisposition to cribra orbitalia, so further isotopic and aDNA work is needed before the influence of genetic conditions on the distribution of cribra orbitalia in Roman Britain can be understood.

On the other hand, the cases of cribra orbitalia seen in the early medieval population may also have been related to migration. As discussed above, disease and infection result in anaemia through loss of blood, prevention of nutrient uptake, or direct destruction of red blood cells and haemoglobin. The act of moving from one region to another exposes individuals to many new pathogens at once (Mascie-Taylor and Krzyżanowska, 2017), a risk to which children would have been more susceptible (Lewis, 2007, 19). The isotopic studies of the Bamburgh and West Heslerton populations (Groves, 2013; Montgomery et al., 2005) confirmed that migration in childhood was common in the early medieval period. Therefore, children under 15 would have been exposed to the stress of new diseases and were capable of developing cribrotic lesions due to the red marrow still present in the cranium at that age (Brickley, 2018). It is less clear whether the introduction to new diseases would have caused cribra orbitalia in the Roman population, because the majority of the identified migrants in the isotopic studies were adult men (Eckardt et al., 2015; Chenery et al., 2011) and probably connected to the military, so would not have moved while the right age to develop cribra orbitalia as a result of becoming ill from new pathogens.

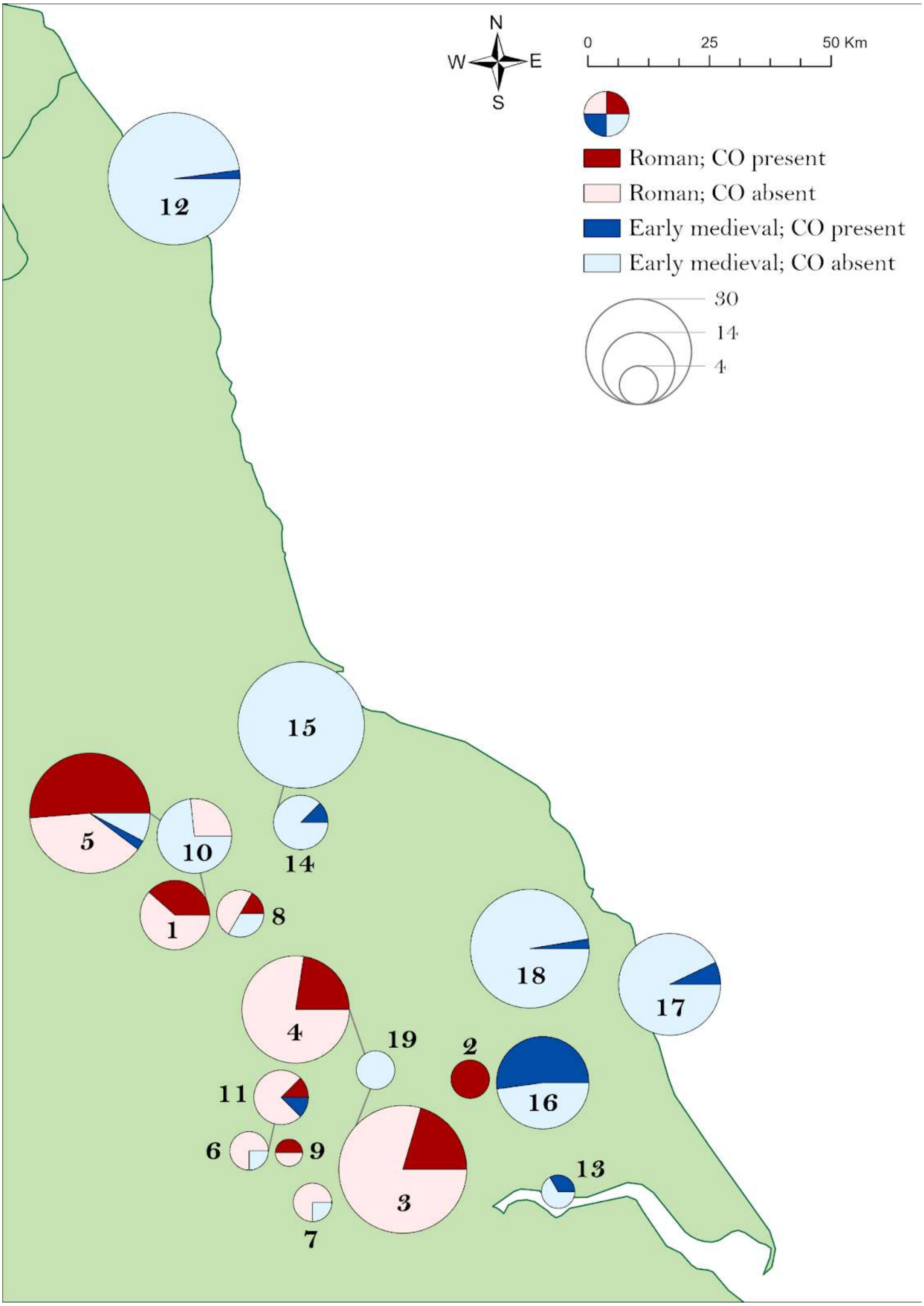


Figure 8.1: The distribution of cribra orbitalia across the case study sites, comparing the number of individuals with cribra orbitalia to those with at least one orbit preserved for analysis, but no evidence of cribra orbitalia. 1: Catterick, *Cataractonium.* 2: Pocklington, Yapham Road. 3: York, Hungate. 4: York, Newington Hotel. 5: Catterick, Bainesse. 6:

Dalton Parlours. 7: Ferrybridge Henge. 8: Healam Bridge. 9: Parlington Hollins. 10: Scorton. 11: Wattle Syke. 12: Bamburgh, Bowl Hole. 13: Melton. 14: Norton, Bishopsmill. 15: Norton, East Mills. 16: Pocklington, Burnby Lane. 17: Sewerby. 18: West Heslerton. 19: York, Queen's Hotel.

8.1.4 Climate change between the Roman and early medieval periods

The climatic downturn at the end of the Roman Warm Period coincided with the decline of Roman authority in Britain, meaning that the Roman and early medieval periods were distinguished not only by their societal practices but also by the weather, as discussed in section 2.1.3. The climate influenced the growth of plants, with cooler, wetter weather having a negative impact, as seen in dendrochronology studies where the climate downturn is visible as a narrowing in growth rings (Esper et al. 2014; Leuschner et al. 2002). There were also more frequent severe floods in the low-lying areas of northern England, especially around the Humber, the Vale of York, and the North Sea coast as recorded by chroniclers of the time such as Simeon of Durham and Bede, and assembled into a chronology by C. E. Britton in 1937 (Doe, 2015; Jones, 1996, 200). Indeed, many of these areas were wetlands or fens, where flooding was routine, until the early modern period when they were gradually drained (Rotherham, 2010). While regular winter floods in fenland areas would have deposited rich, fertile silt, unseasonal flooding would have hindered growing crops, and was recorded to have killed livestock and destroyed grain and other foods in storage, inducing famines (Doe, 2015). This may have been a mechanism by which the cases of cribra orbitalia seen in the early medieval population were formed, as dietary deficiencies, especially a lack of animal products, increase the risk of a person developing anaemia.

The cooler and wetter weather of the early medieval period would have had one benefit, in that malaria would have been less common. The mosquito vector species *Anopheles atroparvus* is native to Britain and Europe, and would have survived the cooler early medieval period, but the malaria strain *Plasmodium vivax* requires temperatures above 15°C to survive in its host (Sallares, 2002), so would not have been persistently present. In the Roman period, though there are no cases documented either historically or archaeologically, it is thought that malaria would have been common in Britain due to the regular trade from Europe and North Africa reintroducing the virus each spring, and the warmer climate allowing it to thrive and spread through coastal and low-lying areas (Sallares, 2002). People living or spending time in marshy areas such as the Humber estuary and river valleys such as the Vale of York would have been at risk of malarial infection, which causes haemolytic anaemia, manifesting in the skeleton as cribra orbitalia. The greater risk of malaria in the Roman period may therefore explain the greater prevalence of cribra orbitalia. On the other hand, Gowland and Western (2012) only took cribra orbitalia to be evidence of malaria in their early medieval populations if the prevalence was greater than that of dental enamel hypoplasia in the same population, deeming greater prevalence of dental enamel hypoplasia to be more indicative of systemic stress. Considering the case study populations in this way, only Pocklington Burnby Lane – an early medieval cemetery – would show evidence of malaria, with the true prevalence of cribra orbitalia (52.2%) greater than that of dental enamel hypoplasia (23.8%). It is therefore unclear whether the greater prevalence of cribra orbitalia in the Roman period can be attributed to the greater risk of malarial infection.

The other transmittable disease influenced by the changing climate at the end of the fourth century was the bubonic plague, *Yersinia pestis*. The cooler weather is theorised to have made much of North Africa more hospitable to the rodent flea *Xenopsylla cheopis*, increasing its breeding rate and therefore encouraging the spread of the plague bacterium the flea played host to (Harper, 2017). Known as the Justinianic Plague, the epidemic spread across Europe in the mid-5th century, and is known to have reached Britain as it has been identified in ancient DNA from the Edix Hill cemetery in Cambridgeshire (Keller et al., 2019). While it is possible that infection with the bubonic plague may have caused anaemia of chronic disease and therefore been responsible for some of the few cases of cribra orbitalia in the early medieval individuals of the case study population, it is more realistic that people would have either recovered before the bone was affected, or died, as the plague is an acute condition which spreads rapidly throughout the body (Sebbane et al., 2005).

8.1.5 Methodological considerations for the study of cribra orbitalia

As this thesis has relied on compiling the results from previous work by many osteologists, the methods used at all stages need to be carefully considered in the conclusions to be drawn. While cribra orbitalia is fairly simple to recognise, identification of any skeletal pathology is subjective. During data collection, the decision was made to standardise the recording of cribra orbitalia to a simple note of presence or absence, as there was no consistent use of scales of severity by the osteologists who originally examined the skeletal assemblages and wrote the case study reports. Additionally, because the majority of publications did not report on cribra orbitalia by single orbit, the true prevalence – the number of affected orbits over the number of orbits present – was modified to calculate the prevalence in individuals with at least one orbit preserved. When compiling the dataset for this thesis, the labelling of those individuals with neither orbit preserved was based on skeletal catalogues describing the presence of bones, excavation photographs, or drawings of the burials. Therefore it is possible some individuals will have been listed in this thesis as not having eye orbits when they do, or as having them when they do not, though it is hoped that the use of multiple sources of evidence will have mitigated this. This potential for error was unavoidable without re-examining every individual personally, which was not possible due to time constraints and issues with accessibility of the skeletal collections due to the Covid-19 pandemic.

Alternative diagnoses of orbital porosity include taphonomic damage, rickets and scurvy, old age, and infection (Brickley, 2018), or indeed co-occurrence of cribra orbitalia with any of these conditions. These conditions should usually be discounted by examination of other areas of the skeleton for other characteristics, such as bowing in the long bones for rickets, to confirm their absence. While most studies utilised in the compilation of the dataset for this thesis stated that conditions such as scurvy and rickets were searched for but not found, many gave very minimal information on how skeletal recording was undertaken. Therefore, it is a possibility that some individuals recorded in this work as having cribra orbitalia may not actually display the necessary lesions.

The final element that may have influenced the study of cribra orbitalia is the ability of the eye orbit to remodel over time. As cribra orbitalia generally forms in children younger than 12, the focus on adult skeletal remains in this study meant no individuals included could have presented an active form of the condition. Therefore some of the individuals included in the case study population for this thesis may have had cribra orbitalia in childhood, but lived long enough for the eye orbits to fully remodel and present no sign of childhood stress.

8.1.6 Summary

Overall, the significant decrease in the prevalence of cribra orbitalia between the Roman and early medieval periods indicates that the Roman population had a poorer diet, and were more frequently afflicted with infectious diseases. There is a strong difference between the prevalence of cribra orbitalia in the case study populations of this thesis, and those of other works focusing on southern England in the Roman period, but not for the early medieval period. This indicates that diet and disease were likely influenced by the divide between north and south in the Roman period, which was created by the stationing of thousands of soldiers in the north, who were a great burden on resources and may have brought new pathogens with them from their regions of origin. While the early medieval population presented a much lower prevalence of cribra orbitalia, the condition was still present, indicating some issues with food supply were encountered, which may have been due to the worsening climate impacting the growth of crops.

8.2 Dental enamel hypoplasia

Dental enamel hypoplasia is a non-specific manifestation of stress, meaning that its array of potential causes cannot be narrowed even to a broad category such as anaemia in the case of cribra orbitalia. Instead, as discussed in section 3.2, any source of stress during the period of tooth crown development can disrupt enamel formation, leading to the tooth crown developing with pits, lines or grooves where insufficient enamel was deposited (Hillson, 2005). The changes seen in settlements, diet and weaning after the Roman withdrawal are considered in light of the decreased prevalence of dental enamel hypoplasia to learn the impact on the health of the population.

8.2.1 The influence of settlements on dental enamel hypoplasia

Although it was not possible to reveal any specific information about how populations were affected by their living environments in the Roman and early medieval periods, assessing the prevalence of enamel defects presented a general picture of especially poor health in the Roman period, matching that seen in the study of cribra orbitalia. The higher prevalence of dental enamel hypoplasia in the Roman period is potentially attributable to urban living and its associated hazards discussed above, such as the spread of disease and exposure to lead and other pollutants. Episodes of ill health due to unhygienic conditions during early childhood, while the permanent tooth crowns are developing in the jaw, disrupts the function of the ameloblasts while growth of the tooth crown continues, creating a ring of thinner enamel around the tooth crown (Hillson, 2005, 174). The comparison of the Roman urban and rural populations in this thesis somewhat supported the inferred impact of living in towns, as the prevalence of dental enamel hypoplasia was significantly greater in the urban assemblage (65.7%) than the rural (37.8%). This observation counters that made by Pitts and Griffin (2012), who noted a spectrum of health in Romano-British populations of southern England, wherein fewer indicators of stress were present the larger a settlement was, and the more connected it was to other large settlements via the road network.

These contrasting results from comparing urban and rural populations demonstrate the divide between northern and southern England during the Roman period, which is also supported by several osteological studies that show lower rates of dental enamel hypoplasia in Roman populations from the south (Table 8.2.1). It is clear from comparing the case study population of this thesis to their contemporaries from other regions that life in northern England during the Roman period caused children to experience greater levels of stress, disrupting the development of their teeth. The markedly poorer health in the north compared to the south did not persist into the early medieval period, with the prevalence of 22.9% found in this thesis firmly in the centre of the range of prevalences found in other works (Table 8.2.2). From this it is clear that the distribution of dental enamel hypoplasia in the early medieval period was more even than in the Roman period, and that the prevalence found in this thesis was not unusual, indicating no particular region-dependent difference in childhood experience of stress after the withdrawal of Roman power. Work directly comparing the health of Roman and early medieval populations in southern England further supports the picture gleaned from individual papers. Klingle found a decrease in the prevalence of dental enamel hypoplasia in Cambridgeshire, from 32.1% in the Roman period to 19% in the early medieval period, and Walther also found a significant decrease in the prevalence of dental enamel hypoplasia after the loss of Roman control across southern England, from 56% to 35%. These changes indicate that Roman administration had negative consequences for the health of people in southern England too, but the change over time does not appear to be of the same magnitude as seen in the populations of this thesis, implying a greater impact from the Roman administration in northern England.

Study	Location	Prevalence of DEH

This thesis	N. England	60.9%
Roberts and Cox, 2003	Britain	9.1%
Brook and Smith, 2006	Poundbury, Dorset	37%
Klingle, 2012	Cambs and Beds	32.1%
Pitts and Griffin, 2012	S. England (Urban)	15%
	S. England (Small towns)	13%
	S. England (Rural)	30%
Bonsall, 2013	Ancaster (Lincs)	16.6%
	Winchester (Hants)	5.5%
McIntyre, 2014	York	53.5%
Keefe et al., 2015	Baldock (Herts)	23.4%
Rohnbogner, 2015	S. England	9.5%
Walther, 2017	S. England	55.7%

Table 8.2.1: Prevalences of dental enamel hypoplasia from Roman populations in Britain.

Study	**Location**	**Prevalence of DEH**
This thesis	N. England	22.9%
Parfitt and Brugmann, 1997	Mill Hill (Kent)	5.3%
Roberts and Cox, 2003	Britain	7.4%
Annable and Eagles, 2010	Wiltshire	57.4%
Craig, 2010	N. England	16.6%
Egging Dinwiddy, 2011	Twyford (Hants)	30.4%
Klingle, 2012	Cambs and Beds	19%
Beavan and Mays, 2013	S. England	13.0%
Walther, 2017	S. England	34.9%

Table 8.2.2: Prevalences of dental enamel hypoplasia in early medieval populations from Britain.

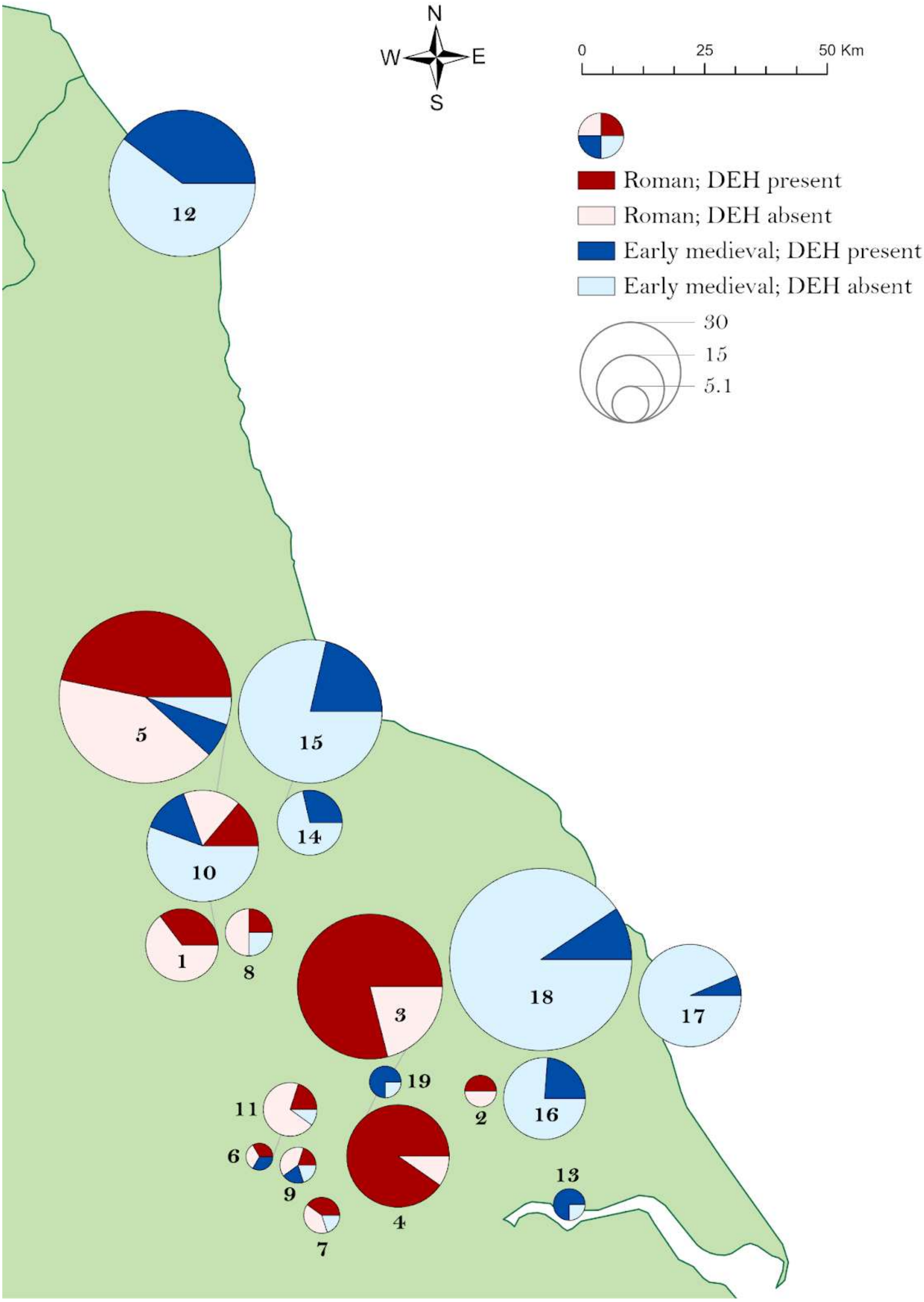


Figure 8.2: The distribution of dental enamel hypoplasia among the case study sites, comparing the number of individuals with individuals with dental enamel hypoplasia to dentate individuals with no evidence of dental enamel hypoplasia. 1: Catterick, *Cataractonium.* 2: Pocklington, Yapham Road. 3: York, Hungate. 4: York, Newington Hotel. 5:

Catterick, Bainesse. 6: Dalton Parlours. 7: Ferrybridge Henge. 8: Healam Bridge. 9: Parlington Hollins. 10: Scorton. 11: Wattle Syke. 12: Bamburgh, Bowl Hole. 13: Melton. 14: Norton, Bishopsmill. 15: Norton, East Mills. 16: Pocklington, Burnby Lane. 17: Sewerby. 18: West Heslerton. 19: York, Queen's Hotel.

8.2.2 The effect of lifestyle and diet on dental enamel hypoplasia

Unlike cribra orbitalia, dental enamel hypoplasia does not allow us to make inferences about changes in diet over time because the aetiology of the condition is so broad. However it can be speculated that the greater prevalence of dental enamel hypoplasia in the population from the Roman period was related to malnutrition disrupting the normal development of the adult dentition. This would have resulted from the poor diet available due to the lack of variety accessible to the urban poor discussed above, and the foodstuffs taken in tax to provision the army, depriving the rural poor (Mattingly, 2007, 494). Dental enamel hypoplasia was also frequently noted in the early medieval population (22.9%, 72/314), though nowhere near as frequently as in the Roman population (60.9%, 131/215). This clearly demonstrated there were sources of stress in the early medieval period, which affected the natural growth and development of children. It is possible that the early medieval diet was affected by unfavourable conditions for crop growth and storage caused by cooler and wetter weather. Climatic disruptions to food supply would have given rise to intermittent famines, causing disturbances in tooth development for children who experienced the food scarcity.

The other aspect of diet often discussed in the literature as a cause of dental enamel hypoplasia is weaning age. The introduction of new foodstuffs and water into an infant's diet during weaning exposes them to many new pathogens at once, and historically, an infant's diet was not nutritionally complete, being based on cereal porridges in both the Roman and early medieval periods (Laes, 2018; Hagen, 2010). However, no causal link has been proven, with a number of studies in populations with known weaning age finding the peak frequency of enamel hypoplasia formation lay outside of that time frame (Palubeckaitė et al., 2002; Saunders and Keenleyside, 1999; Blakey et al., 1994). Therefore, it is more likely that weaning and the development of permanent tooth crowns are simply processes which happen at a similar age. Regardless, the skeletal assemblages from the case study sites were not examined in close enough detail to determine the age at which each enamel defect was formed with the exception of West Heslerton and Parlington Hollins. At West Heslerton, an early medieval cemetery, hypoplastic lines developed most commonly around the age of three years, but were frequently found to have developed at four and five years too. At Parlington Hollins, dental enamel hypoplasia in two early medieval individuals was found to have developed between the ages of three and four years. In comparison to isotopic studies from various Anglo Saxon cemeteries across Britain, where weaning ages varied from nine months to three years (Redfern, 2018b; Haydock et al., 2013; Macpherson et al., 2007), weaning at these two sites would have been unusually late if the hypoplastic lines were in fact caused by weaning. Also at Parlington Hollins, one Roman individual presented hypoplastic lines which developed between 2.5 and 3.5 years, which does correspond with isotopic studies that found the age of weaning to fall between one and four years of age (Redfern, 2018b; Redfern et al., 2018b; Nehlich et al., 2011). However a causal relationship cannot be confirmed, especially with only one individual and such a wide variety in typical weaning times for the period. Overall, while it is considered unlikely that weaning contributed to the prevalence of dental enamel hypoplasia in the study populations, the much greater prevalence of the condition in the Roman population demonstrated that if the stress of weaning were involved, Roman infants were given a much more nutritionally poor and unhygienic introduction to solid foods than their early medieval counterparts.

8.2.3 Methodological considerations in the study of dental enamel hypoplasia

The comparison of the prevalence of dental enamel hypoplasia between this thesis and studies of other sites is somewhat hindered by the modified true prevalence used in this work, where presence or absence was scored for each dentate individual, not on a tooth-by-tooth basis, as described in section 4.5. This resulted in a much greater 'true' prevalence in the populations of this work in comparison to some studies which used the actual true prevalence (for example Peck, 2009), though McIntyre (2014) found a similarly high true prevalence of 53.5% among individuals from Roman York. The high prevalence in the case study population for this thesis cannot, therefore, be attributed solely to methods of calculation, but may be reflective of the actual pervasiveness of the condition. The comparison of true prevalences calculated in different ways was unavoidable, and deemed necessary due to the differences in reporting standards between the original publications on the case study sites, very few of which reported the condition by tooth, and the lack of capacity to re-examine all of the assemblages. Instead of quick and precise comparisons with other reports, this modified method allowed the overall picture of the distribution of dental enamel hypoplasia through time in the study area to be determined. Comparisons were made with the understanding that different methods of calculation were reflected, with several reports (e.g. Klingle, 2012) not specifying how prevalence was calculated. This highlights the importance of considering data for inclusion or comparison critically, to understand where direct comparison may not be valid but seeing, nonetheless, the value in compiling knowledge into a bigger picture.

The study of dental enamel hypoplasia would have been simpler had there been any consistency in recording or reporting by the osteologists originally working on the case study assemblages. In an ideal world with more time available, the presence of dental pathologies would be recorded on a tooth-by-tooth basis. A standardised system for recording the severity and number of hypoplasias on one tooth would also be of use, as many seem to create their own, and the clinical recording system developed by the Fédération Dentaire Internationale Commission on Oral Health, Research & Epidemiology (Hillson, 1996, 172) is not widely used (Hillson, 2024, 239). This resulted in the data being standardised during compilation for this thesis, using a basic presence/absence system which erased the complexity of the condition and led to individuals with one minor enamel defect being scored the same as individuals with severe disruption of enamel development on all teeth, which clearly denote very different experiences of childhood stress. It should also be noted that the exclusion of juveniles, as non-survivors, from this study likely excluded many of the most severe cases of dental enamel hypoplasia, thereby masking the harshest experiences of childhood stress.

8.2.4 Summary

The prevalence of dental enamel hypoplasia decreased significantly between the Roman and early medieval periods, indicating that children experienced less stress in the centuries immediately after the loss of Roman control in Britain. Though the source of that stress cannot be identified by studying enamel defects, it is clear through comparing the prevalence between the populations of this thesis and those from southern England that stressors were greater in the north in the Roman period, but approximately equal in the following centuries.

8.3 Rickets

Rickets is a disorder of growth which occurs as a result of vitamin D and calcium deficiency impairing mineralisation at the growth plates, as discussed in detail in section 3.3. Vitamin D deficiency prevents the absorption of calcium in the intestines, reducing the concentration of calcium in the blood and triggering the release of calcium from bone, hindering mineralisation at the growth plates (Holick, 2006). The active condition is seen only in children, as ongoing growth is essential for the abnormal morphological development (Shore and Chesney, 2013a), but the bowed long bones and frayed epiphyses persist into adulthood, allowing the identification of past nutritional deficiencies (Brickley and Mays, 2019). The potential impacts of clothing style, housing, diet and climate are considered, to assess how the changing prevalence of rickets over time in the case study populations could be used to make inferences about societal changes over the Roman-early medieval transition.

8.3.1 The effect of lifestyle on rickets

Vitamin D is synthesised in the human body when skin is directly exposed to UVB radiation in sunlight, but it is scarce in the diet. Therefore the presence of rickets can indicate sun avoidance, potentially denoting individuals who spent most of their early childhood indoors, or wearing clothes which fully covered the body. Wall paintings and carved depictions of adults, as well as textile remains found in anaerobic burial environments such as that at *Vindolanda*, show that Romano-British adults wore large tunics or tube dresses, generally of wool, draped and pinned around the body (Cool, 2016). Children are thought to have moved from swaddling clothes straight into small versions of adult clothing (Wild, 1968), and therefore would have been well-covered, perhaps to such an extent that vitamin D deficiency could easily develop. Although residual rickets is only present in two Roman individuals from the case study populations, two non-adults from the Newington Hotel site were reported to show signs of rickets in the original osteological report, which may reflect the enveloping nature of typical clothing at the time. Clothing of the early medieval period is more difficult to reconstruct due to the lack of documentary sources from the time, but the comparison of archaeological evidence with contemporary continental depictions of 5th- and 6th-century inhabitants of Britain revealed differing styles for men and women. Men typically wore tunic, trousers and cloak, while women wore tube dresses pinned over a long sleeved shirt, plus a cloak. Children wore simple gowns when young, moving into gendered clothing in the adult style around the age of eight (Gilchrist, 2012, 79-81). Most garments were made of wool, though some could be linen (Owen-Crocker, 1976). Early medieval clothing therefore seems to have offered approximately the same amount of protection from the sun as Roman clothing, so no population-level differences in the prevalence of rickets could be expected on the basis of clothing style.

Investigating the population from Burnby Lane alone, where all six of the early medieval cases were identified, it is clear that rachitic characteristics are more common in males, with only one of the six affected individuals being female. While the sample size is small and therefore may not have been representative of the true distribution of rickets in the population, this pattern is interesting because of the array of cultural practices which may have been involved. Clinically, active rickets is usually seen between four and eighteen months of age (Holick, 2006), while palaeopathologically it is usually found in children under three, but occasionally in those up to five years of age (Mays et al., 2018; Mays et al., 2006). This means young male children would have had to experience very different lives to young female children at Burnby Lane to create this preponderance of the condition, perhaps being kept inside for longer periods of time or dressed in different styles of clothing. Fleming (2011) notes that society was very heterogeneous in the 5th and 6th centuries, so it is not unreasonable to suppose that the community who used the Burnby Lane cemetery had their own unique habits relating to dress, diet or time spent outdoors, causing the unusually high prevalence of rickets in comparison to contemporary populations.

In addition to the clothing style and amount of time spent indoors hindering vitamin D synthesis by blocking out sunlight, the effects of vitamin D deficiency can be somewhat mitigated by a diet with plentiful calcium; vitamin D is required to regulate the metabolism of calcium, and a deficiency can reduce calcium uptake in the intestines by 90% (Holick, 2007). Greater availability of calcium from food intake would therefore result in greater uptake, and a higher blood concentration of Ca^{2+} ions, requiring less calcium to be released from the bones and providing less of a hindrance to normal growth and development. The presence of rickets in the case study populations may therefore point to individuals who had particularly calcium-deficient diets as young children, which could have been due to either a nutritionally poor diet for the individual, or for the mother, leading to the production of calcium-poor breast milk. A study of Iron Age and Roman infant skeletons from Dorset found four cases of rickets in the Roman individuals compared to no cases in the Iron Age individuals, and theorised this was due to poorer nutrition for mothers, and therefore lower nutritional value of breast milk (Redfern et al., 2007). A dietary cause for rickets would be expected to have a more noticeable effect in the populations of the Roman period than the early medieval period, because those living in towns had less access to fresh milk and other dairy products (Erdkamp and Holleran, 2018). As this is not the case, it is tentatively suggested that the evidence for significant growth delay among the Roman population in particular – to be discussed in detail in section 8.4 – may be responsible for the low number of cases seen in this work, because the characteristic malformation of bones occurs when the rate of mineralisation is not fast enough to keep up with the rate of growth. If children were not growing at the usual rate, the hindrance of mineralisation from the lack of calcium would be less problematic.

In contrast to people of the Roman period, the early medieval populations typically reared sheep, goats and cattle within their small village settlements, providing easy access to calcium-rich foods (Hagen, 2010). This was not reflected in the results however, as six cases were reported from the early medieval populations included in this study, in comparison to two from the Roman period. In the Burnby Lane population, it may be theorised that male children were given a diet that was more deficient in calcium. However, this is unlikely as calcium deficiency is known to contribute to dental enamel hypoplasia (Mellanby, 1931), of which there is not an unusually high prevalence in the Burnby Lane population, and no preponderance in males. It is also notable that four of the six cases were in individuals assigned to the mature adult category, and the remaining two were in the young middle adult category, implying that the condition did not hinder them in life. Because the full report of the excavation of the early medieval features at Burnby Lane has not yet been published, it cannot be said whether the settlement was unusual in any way, so it remains unclear as to why this particular case study population stands out from the others when assessing rickets.

8.3.2 The effect of settlements on rickets

Given the evidence for poor living conditions in the Roman period already seen in this thesis, it was anticipated that the prevalence of rickets would reflect this, as it did for the urban children of the industrial revolution who frequently developed rickets due to the lack of exposure to sunlight in the crowded, polluted cities (O'Riordan and Bijvoet, 2014). However, the prevalence in the Roman case study populations is very low overall, with both the crude and true prevalence calculated as 0.8%. This may indicate that despite the density of population in Roman towns, they were not so built up and polluted that children were prevented from getting adequate sun exposure. In a study comparing indicators of stress in juveniles between Roman cemeteries from rural areas as well as major and minor towns, the crude prevalence of rickets was found to be greater in rural areas, and approximately equal in the towns (Rohnbogner, 2015). This supports the theory that urban areas in Britain did not typically block out sunlight in the Roman period.

Another hazard of urban living in the Roman period was lead poisoning. This has been found in association with rickets in both palaeopathological and clinical literature (Lowe, 2024; Moore et al., 2021; Zhang et al., 2019), though the mechanism by which lead contributes to the development of rickets is as yet unknown. The small number of cases of rickets in the Roman populations of this thesis may indicate that lead poisoning was uncommon, though the archaeological evidence shows lead was a common component of household items (Reddy and Braun, 2010; Retief and Cilliers, 2006). It is therefore more likely that the biological processes involved are more complex than simple cause and effect, and other factors need to be involved before lead poisoning can cause rickets. As an additional consideration, the high number of cases of rickets from the Burnby Lane site cannot be explained by those individuals experiencing unusually high levels of lead poisoning, as Pocklington sits on chalk and gravel bedrock, which does not hold much lead and so would not have leached into the water supply (Evans, 2022). Early medieval material culture may have contained lead recycled from Roman items as well, but the lack of industrial mining and processing would have exposed far fewer people to the toxin (Fleming, 2012).

8.3.3 The effect of climate and migration on rickets

One possible explanation for the greater prevalence of rickets in the early medieval population of this study is the climatic downturn at the end of the 4th century (Esper et al. 2014; Leuschner et al. 2002), coinciding with the decline of Roman power in Britain. The poorer weather may be expected to have increased cases of rickets, if people were spending less time outside and wearing more covering clothing to keep themselves warm, thereby decreasing their skin exposure to the sun and production of vitamin D. However, this could not be explored in the case study populations due to the small number of rickets cases. The majority were seen in the early medieval populations, but only from one site, implying that there was either something very unusual about the Burnby Lane settlement, or that there was an issue in data collection, instead of there being a wider pattern in the region caused by climatic shifts in time. The skeletal assemblage from the Burnby Lane site is noted as being unusual in one other way in this thesis: as described in section 8.1.4, this was the only case study site where the prevalence of cribra orbitalia was greater than that of dental enamel hypoplasia, therefore meeting the criteria of Gowland and Western's 2012 study for identifying cases of malaria. It is therefore possible that this population was unusually afflicted with malaria, with ill children being kept indoors and deprived of vitamin D, but further work on the local topography and climate to identify marshy areas would be necessary to indicate whether this is a likely explanation.

Conversely, the lower prevalence of rickets in the Roman period population may be a result of the movement of people between Britain and the Mediterranean region. Southern Europe and North Africa are typically warmer and sunnier than Britain, so children growing up there would have more opportunities to gain sufficient sun exposure for the synthesis of vitamin D. Work by Mays and colleagues (2018) found a correlation between the prevalence of rickets and latitude in sites from across the Roman Empire, with many more cases in Britain and northern France in comparison to sites in Spain and Italy. The exception to this pattern was the assemblage from Ostia in Italy, where the prevalence of rickets was 19% in sub-adults and 21% in adults, though Mays notes that this was likely caused by the densely packed multi-storey buildings, which would have prevented sunlight from reaching the streets or house windows. If the individuals included in the case study population for this present work had grown up in the continental Empire, and then moved to northern England later in life, the evidence of their childhood sunlight exposure would be preserved. They would be recorded as a non-rachitic adult, thereby contributing to the low prevalence of rickets in the Roman period populations of this thesis. It is therefore worth remembering that this work does not necessarily reveal childhood experiences of stress in northern England, but the typical experience of childhood stress for those people who came to live, and die, in northern England.

8.3.4 Methodological considerations in the study of rickets

Given the peculiar distribution of rickets among the populations of this study, the methods used to investigate this condition need to be interrogated. Many of the original osteological reports contain no mention of the condition, so it is unclear whether it was genuinely absent at those sites, or if it was not sought during the examination of the skeletal assemblages, which could mean cases were missed. It is noted that several cases of rickets were recorded in non-adult skeletons from Newington Hotel (Keefe and Holst, 2020), so it can be assumed that signs of residual rickets in adult skeletons would have been recorded if present in this population. Additionally, many other studies from various locations across Britain have found similarly low numbers of cases of rickets in both the Roman and early medieval periods (e.g. McIntyre, 2014; Annable and Eagles, 2010; Craig, 2010; Roberts and Cox, 2003; Parfitt and Brugmann, 1997), suggesting that it was an uncommon condition in both periods, and therefore the low numbers seen in the case study populations of this thesis are not unusual or unexpected.

The Pocklington Burnby Lane case study site was the most notably unusual, with seven cases of rickets found in the 44 early medieval individuals: six adults and one child of 10-12 years. This site was not only an early medieval cemetery, but also an Iron Age cemetery, and the osteological report covered all skeletons from both periods. The prevalence of rickets was also unusually high in the Iron Age assemblage, with 17 cases among the 123 individuals. Although the skeletal catalogue simply notes bowing in various long bones for each individual without confidently diagnosing the condition, all 24 individuals are treated in the report's discussion as cases of rickets. It was for this reason that the decision was made to treat the six adult individuals from the early medieval cemetery with noted bowing as cases of rickets in this thesis. It is briefly noted by Caffell and Holst (2022, 55) that bowing in long bones could be caused by "another pathological condition, or… normal variation", though this is not further explored. It is possible that the six individuals labelled as rachitic in this thesis had a different pathological condition, but it seems unlikely that the same genetic variation causing bowing in the long bones of both arms and legs would appear in both the Iron Age and early medieval cemeteries at Burnby Lane without also appearing at the Iron Age cemetery at The Mile or the Roman cemetery at Yapham Road, both of which are also located in Pocklington (Archaeological Services Durham University, 2019; Ponce and Holst, 2018). As a final consideration, the osteologists involved in analysing the assemblage from Burnby Lane are experienced and well established, and contributed to many of the reports on the case study sites of this thesis (Chapter 4, Table 4.1). Therefore, if the unusually high prevalence of rickets were due to a particularly enthusiastic osteologist who over-interpreted ambiguous signs, other sites included in this thesis would be expected to show the same pattern. As Burnby Lane is the only site with such a high prevalence, it is considered most likely that there was a genuine prevalence of the condition, whether due to unusual cultural practices or an unidentified pathological condition which was able to cause the characteristic signs of rickets.

8.3.5 Summary

Though there were too few cases of rickets to contribute to the aim of assessing changes to health over the Roman-early medieval transition, the cases that were present among the case study populations exhibited interesting patterns. Most notably, the majority of cases were found in males at the Burnby Lane site in Pocklington, strongly indicating that the people buried there had belonged to a community with unique cultural practices regarding clothing, the amount of time spent outside, or the amount of dairy products consumed. This supports the notion that after the withdrawal of Roman administration, society became heterogeneous, with even neighbouring communities differing in organisation, beliefs and practices.

8.4 Stature

Summarised in section 3.4, an individual's adult stature is the result of the combination of genetic and environmental influences throughout childhood and adolescence. While genes control potential stature, environmental stressors limit growth because the body's essential functions are prioritised, as demonstrated in Bogin's equation "Energy required = Maintenance + Immune Function + Repair + Work + Growth" (2020, 418). Any form of stress which limits the available energy can therefore hinder growth, meaning short stature is a non-specific indicator of stress. The potential sources of stress from diet and living conditions, as well as the genetic contribution in both the Roman and early medieval periods, are considered in relation to the increased stature over time seen in the case study populations.

8.4.1 The effect of settlements on stature

Both the males and females of the Roman period case study populations were on average shorter in stature than the males and females of the early medieval period populations, indicating a greater degree of growth delay for the Roman population of northern England. This may be attributed to the effect of urban living, where disease and parasites could spread easily, and people were regularly exposed to lead and other pollutants as discussed above. However, as seen with cribra orbitalia, the results of the comparison of stature between the rural and urban Roman populations did not strongly indicate that urban living had a negative effect on growth. The mean stature was slightly greater (i.e. less subject to growth delay) in the rural populations, at 169.5 cm in males and 158.2 cm in females, in comparison to 167.3 cm in males and

155.9 cm in females from urban cemeteries, but these differences were not statistically significant. It is possible that a greater sample size would have allowed a more robust comparison, as there were only 42 individuals included in this study who were excavated from rural contexts. The sample size was, however, limited by the availability of suitable reports, as well as the poor preservation of skeletal material across the study area, as discussed in section 4.1. Alternatively, the similarity seen in the stature of individuals buried in urban and rural context may reflect movement during life, as it cannot be determined whether an individual grew up in the place that they were then buried. It was especially common for people to move into towns in search of employment (Eckardt et al., 2014), so urban cemeteries should be expected to include individuals with rural upbringings, whose skeletal indicators of stress would reflect the rural environment of their childhood rather than the urban environment of their later life.

8.4.2 The effect of lifestyle on stature

One of the functions in Bogin's (2020, 418) equation is "work", meaning the physical activity a person does in their daily life. It could therefore be inferred that performing excessive manual labour as a child or adolescent would use energy that would otherwise be allocated towards growth. It is difficult to determine the extent to which children would have been involved in labour, as Roman documentary sources generally concerned those of higher status, and written records were very rare in the early medieval period, especially the 5th and 6th-centuries. From funerary practices and the historical evidence, it has been suggested that children were no longer considered children at around 14 years of age in the Roman period, and around 10 years of age in the early medieval period (Gowland, 2016; Crawford, 1999), likely meaning that full-time, physically demanding work would not have been undertaken before this point. Gilchrist writes that youths entered the workforce between 12 and 14 years of age, but based this conclusion on later medieval philosophical and medical writing about stages of life (Gilchrist, 2012, 38). Cribra orbitalia, dental enamel hypoplasia and rickets all develop at younger ages, so growth delay would be the only indicator of stress which could point to manual labour performed in adolescence. It is therefore possible that the greater degree of growth delay seen in the Roman populations reflects a greater amount of work performed by younger individuals, and may be related to the intensity of farming needed to provide grains and other foods to the soldiers stationed in the area.

The mean male stature in the Roman population of this study – 168.0 cm – is very similar in comparison to those found in contemporary populations from other regions (Table 8.4.3). However, it should be noted that McIntyre's work on the city of York (2014) found a greater male mean stature than the present thesis, which looks at the wider area. McIntyre theorised that the greater mean stature reflected the large military population of York, and the height requirements of the Roman army (2014, 260). In contrast, the mean stature of 156.6 cm from the Roman females in this thesis was very low in comparison to those found by other works, which were more often around 158 cm (Table 8.4.3). Overall, the comparison of stature in the Roman period populations of Britain shows only a few centimetres of variation in the means of both males and females. The populations of northern England examined in this thesis show that the males did not differ notably from those of other areas, but that the females were on average shorter than their contemporaries. This indicates that young females experienced greater levels of stress and therefore more growth delay in northern England, in comparison to males from the same region and in comparison to females from other regions.

Study	**Period**	**Location**	**Male mean stature (cm)**	**Female mean stature (cm)**
This thesis	Roman	N. England	168.0	156.6
Roberts and Cox, 2003	Roman	Britain	169	159
Klingle, 2012	Roman	Cambs and Beds	170	158
Bonsall, 2013	Roman	Ancaster (Lincs)	169.0	155.4
		Winchester (Hants)	167.6	156.4
McIntyre, 2014	Roman	York	171.0	159.3
Keefe et al., 2015	Roman	Baldock (Herts)	167.7	158.5

Table 8.4.1: Mean stature in Roman populations from this study in comparison to other populations from around Britain.

Similarly to the Roman males, the mean male stature in the early medieval case study populations from this thesis was approximately the same in comparison to others from studies of the same period around Britain (Table 8.4.3). The mean stature of early medieval females in this thesis was 163.5 cm, which was slightly greater than most of the reported mean statures in contemporary populations, which were more commonly around 160 cm (Table 8.4.3), with the exception of Egging Dinwiddy's (2011) work on early medieval Winchester, and Klingle's (2012) work on Roman and early medieval Cambridgeshire. The uniformity in stature across Britain in the early medieval period indicates that there were no regional differences in either growth delay caused by stress, or increasing mean stature from an influx of genetically taller populations from Europe. As both the male and female values of mean stature calculated in this work were approximately equal to their contemporaries of the early medieval period, it implies that life improved for females more so than males, as the females from northern England were no longer displaying a greater degree of growth delay than the males.

Study	Period	Location	Male mean stature (cm)	Female mean stature (cm)
This thesis	Early med	N. England	173.6	163.5
Parfitt and Brugmann, 1997	6th c.	Kent	173	158
Roberts and Cox, 2003	5th-11th c.	Britain	172	159
Annable and Eagles, 2010	5th-6th c.	Wiltshire	172.9	162.4
Craig, 2010	7th-9th c.	N. England	173.0	161.7
Egging Dinwiddy, 2011	5th-8th c.	Winchester (Hants)	173	163
Klingle, 2012	5th-7th c.	Cambs and Beds	176	164
Beavan and Mays, 2013	6th-7th c.	S. England	176.7	161.3

Table 8.4.2: Mean stature in early medieval populations from this study in comparison to other populations from around Britain.

8.4.3 The influence of migration on population mean stature

The influence of migration on the gene pool must be considered when examining stature. Though stature is used by economists to study deprivation in modern populations due to its sensitivity to stress (Steckel, 1995), it is estimated that 90% of variation in stature within a population is determined by the many contributing genes (Henneberg, 2001). Therefore, while Steckel claims that genetic variation approximately cancels out between populations worldwide, it may be expected that groups living in different regions of Europe during the Roman and early medieval periods would have had genetically different mean heights. In a study spanning the Neolithic to the Medieval period, the mean stature in populations from Britain and Germany was found to be consistently greater than those from France, Spain and Italy, regardless of the trends through time (Danubio et al., 2017; Table 8.1.1). Ruff and colleagues (2017) saw the same pattern, with mean stature greatest in Scandinavia in both periods, and least in the Mediterranean regions (Table 8.1.2). These studies suggest the influence of Bergmann's Rule, wherein stature and overall body size increase with increasing distance from the equator (Bergmann, 1847; cited in Ruff, 2017). However the validity of Bergmann's Rule in humans is debated due to the number of socio-economic factors which also exist in a somewhat latitudinal gradient (Bogin et al. 2022), obscuring the degree to which stature variation within Europe may have been genetically controlled. This regional variety – if materially genetic in nature – was likely a factor in the significant increase in stature between the Roman and early medieval periods seen in the study population; the Roman period saw an influx from those regions with persistent shorter stature, whereas more migrants in the early medieval period came from the northern regions of continental Europe, where the population was generally taller.

Region	Roman		Early medieval	
	Male	Female	Male	Female
Britain	169.0	159.0	172.0	161.0
Italy	164.4	152.1	166.9	154.5
Sardinia	163.2	152.6	165.2	152.9
Spain	163.2	151.8	-	-
Portugal	165.5	151.1	-	-
Germany	-	-	172.0	160.6

Table 8.4.3: Mean stature in European populations from the Roman and early medieval periods, or equivalent centuries for regions with different cultural periods. Data from Danubio et al. (2017).

Region	Roman		Early medieval	
	Male	Female	Male	Female
Britain	164.1	156.5	-	-
France and Italy	162.1	155.3	-	-
Iberia	-	-	164.8	156.9
Central Europe	-	-	164.9	157.3
Scandinavia	171.9	160.9	171.4	165.2

Table 8.4.4: Mean stature in European populations from the Roman and early medieval periods, or equivalent centuries for regions with different cultural periods. Data from Ruff (2017).

Only three of the case study sites have been previously subject to isotopic analysis to determine the geographic origins of the people buried there: Scorton, Bamburgh and West Heslerton. The analysis of the Roman individuals from Scorton found that most individuals likely originated from central or eastern Europe (Eckardt et al., 2015), while the early medieval individuals from this site have not been subject to any known isotopic analysis to date. At Bamburgh, a higher status early medieval site, the majority of individuals were from Ireland and Scotland, with several from Scandinavia and the Mediterranean too (Groves et al. 2013). The population at West Heslerton was found to comprise a mixture of locals and migrants from Scandinavia (Montgomery et al. 2005). Isotopic analysis has also been performed on Roman burials from various excavations around Catterick and Bainesse too, though not the more recently excavated cemeteries included as case study sites. This analysis found that on the whole, the population around Catterick and Bainesse was composed of locals, with only two individuals likely to have originated outside Britain (Chenery et al. 2011). There is of course the chance that the case study cemeteries contained a greater proportion of migrants than the group of burials chosen for the isotopic study, especially because two individuals from *Cataractonium* and one from Bainesse were identified as possibly having African ancestry (Speed and Holst, 2019). It is particularly interesting to note that the Scorton and Catterick populations had such different origins when their burial locations were within a kilometre of each other, and these contrasting studies reinforce the view that the results of this work cannot be assumed to represent solely the childhood experience of health within northern England.

Stature has also been seen to vary throughout time across the regions of Europe, with one common trend emerging. Many studies note a fall in mean stature between the Iron Age and Roman periods, and subsequent rise in early medieval populations, including those from Italy (Giannecchini and Moggi-Cecchi, 2008), Sardinia (Martella et al. 2018), the eastern Mediterranean (Angel, 1984), and Britain (Roberts and Cox, 2003). A study pooling populations into three groups – Central-Western, North-Eastern and Mediterranean Europe – did not include any Iron Age populations, but saw a consistent increase in mean stature between the Roman and early medieval period in all three regions, in a similar manner to the aforementioned works (Koepke and Baten, 2008). There are of course exceptions to this trend, for example in Milan, Italy, where mean stature remained stable from the Roman period to the modern day (Biehler-Gomez et al. 2023). A paper from the Netherlands noted a decrease in male stature between the Roman and early medieval periods, but only compared a total of 17 individuals (Maat, 2005). Finally a continual increase in mean stature was noted throughout the Iron Age, Roman and early medieval periods in Portugal (Cardoso and Gomes, 2009). This evidence of widespread increase in stature between the Roman and early medieval periods suggests that the shorter stature in the Roman populations of this work was more likely related to the negative health consequences of Roman rule, seen across the continental empire, than the influence of migration on the gene pool.

Further evidence for the greater influence of environmental conditions on stature can be seen when comparing the mean male and female stature in the study populations in more detail. The difference between males and females was approximately equal in both the Roman and early medieval assemblages, with the male mean stature 10.7cm greater than the female mean in the Roman population, and 10.1cm greater in the early medieval population (section 6.6.1). Due to the differing patterns of mobility of males and females, changes in stature that arose from migration from different regions would have been expected to affect each sex differently. Long distance migration was not common for women in the Roman Empire, most remaining within the same region and moving between urban and rural areas in search of work, with movement from the European continent and North Africa to Britain largely limited to men (Woolf, 2013). Yet the isotopic studies at West Heslerton and Bamburgh – early medieval sites – showed that males, females and children were all migrants (Groves, 2013; Montgomery et al., 2005). Therefore, if the introduction of men from regions with genetic short stature was responsible for the difference between the Roman and early medieval populations, it would be expected to have affected the males to a greater degree, which was not seen in the study population.

8.4.4 Methodological considerations in the study of stature

The main concern when studying stature in a dataset compiled from many authors' work is the potential for different calculations to be used. For this reason, the citations in each report were checked carefully to understand any differences in methods for estimating living stature. In all reports where the method of stature calculation was referenced, the osteologists used Trotter's 1970 formula, with the exception of Hirst's study of Sewerby (1985), where the earlier Trotter and Gleser (1958) formulae were used. These are the most commonly used formulae, so the majority of the estimated statures among the case study population are comparable to each other and to contemporary populations from the wider area. The formulae were developed on 20th-century white Americans, so it is unlikely the estimated statures of 3rd-7th century people from northern England would be true to life, but this is not necessary to make valid comparisons between the two groups. Five of the original osteological reports on the case study sites – Bamburgh, Dalton Parlours, Ferrybridge Henge, Parlington Hollins and Wattle Syke – did not mention which formulae were used to calculate stature, but the analyses of the skeletal assemblages were each performed by experienced osteologists. It is therefore believed the standard Trotter formulae were most likely to have been used, and the referencing of the methods omitted due to the condensed nature of the reports within each of the site monographs.

Additional opportunity for incomparable statures was created by the poor preservation affecting skeletal remains across northern England. This is because the Trotter method includes formulae to estimate stature from long bones which do not contribute to living height, such as the humerus. Due to the high degree of fragmentation on all sites, it can be expected that some estimates of stature were calculated from such bones in the absence of suitable bones from the lower limbs. While humans tend towards proportionality in arms, legs and trunk, with arm span approximately equal to height, estimating stature from the long bones of the arm is considered less reliable as they do not directly contribute to a person's height (Brickley and McKinley, 2004). The original osteological reports generally did not specify which bones had been used in the calculations of stature, so it was unclear which – and how many – individuals may have contributed a greater margin for error to the compiled dataset.

Finally, it should be remembered that catch-up growth may or may not have affected every individual included in this study. Though the intention of the inclusion of the vertebral neural canal analysis was to address this issue, the lack of variation meant that growth delay was not captured as expected. In future studies, the issue of catch-up growth could be addressed by examining the estimated statures of non-survivors, and comparing their attained stature to the expected mean for their age group.

8.4.5 Summary

The overall picture presented by the analysis of stature supports that seen with cribra orbitalia and dental enamel hypoplasia: that stress in childhood was greater in the Roman period. A distinct difference between males and females is noted, wherein the increase in stature over time was greater for females, indicating that growth delay had a greater effect on females than on males in the Roman period. Comparing the results of this thesis to those of works focusing on other regions of Britain shows that the disproportionate effect on females was primarily seen in the north, with stature increases over time in the south more alike between males and females.

8.5 Vertebral neural canal

The vertebral neural canal, the protective space between the vertebral bodies and their neural arches which houses the spinal cord, can be affected by growth delay like any other region of the body, as discussed in section 3.5. While the anterior-posterior diameter reaches its full size by the time an individual is five years old, the transverse diameter reaches 90% of its final size at five years, and continues to grow up to approximately 15 years of age (Watts, 2013a). This means it cannot undergo catch-up growth in the same way as stature, so is thought to be a more sensitive measure of childhood stress, but it is not widely applied to skeletal populations. The development of the vertebral neural canal during early life is considered here, to ascertain what the results of the comparison between the Roman and early medieval case study populations reveal about childhood stress in each period.

8.5.1 The unexpected results from the vertebral neural canal

The dramatic societal change at the end of the Roman period from urban communities focused on the production and exchange of goods, to rural smallholdings focused on subsistence reduced the population's exposure to disease and toxic substances. It also improved access to a nutritious diet, and these factors are reflected in the decreased prevalence of cribra orbitalia and dental enamel hypoplasia, and increased mean stature of the case study populations. The lack of difference in vertebral neural canal size between the Roman and early medieval populations was therefore unexpected when contrasted with the significant change in health demonstrated by the pathological and stature data. Additionally, the anterior-posterior diameter was expected to correspond with indicators of health which form earlier in childhood such as dental enamel hypoplasia and cribra orbitalia, and the transverse diameter was expected to correspond with stature as well as the prevalence of dental enamel hypoplasia and cribra orbitalia because they develop over a longer period of time. However, the only relationship between either diameter and the other conditions studied was between the transverse diameter and cribra orbitalia, wherein the group of individuals with cribra orbitalia had a smaller mean diameter in most vertebrae than the group of individuals with at least one orbit preserved for assessment but no indication of cribra orbitalia. A similar relationship was found in modern American populations (O'Donnell et al., 2025).

If energy is directed away from growth and development in order to prioritise the general maintenance of the body when experiencing any form of stress which limits energy, it is expected that growth and development would be affected uniformly throughout the body. Indeed, this is the assumption underlying the study of the vertebral neural canal; that it is impacted by growth delay in the same way as stature, but because it does not undergo catch up growth, preserves the evidence of the period of stress (Clark et al., 1986). This relationship between early childhood stress and delayed growth in the vertebral neural canal has been seen in both clinical and palaeopathological studies (O'Donnell et al., 2023; Trombley et al., 2023; Muthuuri, 2021; Muthuuri et al., 2018; Watts, 2015). However, the results of this thesis, wherein stature, cribra orbitalia and dental enamel hypoplasia exhibited clear evidence of stress, but neither diameter of the vertebral neural canal presented any difference between the Roman and early medieval populations, imply that that stress is not manifested equally across the body.

8.5.2 The formation of skeletal indicators of stress in early life

Growth in the vertebral neural canal is approximately 65% complete at birth, and only increases marginally in the transverse diameter after the age of five (Watts, 2013a; Hinck, 1966). The high prevalence of dental enamel hypoplasia demonstrates that many of the individuals in the case study population were experiencing physiological stress in early childhood, at the time when the vertebral neural canal is developing, so the seeming absence of growth delay in the vertebral neural canal cannot be due to the absence of stress. Several theories may be considered to explain this discrepancy. The lack of growth delay in the vertebral neural canal could be due to the majority of its development happening in the womb, if the mother acts as a buffer between environmental sources of stress and the developing foetus. However the maternal buffering theory, wherein the foetus is provided with all necessary nutrients at the cost of the mother in times of external stress, is less accepted than previously due to its oversimplification of the many social and environmental factors which can affect nutrient transfer as well as maternal and foetal health (Tibbetts, 2017; Richardson et al., 2014). If, therefore, the foetus bears the consequences of the mother's ill-health and the conditions experienced in utero affect the development of the vertebral neural canal, the similarity between the Roman and early medieval populations could indicate that the stress experienced during pregnancy was of similar intensity and duration in both time periods. This is considered unrealistic, as there would have to be material improvements in diet, hygiene and workload during pregnancy and the breastfeeding period, in order to overcome the greater sources of physiological stress present during the Roman period, and produce an equitable experience for Roman and early medieval women. Roman medicine likely did not improve matters either, as Soranus' treatise on gynaecology advises against "eating for two", which implies sufficient nutrition would not be taken even if available (Allason-Jones, 2005, 25). Therefore, it is likely that the stress experienced by a foetus during pregnancy was proportional to the stress experienced by children and adults, and so cannot explain the similarity of the results of the vertebral neural canal measurements in the Roman and early medieval populations.

It could be possible that the growth of the vertebral neural canal is prioritised by the body when energy supply is limited, because it houses the central nervous system and may therefore have lower tolerance for developmental changes. However, Clark and colleagues stated in their 1986 paper on growth delay that the possibility of the vertebral neural canal and other neuro-osseous tissues being protected from growth delay was "complete myth". Therefore, the opposite is proposed: that the vertebral neural canal and other neuro-osseous tissues may be the most sensitive of all tissues to stress and disruption during childhood development. A greater degree of sensitivity to growth disruption was found in the vertebral neural canal compared to other skeletal elements in pigs, when their diet was deliberately limited (Platt and Stewart, 1962). In humans, smaller head circumferences have been found in several studies of low birth weight infants (Brooke et al., 1984), demonstrating that the decrease in size also applies to the brain, which is closely associated with the spinal cord. This would explain the similarity of the measurements between the Roman and early medieval populations despite the differences in other skeletal indicators of stress, as both populations may have been subject to sufficient stress to restrict neural canal growth, with excess stress expressed in other regions of the body.

Narrow vertebral neural canals can lead to impingement on the spinal cord, either directly if very narrow, or indirectly as the smaller space incorporates less of a buffer to allow for protruding discs, osteophytes, thickening ligaments or injury. Clinical studies into narrow vertebral neural canals refer to it as spinal stenosis, and have linked it to a range of health issues including pain, weakness and numbness in the limbs, especially the legs (Goh et al., 2004; Jones and Thompson, 1968), though these studies were conducted with elderly patients whose spinal stenosis had a secondary cause. Those with smaller vertebral neural canals have also been found to be at greater risk of both temporary and permanent neurological damage including paralysis after an injury (Kang et al., 1994; Scher, 1991; Eismont et al., 1984). Therefore, those individuals with significantly delayed growth in the vertebral neural canal may not have lived to adulthood, and so were not included in the case study group for this thesis, meaning only those showing normal development in the vertebral neural canal were studied.

Another possibility is that each individual presents different skeletal manifestations in response to similar stressors. This is supported by the lack of correspondence between cribra orbitalia, dental enamel hypoplasia, rickets and stature in the case study populations. Additional support is given by studies of populations diverse in temporal and geographic distribution, which commonly find no co-occurrence of skeletal indicators of stress such as cribra orbitalia, porotic hyperostosis, dental enamel hypoplasia, rickets, scurvy, Harris lines and infections (for example Mangas-Carrasco and López-Costas, 2021; Rivera and Mirazón Lahr, 2017; D'Anastasio et al., 2013; Liebe-Harkort, 2012; Kozak and Krenz-Niedbała, 2002; Turbón et al., 1991). With the exception of O'Donnell and colleagues' (2025) work on modern American populations, in which cribra orbitalia was associated with smaller vertebral neural canal diameters, there has not yet been research conducted into the correspondence of the vertebral neural canal size with other skeletal manifestations of stress. Therefore it is unclear whether the lack of association found in this thesis is unusual, or a typical presentation of physiological stress in the body.

A lack of correspondence between the presence of different indicators of stress may be a function of developmental prioritisation, responses of different tissues, or the different ages at which each of the indicators of stress studied in this thesis are able to form in the skeleton. The correspondence between smaller transverse diameter and the presence of cribra orbitalia indicates that the age at which a person experiences stress affects its skeletal manifestation, because both continue to develop through childhood and into adolescence (Brickley, 2018; Watts, 2013a), whereas dental enamel hypoplasia and rickets, along with the anterior-posterior diameter, do not often continue development after around six years of age (Hillson, 2024, 163; Shore and Chesney, 2013a; b; Watts, 2013a). It is also considered that the intensity and duration of stress will affect its impact on the skeleton. Many enamel defects can appear on one tooth, each indicating a short period of stress, with larger plane-form defects indicating constant ill-health (for example Towle et al., 2018; King et al., 2002). Stature can recover after delayed growth in early life if an adolescent or young adult experiences an improvement in their condition (Bogin, 2020, 119). These facts demonstrate that stress is not a constant, fixed phenomenon, but something which can fluctuate in intensity, occasionally leaving its mark on the skeleton and sometimes not. It is proposed that short term stressors such as might cause the formation of dental enamel hypoplasia are not strong enough to influence the development of the vertebral neural canal. Additionally, the short timescale over which the vertebral neural canal grows is proposed to limit the possibility of sufficient stress accumulating so as to cause noticeable differences in size.

8.5.3 Comparison of the measurements with other studies

Still a developing field of study, comparative data on the vertebral neural canal dimensions of archaeological populations is scarce. Examining the data from this study in comparison to the mean values from those few studies identified, of medieval York, London and Czechia, and late modern Portugal, sees generally greater mean values of both the transverse and anterior-posterior diameters from this work (Tables 8.5.1 and 8.5.2). Of course, the statistical significance of this cannot be tested as only the mean values were available in the published works, but it is noted that they are overall more similar to each other than to the results of this study, with the exception of the anterior-posterior diameters from the study of Portuguese individuals, which were especially large in the lower thoracic and lumbar vertebrae (Amoroso and Garcia, 2018). This perhaps implies that the similarity between the Roman and early medieval populations in this thesis is not a result of equal burdens of stress in early life, with improvement in later childhood for early medieval people, but instead results from early childhood stress in both periods being less intense than necessary to affect the vertebral neural canal. Therefore, it is proposed that the greater size of the vertebral neural canal in this study is mostly indicative of the severity of the early life stress experienced by the medieval populations subject to study by Watts, Brzobohatá and colleagues, and Amoroso and Garcia. It is also suggested that hindered growth in the vertebral neural canal requires this severe stress to manifest in a measurable way, as there is a much shorter period of formation for vertebral neural canals in comparison to teeth, eye orbits and stature, so less opportunity for the evidence of stress to accumulate. From this theory, it can be extrapolated that the Roman population of northern England may have been subjected to chronic lower levels of stress, from long-term malnutrition and exposure to pollution and disease, in order to have had such a notable impact on stature but not affected the vertebral neural canal. In comparison, stress may have been experienced as discrete events for the early medieval population of this thesis, such as outbreaks of a particular disease, or poor weather affecting crop growth and inducing famine, causing occasional cases of cribra orbitalia and dental enamel hypoplasia but not overly affecting stature.

	Study	This work	This work	Watts, 2013a	Brzobohatá et al 2024	Watts, 2011	Amoroso and Garcia, 2018
	Period	Roman	Early Med.	14th c.	13th-15th c.	10th-15th c.	19th-20th c.
	Location	N. England	N. England	London	Czechia	York	Portugal
Vertebra	C1	28.6	28.5				27.8
	C2	24.1	24.3				23.1
	C3	23.2	23.2				22.4
	C4	24.4	24.2				23.2
	C5	25.1	24.9				23.9
	C6	24.8	25.1				24.2
	C7	23.9	24.3				23.1
	T1	20.3	21.0				20.0

	T2	18.0	18.2				17.0
	T3	16.9	16.9				16.0
	T4	16.4	16.1				15.8
	T5	16.2	16.0				15.6
	T6	15.9	16.0				15.7
	T7	15.4	16.0				15.7
	T8	15.9	16.0				16.0
	T9	16.5	16.5				16.0
	T10	17.0	16.5		16.3	16.0	16.0
	T11	18.1	18.0		17.3	17.4	17.2
	T12	20.9	20.3		19.8	19.9	20.3
	L1	23.2	21.8	21.3	21.1	21.4	21.8
	L2	23.0	22.2	21.4	21.2	21.5	21.8
	L3	22.7	22.3	21.3	21.2	21.4	22.1
	L4	23.4	22.5	21.6	21.4	22.0	22.3
	L5	25.9	24.7	24.1	24.1	24.5	24.4

Table 8.5.1: Mean transverse diameter in each vertebra from the Roman and early medieval populations of this work, and from other studies.

	Study	This work	This work	Watts, 2013a	Brzobohatá et al 2024	Watts, 2011	Amoroso and Garcia, 2018
	Period	Roman	Early Med.	14th c.	13th-15th c.	10th-15th c.	19th-20th c.
	Location	N. England	N. England	London	Czechia	York	Portugal
Vertebra	C1	31.0	30.7				30.0
	C2	17.1	16.8				20.6

	C3	15.1	15.2				14.1
	C4	14.7	14.7				13.5
	C5	14.6	14.8				13.5
	C6	14.5	14.1				13.4
	C7	14.9	14.4				13.7
	T1	14.9	14.6				14.8
	T2	15.3	14.7				15.4
	T3	15.1	14.9				15.6
	T4	15.4	14.8				15.8
	T5	15.7	15.0				15.9
	T6	15.2	14.9				15.8
	T7	14.9	14.9				15.7
	T8	15.4	15.2				15.6
	T9	15.5	14.8				15.5
	T10	14.9	15.1		14.7	14.6	15.7
	T11	15.2	15.8		15.4	15.1	16.1
	T12	16.5	16.4		16.3	16.0	17.4
	L1	17.6	16.5	16.1	16.3	15.9	17.6
	L2	16.0	16.2	15.0	15.4	15.3	16.8
	L3	14.6	15.3	14.0	14.4	14.1	15.9
	L4	17.1	14.6	13.9	14.6	14.6	16.2
	L5	16.1	15.3	15.2	15.3	16.0	16.9

Table 8.5.2: Mean anterior-posterior diameter in each vertebra from the Roman and early medieval populations of this work, and from other studies.

8.5.4 Methodological considerations in the study of the vertebral neural canal

Given the surprising nature of the results from the study of the vertebral neural canal, the methods used need to be scrutinised to ensure the validity of the measurements gathered for this thesis. The transverse and anterior-posterior diameters were measured with digital callipers accurate to 0.1mm, using the method described by Watts (2013b, 2011). The studies by Amoroso and Garcia (2018) and Brzobohatá and colleagues (2024), cited above for comparative purposes, also used the technique developed by Watts, and so all the data is comparable in the sense that it was collected in the same manner.

It is likely that the preservation of the skeletal remains affected the validity of the statistical comparisons between the Roman and early medieval groups. From the 86 individuals included in the study of the vertebral neural canal in this thesis, a total of 4128 measurements were possible if each individual was preserved well enough for both diameters to be measured in all 24 vertebrae. Instead, 1709 measurements were taken, less than half of the potential. This resulted in several measurements being represented by fewer than 20 data points, and many comparisons between the Roman and early medieval populations being performed with fewer than 10 measurements on each side, negatively impacting the robusticity of the statistical comparisons. If more time and more skeletal collections were available, collecting extra data would have increased the validity of the comparative study. Alternatively, the thoracic vertebrae – in which fewest measurements were taken – could have been discounted and analysis performed only on the cervical and lumbar vertebrae, where the number of observations for each diameter approximately equalled the number taken by Watts in her 2013 study of medieval York, and Amoroso and Garcia's 2018 study of late modern Portugal. Analysing only the lower thoracic and lumbar vertebrae, which are the sturdiest and most likely to survive intact, is a common technique in the study of the vertebral neural canal (as seen in Brzobohatá et al., 2024; Watts, 2013a, 2011), and should be employed in future works of this nature in order to achieve a balance between time taken and data collected.

8.5.5 Summary

Overall, the study of the vertebral neural canal produced an unexpected lack of significant change over time. This may potentially indicate that the vertebral neural canal is more sensitive to stress than the other indicators examined in this thesis, and therefore that all individuals involved in the study met this low stress threshold, experiencing the same amount of growth delay in the vertebral neural canal and presenting no change between the Roman and early medieval periods. Alternatively, it may indicate that growth delay in the vertebral neural canal only occurs in response to extreme stress, which was not experienced by the case study populations. In this case, it would appear from the comparison of stature and the vertebral neural canal that the Roman population experienced chronic, low-level stress, the effects of which accumulated over time into noticeable reduction in stature, but that the shorter time frame over which the vertebral neural canal develops did not offer the same opportunity to accumulate the effects of stress.

Chapter 9: Conclusions and Future Directions

This thesis aimed to reveal the effect of the loss of Roman control on the health status of the people of northern England. Through the exploration of skeletal indicators of stress which originate in childhood, along with the examination of archaeological, historical and palaeopathological evidence of the typical lifestyle, it has been demonstrated that health improved after the withdrawal of Roman rule in this remote province. It has also been demonstrated that the magnitude of changes in health over time depended on sex, with females presenting a greater degree of growth delay than their male contemporaries in the Roman period, and a smaller decrease in the prevalence of cribra orbitalia over time. This work has added to the limited literature using the vertebral neural canal as a measure of childhood health, concluding that intense stress in early childhood is necessary to create a measurable impact, and that this sort of stress was not present for the 3rd to 7th-century populations of northern England. This is the first study of the Roman-early medieval transition in the region, and has produced a unique result not seen in similar regional studies of other areas of the Empire, illustrating the need for large-scale regional studies in more areas to fully understand this dynamic period. Additionally, this work has created a database of skeletal information on 656 individuals, augmenting the value of several neglected smaller assemblages, and produced vertebral neural canal measurements for 86 individuals, increasing the amount of data available from this novel technique. Overall this thesis has shown another side to the Roman occupation, where the benefits touted by the classic "what have the Romans ever done for us" sketch were for the privileged few, and most people suffered under the weight of military occupation, to the extent that the subsistence farmers of the early medieval period were notably better off. This chapter considers the osteological and archaeological evidence for changes in diet, disease exposure and migration as the major factors which influenced the health of Roman and early medieval populations in northern England, with the overarching theme of Roman military occupation connecting them. Recommendations for areas requiring focus in future studies will also be made.

9.1 Summary of the impact of diet on health

The osteological evidence shows that people's diet was generally poorer in the Roman period than the early medieval period. The greater prevalence of cribra orbitalia indicates a more iron deficient diet, and the greater prevalence of dental enamel hypoplasia and shorter stature imply that for most people, the body did not have sufficient resources for tooth development and growth throughout childhood. From the archaeological and historical evidence, it can be inferred that the poor diet eaten by the people of northern England in the 3rd-4th centuries AD resulted from economic factors. While Roman towns were centres for trade, with goods imported from across the empire, most townspeople could not afford more than a simple diet of grains and pulses (Erdkamp and Holleran, 2018), and those who farmed had much of their produce taken in tax to provision the army, so could not eat well themselves (Gerrard, 2013; Mattingly, 2007). While the decrease in markers of stress shows that diet improved in the early medieval period, it was still occasionally insufficient to prevent the development of skeletal lesions, indicating that access to food was not as plentiful or reliable as necessary, even after the removal of the Roman tax burden. The insecurity in food supply may have been due to the weather; palaeoclimatic studies show a sudden downturn in the weather concurrent with the withdrawal of imperial control in Britain (Blackford and Chambers, 1991; Baillie and Munro, 1988). The colder and wetter weather affected the growth of plants, jeopardising food production for the people of the early medieval period who were largely self-sufficient and did not have widespread trade networks to fall back on. The contrasting results of the analysis of stature and the vertebral neural canal, wherein stature was significantly reduced in the Roman population, but no reduction in size was evident in the vertebral neural canal, supports the picture of persistent lack of food in the Roman period, compared with limited food supply issues in the early medieval period.

9.2 Summary of the impact of disease on health

The higher prevalence of stress indicators in the Roman period case study populations also indicated greater disease exposure, either from the additional stress on the body disrupting growth and development, or from the loss of iron which can accompany infections. The greater risk of disease may be linked to the poorer diet, as the immune system is weakened if the body does not receive sufficient nutrients to sustain all systems and processes (Scrimshaw et al., 1968). Alternatively, the greater prevalence of stress indicators can be used to make inferences about the living conditions of the Roman period, suggesting that the typical environment people inhabited was more unhygienic than that of the early medieval period, so people were exposed to a greater number of pathogens and parasites. This may be linked to the types of settlements which existed in each period. The majority of individuals from the case study population of the Roman period were from urban environments, where they likely experienced poorer hygiene than the populations from the villages of the early medieval period. This was despite the provision of clean water and methods for dealing with waste in Roman towns, and was probably due to the population density facilitating the spread of disease.

9.3 Summary of the impact of migration on health

The final factor considered to have contributed to the difference between the health status of the Roman and early medieval populations is migration. This can be linked to disease, because when people move to a new area, they encounter many new pathogens at once, causing greater stress on the immune system than usual (Mascie-Taylor and Krzyżanowska, 2017). They also carry pathogens that the people living in the area have not been exposed to before, increasing the stress on the resident population. However, the effect of migration on the spread of disease does not solely explain the more prevalent indicators of stress in the Roman population because migration was common in both periods. The drivers for migration were slightly different in the Roman and early medieval periods, which may account for the difference in health status between the populations of the two periods. In the Roman period, migrants to Britain were often legionaries, and therefore adult males, recruited from recently conquered provinces such as North Africa and sent to Britain to defend the northern border with Scotland (Mattingley, 2007). In the early medieval period, migrants were of all ages and genders, and generally came from the Germanic regions which had never experienced Romanisation (Fleming, 2011). It is therefore likely that people who moved to northern England in the Roman period experienced greater levels of childhood stress than those who moved to the area in later centuries, due to growing up in conquered and subjugated territory, thus influencing the overall picture of childhood stress in the case study population. Due to the large numbers of migrants in both periods, this thesis can be more accurately said to investigate the childhood health experiences of people who spent the end of their lives in northern England. Given it has been shown that childhood health was not universally poor across the Roman Empire, it therefore seems that those who were most disadvantaged were most likely to migrate to northern England, and eventually, to die there.

9.4 The distinctiveness of northern England

This thesis has shown a clear distinction between the health status of populations from the Roman and early medieval periods in northern England. Yet similar comparisons in other regions have found health status to remain largely unchanged, or to deteriorate over time as the Roman Empire declined (Griffin, 2017; Walther, 2017; Klingle, 2012; Šlaus et al., 2011; Belcastro et al., 2007; Salvadei et al., 2001). To explain this regional variation in response, we must look to the military. Northern England hosted 40,000 legionaries at the height of Roman control in the region, an eighth of the imperial forces, despite only being a small part of just one conquered province (Fleming, 2011). The threat of rebellion from the local tribes, and the threat of invasion from north of Hadrian's Wall required the presence of such an excess of soldiers, and therefore there was a greater strain on access to resources of all varieties, from pottery, to metalwork, to grain and meat. The heavy taxation of food produce would have seriously hampered the availability of a varied, nutritious diet for the large numbers of poor labourers, and the presence of soldiers with disposable income drew many people to live in towns, where disease could spread more readily, and industries polluted the air, water and ground. The military also influenced migration, driving an influx into northern England of people from across the empire who likely had stressful childhoods, and therefore presented the indicators of stress examined in this thesis.

9.5 Recommendations for future work

The improvement in population health over the Roman-early medieval transition in northern England could be explored in more depth through a variety of avenues, for which there was not sufficient time in the course of this thesis. The examination of a wider array of skeletal indicators of stress, such as evidence of periosteal reactions and degenerative joint disease, which can form in adults, would complement this work and help to develop a broader understanding of the development of health throughout life. These conditions can be used to indicate how physically demanding an individual's life was, and would show if there was any change in the amount of manual labour being performed between the Roman and early medieval periods. Osteological evidence could also be combined with aDNA assessments or isotopic analysis, to identify the people who moved to northern England from other areas of Europe and Africa. This would then provide the basis for determining how their experiences of childhood stress may have been similar or different to those of people born in Britain. Incremental dentine sampling for carbon and nitrogen isotope analysis could also be used to track changes in diet during the course of childhood, and identify the outcomes of episodes of nutritional stress.

Aside from research exploring the populations of northern England in further detail, work should also be conducted on similar populations from other regions of the former Roman Empire. While this thesis focuses on northern England, osteological studies of changing health over the transition from the Roman to the early medieval period have also been conducted in southern England, Italy and Croatia. However the Roman Empire had a much wider reach than this, encircling the Mediterranean Sea and covering much of North Africa, Western Asia, and Southern and Western Europe. There are therefore large swathes of the former Roman Empire for which the effect of Imperial control – and its subsequent loss – on the health of the population is not understood. This thesis has demonstrated the clear regional differences in changes in health over the Roman-early medieval transition, illustrating the need for comparative osteological studies to be conducted in more regions such as North Africa, the Middle East, the Iberian Peninsula, and the Black Sea.

9.6 Final comments

Ultimately, this work has challenged the perception of the Roman Empire and the so-called "Dark Ages", offering new evidence from northern England to counter that from different regions of the former empire. It has shown that the Roman administration had a significant negative impact on the health of the population due to the heavy military presence, and the reprieve in the centuries following the withdrawal allowed the health of the population to recover back to levels more similar to those of their contemporaries in other regions of Britain. Additionally, the inclusion of vertebral neural canal measurements has shown that the stress experienced by children in the Roman period was of a chronic nature, rather than intense acute episodes, giving an insight into the persistent hardship of the time.

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Appendix 1: Compiled skeletal data

Key

Period

R = Roman

EM = Early medieval

Type

U = Urban

R = Rural

Blank = Early medieval site

CO/DEH/Rickets

Y = Pathology present

N = Pathology absent

NP = Skeletal element not present for analysis

Stature measured in cm

Site Name	SK number	Period	Type	Sex	Age	CO	DEH	Rickets	Stature	Notes
Cataractonium	SK7182	R	R	M	YMA	N	N	N	163.3	
Cataractonium	SK10869	R	U	U	A	NP	N	N		
Cataractonium	SK11815	R	U	U	YA	NP	Y	N		
Cataractonium	SK20116	R	U	M	MA	N	N	N	166.6	
Cataractonium	SK20117	R	U	F	YMA	N	Y	N	158.3	
Cataractonium	SK20190	R	U	U	A	NP	NP	N		
Cataractonium	SK20197	R	U	F	A	NP	N	N		
Cataractonium	SK20342	R	U	F	YA	NP	Y	N	153.5	
Cataractonium	SK20395	R	U	M	YA	N	N	N		
Cataractonium	SK20416	R	U	M	OMA	N	Y	N	163.7	
Cataractonium	SK20475	R	U	?F	A	NP	Y	N		
Cataractonium	SK20573	R	U	M	OMA	Y	N	N		
Cataractonium	SK20585	R	U	F	YMA	N	Y	N		
Cataractonium	SK20603	R	U	U	YA	Y	N	N	155	
Cataractonium	SK20604	R	U	U	A	NP	N	N		
Cataractonium	SK20615	R	U	?F	A	N	N	N		
Cataractonium	SK20721	R	U	?M	MA	Y	N	N		
Cataractonium	SK20813	R	U	U	OMA	Y	N	N	172.1	
Cataractonium	SK20844	R	U	?M	YMA	Y	Y	N		
Cataractonium	SK20957	R	U	M	OMA	N	N	N	158	Unclear African or mixed ancestry

Site Name	SK number	Period	Type	Sex	Age	CO	DEH	Rickets	Stature	Notes
Yapham Road	13	R	R	M	MA	Y	N	N	170.2	
Yapham Road	18	R	R	M	OMA	Y	Y	N	166.8	
Yapham Road	19	R	R	M	YA	Y	Y	N	167.5	
Yapham Road	22	R	R	M	MA	Y	N	N	173.1	
Hungate	5	R	U	U	A	NP	NP	N		
Hungate	6	R	U	U	YMA	N	Y	N		
Hungate	7	R	U	M	OMA	N	Y	N	170.9	
Hungate	8	R	U	U	OMA	NP	Y	N		
Hungate	9	R	U	?M	YMA	Y	Y	N		
Hungate	11	R	U	U	A	NP	NP	N	170.9	
Hungate	12	R	U	M	OMA	Y	Y	N		
Hungate	14	R	U	U	YA	NP	N	N		
Hungate	15	R	U	F	YMA	N	Y	N		
Hungate	16	R	U	U	A	NP	NP	N		
Hungate	17	R	U	?F	A	NP	Y	N		
Hungate	19	R	U	U	YA	N	Y	N		
Hungate	33	R	U	M	OMA	N	Y	N		
Hungate	37	R	U	F	YA	Y	Y	N		
Hungate	40	R	U	U	YMA	N	N	N		
Hungate	41	R	U	?M	OMA	NP	NP	N		
Hungate	42	R	U	?M	OMA	N	Y	N		
Hungate	43	R	U	U	YA	N	Y	N		
Hungate	44	R	U	U	YA	N	Y	N		
Hungate	47	R	U	?F	OMA	N	Y	N		
Hungate	48	R	U	M	MA	N	N	N		
Hungate	50	R	U	U	A	NP	N	N		
Hungate	55	R	U	?M	YMA	NP	Y	N		
Hungate	56	R	U	M	YA	NP	NP	N	169.8	
Hungate	57	R	U	M	OMA	NP	NP	N		
Hungate	58	R	U	M	OMA	N	N	N	159.5	
Hungate	59	R	U	?F	OMA	Y	Y	N	143.7	
Hungate	60	R	U	M	YA	N	Y	N	168.4	

Site Name	SK number	Period	Type	Sex	Age	CO	DEH	Rickets	Stature	Notes
Hungate	61	R	U	?M	YMA	N	Y	N		
Hungate	62	R	U	U	YMA	NP	N	N		
Hungate	63	R	U	U	OMA	NP	N	N		
Hungate	64	R	U	U	A	NP	NP	Y		
Hungate	65	R	U	M	YA	N	Y	N		
Hungate	66	R	U	F	YMA	Y	Y	N	144	
Hungate	67	R	U	?M	YA	NP	Y	N		
Hungate	68	R	U	M	A	NP	Y	N		
Hungate	69	R	U	?F	OMA	NP	NP	N		
Hungate	70	R	U	?M	YMA	NP	Y	N		
Hungate	71	R	U	?F	OMA	N	Y	N		
Hungate	76	R	U	F	OMA	N	Y	N	165.6	
Hungate	79	R	U	M	YA	N	Y	N	168.7	
Hungate	80	R	U	M	YMA	N	Y	N	162.5	
Hungate	81	R	U	?F	YA	NP	Y	NP		
Hungate	82	R	U	F	MA	N	Y	N	155.9	
Hungate	83	R	U	U	YMA	NP	Y	N	158.9	
Hungate	84	R	U	M	YA	N	N	N	166.6	
Hungate	85	R	U	F	YA	N	Y	N		
Hungate	86	R	U	F	OMA	N	Y	N	154.7	
Hungate	88	R	U	F	OMA	N	Y	N	150.6	
Hungate	89	R	U	F	YMA	Y	Y	N		
Hungate	91	R	U	F	YMA	N	Y	N		
Hungate	92	R	U	F	MA	N	Y	N	153.3	
Hungate	93	R	U	F	YMA	N	Y	N	159.5	
Hungate	94	R	U	?M	MA	NP	NP	N		
Hungate	96	R	U	?M	OMA	NP	Y	N		
Hungate	99	R	U	?F	MA	N	N	NP		
Hungate	102	R	U	?M	YA	N	Y	N	164.2	
Hungate	103	R	U	M	MA	Y	N	N	158.3	
Hungate	104	R	U	?M	YMA	N	Y	N		
Hungate	107	R	U	F	MA	N	Y	N	153.4	

Site Name	SK number	Period	Type	Sex	Age	CO	DEH	Rickets	Stature	Notes
Hungate	109	R	U	U	YA	N	Y	N		
Hungate	110	R	U	F	YMA	N	Y	N	155.2	
Hungate	124	R	U	M	MA	N	N	N	159.6	
Hungate	125	R	U	F	OMA	Y	N	N	157.6	
Hungate	126	R	U	F	MA	N	Y	N	164.6	
Hungate	130	R	U	?F	MA	Y	Y	N		
Newington Hotel	1	R	U	?M	MA	N	Y	N		
Newington Hotel	2	R	U	?M	A	NP	NP	N	169.7	
Newington Hotel	5	R	U	F	MA	N	Y	N	151.1	
Newington Hotel	9	R	U	I	YA	Y	Y	N		
Newington Hotel	10	R	U	M	A	N	Y	N		
Newington Hotel	12	R	U	?M	A	NP	NP	N	162.1	
Newington Hotel	13	R	U	?M	A	NP	NP	N	176.4	
Newington Hotel	16	R	U	F	YA	N	Y	N	151.3	
Newington Hotel	17	R	U	F	YMA	NP	NP	N	166	
Newington Hotel	18	R	U	F	YMA	Y	NP	N		
Newington Hotel	19	R	U	?M	A	NP	NP	N	170.7	
Newington Hotel	20	R	U	U	YA	NP	NP	N		
Newington Hotel	21	R	U	?F	MA	NP	NP	N	156.9	
Newington Hotel	22	R	U	U	YA	NP	NP	N		
Newington Hotel	23	R	U	M	MA	NP	NP	N	160.3	
Newington Hotel	25	R	U	U	YA	NP	NP	N		
Newington Hotel	26	R	U	M	A	Y	Y	N	166.5	
Newington Hotel	27	R	U	F	YMA	N	Y	N	157.7	
Newington Hotel	28	R	U	M	YMA	N	Y	N		
Newington Hotel	29	R	U	M	OMA	NP	NP	N	174.6	
Newington Hotel	30	R	U	?M	YA	Y	Y	N	172.7	
Newington Hotel	31	R	U	F	MA	NP	NP	N		
Newington Hotel	32	R	U	M	YMA	N	Y	N	169.2	
Newington Hotel	33	R	U	?M	YA	N	Y	N	163.5	
Newington Hotel	35	R	U	?F	OMA	N	Y	N		
Newington Hotel	37	R	U	?M	A	N	Y	N		

Site Name	SK number	Period	Type	Sex	Age	CO	DEH	Rickets	Stature	Notes
Newington Hotel	44	R	U	U	A	NP	NP	N	166	
Newington Hotel	46	R	U	U	A	NP	NP	N		
Newington Hotel	47	R	U	M	OMA	NP	NP	N		
Newington Hotel	49	R	U	?M	MA	N	Y	N	171.5	
Newington Hotel	50	R	U	F	A	Y	N	N		
Newington Hotel	51	R	U	?M	MA	NP	NP	N	168.7	
Newington Hotel	52	R	U	?F	YMA	N	Y	N		
Newington Hotel	53	R	U	U	A	NP	NP	N	173.1	
Newington Hotel	56	R	U	?F	YMA	N	Y	N	158.6	
Newington Hotel	57	R	U	M	OMA	N	Y	N		
Newington Hotel	58	R	U	M	A	N	Y	N	174.3	
Newington Hotel	59	R	U	M	A	N	Y	N		
Newington Hotel	60	R	U	U	A	N	N	N		
Newington Hotel	61	R	U	?F	A	NP	NP	N		
Newington Hotel	62	R	U	U	A	NP	Y	NP		
Newington Hotel	63	R	U	F	YMA	N	Y	N	156.1	
Newington Hotel	66	R	U	U	A	NP	NP	N		
Newington Hotel	68	R	U	M	A	Y	Y	N		
Newington Hotel	70	R	U	M	YA	N	NP	N	168.7	
Newington Hotel	75	R	U	M	MA	Y	Y	N	171.6	
Newington Hotel	76	R	U	U	A	NP	NP	N		
Newington Hotel	78	R	U	M	OMA	N	Y	N	169.2	
Newington Hotel	79	R	U	U	A	NP	NP	N	166	
Newington Hotel	80	R	U	M	YMA	N	Y	N		
Newington Hotel	81	R	U	M	YMA	N	Y	N	166.5	
Newington Hotel	82	R	U	M	MA	N	Y	N	188.2	
Newington Hotel	84	R	U	U	A	NP	NP	N	168.4	
Bainesse	G6	R	U	?M	OMA	Y	Y	N		Potential African heritage
Bainesse	G7	R	U	M	YMA	N	Y	N	164	Potential African heritage
Bainesse	G8	R	U	U	A	NP	Y	N		
Bainesse	G10	R	U	U	A	NP	N	N		
Bainesse	G12	R	U	U	A	NP	N	NP		

Site Name	SK number	Period	Type	Sex	Age	CO	DEH	Rickets	Stature	Notes
Bainesse	G15	R	U	M	YA	Y	Y	N		
Bainesse	G16	R	U	F	MA	Y	Y	N	161.5	
Bainesse	G17	R	U	M	YMA	Y	Y	N	161.4	
Bainesse	G18	R	U	U	A	Y	Y	N		
Bainesse	G22	R	U	M	YMA	Y	Y	N	165.9	
Bainesse	G23A	R	U	U	A	NP	N	N		
Bainesse	G23B	R	U	U	A	NP	NP	N		
Bainesse	G24	R	U	U	YA	NP	Y	NP		
Bainesse	G26	R	U	?M	A	N	N	N		
Bainesse	G27	R	U	U	A	NP	NP	N		
Bainesse	G28	R	U	U	A	Y	NP	N		
Bainesse	G35	R	U	U	A	NP	N	N		
Bainesse	G36	R	U	U	A	NP	N	NP		
Bainesse	G41	R	U	U	A	NP	N	N		
Bainesse	G44	R	U	U	A	NP	N	N		
Bainesse	G50	R	U	U	A	NP	Y	NP		
Bainesse	G51	R	U	U	A	NP	Y	NP		
Bainesse	G56	R	U	U	A	NP	NP	N		
Bainesse	G57	R	U	?M	YMA	N	N	N		
Bainesse	G61	R	U	U	A	NP	N	N		
Bainesse	G62	R	U	?M	A	NP	N	N		
Bainesse	G64B	R	U	U	A	NP	N	NP		
Bainesse	G67	R	U	U	A	NP	Y	N		
Bainesse	G68	R	U	U	A	NP	N	N		
Bainesse	G69	R	U	U	YA	NP	Y	NP		
Bainesse	G71	R	U	U	A	NP	Y	N		
Bainesse	G72	R	U	U	A	NP	N	NP		
Bainesse	G73	R	U	?F	YMA	N	Y	N		
Bainesse	G78	R	U	?F	YMA	NP	Y	N		
Bainesse	G86	R	U	?M	YMA	Y	N	N	167.3	
Bainesse	G87	R	U	?M	MA	Y	Y	N		
Bainesse	G92A	R	U	U	A	N	N	NP		

Site Name	SK number	Period	Type	Sex	Age	CO	DEH	Rickets	Stature	Notes
Bainesse	G92B	R	U	U	A	NP	NP	N		
Bainesse	G93	R	U	U	A	NP	N	NP		
Bainesse	G96	R	U	U	A	NP	N	NP		
Bainesse	G99	R	U	?M	YMA	Y	Y	N		
Bainesse	G104	R	U	U	YA	N	N	NP		
Bainesse	G106	R	U	U	A	NP	NP	N		
Bainesse	G107	R	U	U	A	N	N	NP		
Bainesse	G119	R	U	F	YMA	N	Y	N		
Bainesse	G120	R	U	M	YMA	N	N	N		
Bainesse	G123	R	U	M	OMA	Y	N	N	161.8	
Bainesse	G125	R	U	U	A	NP	N	N		
Bainesse	G130	R	U	U	A	NP	Y	N		
Bainesse	G135A	R	U	U	YMA	NP	Y	N		
Bainesse	G139	R	U	U	A	NP	Y	NP		
Bainesse	G140	R	U	M	YMA	Y	Y	N	160.7	
Bainesse	G142	R	U	U	A	NP	NP	N		
Bainesse	G143	R	U	U	A	NP	NP	N		
Bainesse	G144	R	U	?F	YMA	N	N	N	161	
Bainesse	G154	R	U	?M	YMA	Y	N	N		
Bainesse	G155	R	U	U	A	NP	N	NP		
Bainesse	G156	R	U	?M	YMA	N	Y	N		
Bainesse	G158	R	U	?F	A	Y	N	N		
Bainesse	G160	EM		U	A	NP	Y	N		
Bainesse	G165	EM		U	YA	NP	Y	N		
Bainesse	G173	R	U	?M	YMA	NP	Y	N		
Bainesse	G178A	EM		?F	OMA	N	Y	N		
Bainesse	G178B	R	U	U	A	NP	N	N		
Bainesse	G185	EM		?M	YMA	N	N	N		
Bainesse	G186	R	U	F	MA	Y	Y	N		
Bainesse	G187	EM		U	A	NP	Y	N		
Bainesse	G197A	R	U	M	OMA	Y	Y	Y	171.1	
Bainesse	G198	R	U	?M	YMA	N	Y	N		

Site Name	SK number	Period	Type	Sex	Age	CO	DEH	Rickets	Stature	Notes
Bainesse	G202	R	U	U	A	NP	Y	N		
Bainesse	G208	R	U	M	OMA	Y	Y	N	170.9	
Bainesse	G209	EM		F	YMA	Y	N	N	156.9	
Bainesse	G213	R	U	F	OMA	N	Y	N	153.2	
Bainesse	G216	EM		U	A	NP	N	NP		
Bainesse	G217	EM		M	YMA	N	N	N		
Bainesse	G234	R	U	M	MA	NP	NP	N	162.8	
Bainesse	G237B	R	U	F	YMA	Y	Y	N	155.6	
Bainesse	G237A	EM		?F	OMA	NP	Y	N		
Bainesse	G239	R	U	F	OMA	N	N	N	155.2	
Bainesse	G242	R	U	U	A	NP	Y	NP		
Bainesse	G244	R	U	?M	YMA	NP	N	N		
Bainesse	G254	R	U	U	YA	NP	Y	NP		
Bainesse	G255	R	U	U	A	NP	N	NP		
Bainesse	G13586	R	U	?F	YMA	Y	N	N		
Bainesse	G13420	R	U	M	MA	Y	Y	N		
Bainesse	G13435	EM		?M	OMA	NP	NP	N	171.8	
Bainesse	G13460	R	U	M	YMA	N	Y	N	171.3	
Dalton Parlours	4	R	R	?F	OMA	N	NP	N	168	
Dalton Parlours	8	R	R	?M	YA	N	Y	NP		
Dalton Parlours	10	R	R	M	YMA	N	N	N	174	
Ferrybridge Henge	SK01	EM		F	MA	N	N	N		
Ferrybridge Henge	SK02	R	R	M	YMA	N	Y	N	163	
Ferrybridge Henge	SK04	R	R	M	YA	NP	Y	N		
Ferrybridge Henge	SK10	R	R	M	MA	N	N	N	175	
Ferrybridge Henge	SK15	R	R	?M	MA	N	N	N		
Healam Bridge	SK1994/22 10	R	R	?F	OMA	N	N	N		Excavated in 1994 by Birmingham University Field Archaeology Unit
Healam Bridge	SK2581/25 90	R	R	U	A	NP	Y	N		
Healam Bridge	SK5016	R	R	M	OMA	N	N	N	161	
Healam Bridge	SK5026	EM		M	OMA	N	N	N	173	

Site Name	SK number	Period	Type	Sex	Age	CO	DEH	Rickets	Stature	Notes
Healam Bridge	SK5301	EM		U	OMA	N	N	N		
Healam Bridge	SK5305	EM		U	A	NP	NP	N		
Healam Bridge	SK7275	R	R	?M	YMA	NP	N	N		
Healam Bridge	SK8126	R	R	F	OMA	Y	N	N		
Healam Bridge	SK8247	R	R	F	MA	N	Y	N		
Parlington Hollins	9	R	R	F	YMA	N	N	N	164	
Parlington Hollins	75	R	R	F	MA	Y	N	N	151	
Parlington Hollins	880	EM		?F	YMA	NP	Y	N	158.5	
Parlington Hollins	1008	EM		U	YMA	NP	N	N	154.5	
Parlington Hollins	2009	R	R	M	YMA	NP	Y	N	171	
Scorton	46	EM		U	A	NP	NP	N		
Scorton	74	EM		M	YMA	N	N	N	179.5	
Scorton	147	EM		F	YMA	NP	N	N	151.4	
Scorton	196	EM		U	A	NP	NP	NP		
Scorton	199	EM		U	A	NP	NP	NP		
Scorton	202	EM		U	A	NP	NP	NP		
Scorton	217	EM		U	YMA	NP	N	NP		
Scorton	223	EM		U	A	N	NP	NP		
Scorton	224A	EM		U	A	NP	N	NP		
Scorton	229	EM		U	A	N	NP	NP		
Scorton	230	EM		F	YMA	N	N	N		
Scorton	237	EM		U	A	NP	NP	NP		
Scorton	242	EM		U	YA	NP	N	NP		
Scorton	243	EM		?F	YMA	N	N	N	175	
Scorton	246	EM		U	YA	NP	N	NP		
Scorton	257	EM		M	YMA	N	Y	N	174.5	
Scorton	261	EM		F	YA	N	N	N	169	
Scorton	266	EM		U	YMA	NP	N	N		
Scorton	269ii	EM		U	A	NP	NP	NP		
Scorton	276	EM		?F	YMA	N	Y	N	160	
Scorton	288	EM		?M	A	NP	NP	N		
Scorton	294	EM		F	YMA	N	Y	N		

Site Name	SK number	Period	Type	Sex	Age	CO	DEH	Rickets	Stature	Notes
Scorton	300	EM		U	A	NP	NP	NP		
Scorton	301	EM		U	A	NP	NP	NP		
Scorton	308	EM		U	OMA	NP	Y	NP		
Scorton	318	EM		U	A	NP	NP	NP		
Scorton	326	EM		U	A	NP	NP	NP		
Scorton	351	EM		U	A	NP	NP	NP		
Scorton	362	EM		M	YMA	N	N	N	183	
Scorton	366	EM		U	YMA	NP	N	NP		
Scorton	370	EM		U	A	NP	NP	NP		
Scorton	400	EM		U	YA	NP	N	N		
Scorton	405	EM		?F	A	N	NP	N		
Scorton	502	R	R	U	YA	NP	Y	N		
Scorton	505	R	R	?M	YMA	NP	NP	N	167	
Scorton	508	EM		?M	YA	NP	Y	NP		
Scorton	511	R	R	?M	YMA	NP	Y	N	175	
Scorton	514	R	R	?M	YA	N	N	N	175	
Scorton	523	R	R	M	YMA	N	N	N	172.5	
Scorton	526	EM		U	A	NP	NP	NP		
Scorton	529	R	R	U	YMA	NP	N	NP		
Scorton	535	R	R	?M	YMA	N	Y	N	172	
Scorton	538	EM		U	YA	NP	N	N		
Scorton	541	R	R	U	YMA	NP	Y	N		
Scorton	549	EM		U	A	NP	NP	N		
Scorton	556	R	R	?M	YMA	NP	Y	N		
Scorton	559	EM		U	YMA	NP	N	NP		
Scorton	562	EM		?F	YMA	NP	N	N		
Scorton	565	R	R	F	YA	N	N	N	158	
Scorton	568	EM		?F	YA	NP	N	NP		
Scorton	577	EM		U	YA	NP	N	NP		
Scorton	582	EM		?F	YA	NP	NP	N		
Scorton	594	R	R	M	YMA	NP	N	N	173	
Scorton	600	R	R	M	YMA	NP	N	N	175	

Site Name	SK number	Period	Type	Sex	Age	CO	DEH	Rickets	Stature	Notes
Scorton	602	EM		U	A	NP	NP	N		
Scorton	616	EM		U	YMA	NP	N	N		
Scorton	W4338	EM		M	YMA	NP	N	N	174	
Wattle Syke	SK1	R	R	F	YMA	NP	N	N	160.4	
Wattle Syke	SK2	R	R	F	MA	N	N	N	159.6	
Wattle Syke	SK3	R	R	F	MA	NP	Y	N	154.2	
Wattle Syke	SK4	R	R	M	YMA	N	N	N	163.6	
Wattle Syke	SK5	R	R	?F	MA	N	N	N		
Wattle Syke	SK6	R	R	?M	MA	NP	NP	N		
Wattle Syke	SK7	R	R	F	MA	N	N	N	157.7	
Wattle Syke	SK23	R	R	F	OMA	NP	NP	N	157.4	
Wattle Syke	SK29	R	R	M	MA	N	N	N	166.5	
Wattle Syke	SK30	R	R	?M	YMA	N	N	N	166.2	
Wattle Syke	SK34	R	R	F	MA	Y	Y	N	154.3	
Wattle Syke	SK39	R	R	?F	YA	NP	NP	N	155.9	
Wattle Syke	SK44	EM		M	MA	Y	N	N		
Bamburgh	5	EM		U	A	NP	N	N		
Bamburgh	6	EM		M	YA	NP	N	N	173	
Bamburgh	9	EM		F	YMA	N	Y	N		
Bamburgh	19	EM		F	MA	N	N	N	169	
Bamburgh	29	EM		?F	YMA	N	N	N	162	
Bamburgh	37	EM		F	A	N	Y	N	159	
Bamburgh	57	EM		M	MA	N	N	N	166	
Bamburgh	70	EM		F	YA	N	N	N		
Bamburgh	73	EM		F	YA	N	N	N	165	
Bamburgh	76	EM		M	MA	N	N	N	166	
Bamburgh	79	EM		M	MA	N	N	N	172	
Bamburgh	95	EM		F	MA	N	N	N		
Bamburgh	98	EM		F	MA	N	N	N		
Bamburgh	107	EM		?F	YA	N	N	N	164	
Bamburgh	125	EM		U	YA	NP	N	NP		
Bamburgh	128	EM		M	A	NP	NP	N		

Site Name	SK number	Period	Type	Sex	Age	CO	DEH	Rickets	Stature	Notes
Bamburgh	129	EM		M	MA	N	N	N		
Bamburgh	130	EM		M	MA	NP	N	N		
Bamburgh	131	EM		F	YMA	N	Y	N	166	
Bamburgh	131	EM		M	YA	NP	NP	N	159	
Bamburgh	134	EM		M	YA	N	N	N	169	
Bamburgh	135	EM		F	MA	NP	N	N		
Bamburgh	147	EM		?M	YMA	NP	N	N	162	
Bamburgh	150	EM		F	MA	N	Y	N	156	
Bamburgh	156	EM		M	OMA	NP	NP	N	179	
Bamburgh	164	EM		M	MA	N	Y	N		
Bamburgh	167	EM		M	MA	N	N	N	172	
Bamburgh	170	EM		F	YA	NP	Y	N	177	
Bamburgh	176	EM		M	MA	N	N	N	178	
Bamburgh	185	EM		F	YMA	N	N	N		
Bamburgh	209	EM		M	MA	NP	N	N	175	
Bamburgh	234	EM		F	MA	N	Y	N	158	
Bamburgh	235	EM		M	YA	N	Y	N	178	
Bamburgh	238	EM		F	MA	N	Y	N	158	
Bamburgh	245	EM		M	YA	N	N	N	177	
Bamburgh	250	EM		F	MA	NP	Y	N	169	
Bamburgh	260	EM		M	MA	N	N	N	184	
Bamburgh	268	EM		U	MA	N	Y	N		
Bamburgh	276	EM		M	YMA	N	N	N	166	
Bamburgh	282	EM		M	MA	N	N	N	174	
Bamburgh	288	EM		F	MA	N	N	N	163	
Bamburgh	289	EM		F	MA	N	Y	N	166	
Bamburgh	292	EM		M	MA	N	Y	N	179	
Bamburgh	293	EM		M	MA	N	NP	N	174	
Bamburgh	297	EM		F	MA	NP	Y	N		
Bamburgh	316	EM		M	MA	N	N	N	187	
Bamburgh	321	EM		M	MA	N	Y	N	172	
Bamburgh	335	EM		M	MA	N	N	N	179	

Site Name	SK number	Period	Type	Sex	Age	CO	DEH	Rickets	Stature	Notes
Bamburgh	349	EM		?F	YA	N	Y	N	168	
Bamburgh	357	EM		M	MA	N	N	N	173	
Bamburgh	358	EM		?M	YMA	N	Y	N	179	
Bamburgh	360	EM		?F	YMA	N	N	N	156	
Bamburgh	382	EM		F	OMA	NP	N	N		
Bamburgh	386	EM		F	YMA	N	Y	N	163	
Bamburgh	387	EM		M	YMA	NP	Y	N	163	
Bamburgh	390	EM		F	YMA	N	Y	N	167	
Bamburgh	395	EM		F	OMA	N	Y	N	168	
Bamburgh	408	EM		?F	MA	N	Y	N	162	
Bamburgh	413	EM		M	OMA	N	N	N	159	
Bamburgh	416	EM		M	MA	N	N	N	177	
Bamburgh	438	EM		F	YA	Y	N	N	154	New bone formation on face so potentially scurvy not CO
Bamburgh	440	EM		M	YA	N	Y	N	178	
Melton	5316	EM		?F	OMA	NP	Y	N		
Melton	5319	EM		M	YMA	Y	Y	N	177.2	
Melton	5400	EM		?M	YMA	N	N	N	183.8	
Melton	4506	EM		F	YA	N	Y	N	158.1	
Bishopsmill School	3	EM		?M	MA	N	N	N		
Bishopsmill School	39	EM		U	A	NP	NP	NP		
Bishopsmill School	43	EM		M	YMA	N	N	N		
Bishopsmill School	57	EM		F	YMA	NP	Y	N		
Bishopsmill School	72	EM		U	OMA	NP	NP	NP		
Bishopsmill School	73	EM		U	A	NP	NP	NP		
Bishopsmill School	187	EM		U	A	NP	NP	NP		
Bishopsmill School	190	EM		?M	MA	N	Y	N	172.3	
Bishopsmill School	196	EM		U	A	NP	NP	NP		
Bishopsmill School	200	EM		U	YA	NP	N	NP		
Bishopsmill School	240	EM		F	YMA	N	N	NP		
Bishopsmill School	246	EM		U	A	NP	NP	NP		
Bishopsmill School	268	EM		?M	YMA	Y	Y	N		
Bishopsmill School	289	EM		U	YA	NP	N	N		

Site Name	SK number	Period	Type	Sex	Age	CO	DEH	Rickets	Stature	Notes
Bishopsmill School	294	EM		U	A	NP	NP	N		Skull originally labelled 476 but probably same individual
Bishopsmill School	303	EM		U	YMA	NP	Y	NP		
Bishopsmill School	306	EM		U	A	NP	NP	N		
Bishopsmill School	309	EM		?M	YMA	N	N	N	168.9	
Bishopsmill School	313	EM		U	OMA	NP	N	NP		
Bishopsmill School	317	EM		U	A	NP	NP	NP		
Bishopsmill School	320	EM		M	YMA	NP	NP	N	182.9	
Bishopsmill School	336	EM		?F	OMA	N	N	N	164.8	
Bishopsmill School	339	EM		?M	A	NP	NP	N		
Bishopsmill School	344	EM		U	A	NP	NP	N		
Bishopsmill School	462	EM		U	A	NP	N	N		Skull originally labelled 322 but probably same individual
Bishopsmill School	482	EM		U	A	NP	NP	N		
Bishopsmill School	494	EM		U	OMA	N	N	N		
Bishopsmill School	498	EM		U	A	NP	NP	NP		
East Mills	1	EM		F	YMA	N	Y	N	159	
East Mills	2	EM		F	A	N	N	N		
East Mills	4	EM		?M	YA	N	Y	N		
East Mills	7	EM		M	MA	N	NP	N	167	
East Mills	8	EM		F	MA	NP	NP	N		
East Mills	9	EM		F	YMA	N	N	N	162	
East Mills	12	EM		M	YA	NP	N	N	173	
East Mills	13	EM		M	OMA	N	N	N		
East Mills	17	EM		M	YMA	NP	NP	N		
East Mills	18	EM		M	YMA	N	N	N	179	
East Mills	20	EM		?M	YMA	NP	NP	NP		
East Mills	21	EM		U	YMA	NP	N	N		
East Mills	22	EM		F	YMA	N	N	N		
East Mills	23	EM		?F	YMA	N	N	N		
East Mills	25	EM		M	YA	N	N	N		
East Mills	29	EM		F	YMA	N	N	N		
East Mills	30	EM		?F	YMA	NP	N	N		
East Mills	31	EM		M	YA	NP	Y	N		

Site Name	SK number	Period	Type	Sex	Age	CO	DEH	Rickets	Stature	Notes
East Mills	32	EM		M	A	NP	NP	N		
East Mills	34	EM		M	YMA	NP	N	N		
East Mills	35	EM		F	YMA	N	Y	N	147	
East Mills	37	EM		F	MA	N	N	N		
East Mills	38	EM		F	YA	N	N	N	161	
East Mills	40	EM		F	YA	N	N	N	170	
East Mills	41	EM		F	YA	N	Y	N		
East Mills	42	EM		M	YA	N	Y	N		
East Mills	47	EM		?F	YMA	NP	NP	N		
East Mills	48	EM		?F	YA	NP	NP	N		
East Mills	49	EM		F	YA	N	Y	N	177	
East Mills	51	EM		U	A	NP	NP	N		
East Mills	52	EM		F	YMA	N	N	N	167	
East Mills	55	EM		M	YMA	N	Y	N		
East Mills	56	EM		M	OMA	N	N	N		
East Mills	57	EM		M	YA	N	N	N	174	
East Mills	59	EM		M	OMA	N	N	N		
East Mills	61	EM		?F	YMA	NP	N	N		
East Mills	63	EM		M	YMA	N	N	N		
East Mills	64	EM		M	OMA	NP	N	N		
East Mills	65	EM		F	OMA	N	N	N		
East Mills	67	EM		M	YA	NP	N	N		
East Mills	68	EM		F	OMA	N	N	N		
East Mills	69	EM		M	YA	N	N	N	167	
East Mills	70	EM		?M	OMA	N	Y	N	170	
East Mills	73	EM		F	YA	NP	N	N		
East Mills	74	EM		U	A	NP	NP	N		
East Mills	76	EM		M	YMA	NP	NP	N		
East Mills	78	EM		M	MA	N	N	N		
East Mills	79	EM		M	YMA	NP	N	N		
East Mills	82	EM		U	A	NP	NP	N		
East Mills	83	EM		U	A	NP	NP	NP		

Site Name	SK number	Period	Type	Sex	Age	CO	DEH	Rickets	Stature	Notes
East Mills	84	EM		F	OMA	N	N	N		
East Mills	86	EM		M	YMA	N	N	N		
East Mills	87	EM		F	YA	NP	N	N		
East Mills	90	EM		M	YMA	N	Y	N		
East Mills	91	EM		M	YA	N	N	N	171	
East Mills	93	EM		M	YMA	N	Y	N		
East Mills	94	EM		F	YMA	N	N	N	162	
East Mills	96	EM		F	MA	N	N	N		
East Mills	97	EM		U	A	NP	N	NP		
East Mills	98	EM		M	YA	N	N	N	173	
East Mills	99	EM		F	YA	N	Y	N	168	
East Mills	100	EM		U	OMA	NP	N	N		
East Mills	105	EM		F	MA	NP	N	N	167	
East Mills	106	EM		F	OMA	N	N	N	163	
East Mills	111	EM		U	A	N	N	N		
East Mills	112	EM		?F	YA	N	N	N		
East Mills	113	EM		?M	YMA	N	N	N		
East Mills	120	EM		M	YMA	N	N	N	168	
Burnby Lane	15	EM		F	YMA	Y	N	N		
Burnby Lane	22	EM		F	OMA	Y	N	N	163	
Burnby Lane	31	EM		U	A	NP	NP	N		
Burnby Lane	37	EM		M	OMA	Y	N	N		
Burnby Lane	46	EM		U	A	NP	NP	N		
Burnby Lane	49	EM		F	MA	N	N	N		
Burnby Lane	91	EM		M	YMA	N	N	Y		
Burnby Lane	103	EM		?M	OMA	Y	N	N		
Burnby Lane	104	EM		M	YMA	NP	NP	N		
Burnby Lane	108	EM		F	MA	Y	N	Y		
Burnby Lane	110	EM		U	A	N	N	N		
Burnby Lane	111	EM		?F	OMA	Y	N	N		
Burnby Lane	112	EM		M	OMA	N	N	N		
Burnby Lane	114	EM		U	A	NP	NP	N		

Site Name	SK number	Period	Type	Sex	Age	CO	DEH	Rickets	Stature	Notes
Burnby Lane	128	EM		M	YA	Y	N	N	174.9	
Burnby Lane	131	EM		F	MA	N	NP	N	171.3	
Burnby Lane	132	EM		F	YMA	Y	N	N	160.5	
Burnby Lane	134	EM		M	MA	N	Y	Y		
Burnby Lane	135	EM		M	MA	N	N	N		
Burnby Lane	137	EM		M	MA	Y	Y	Y		
Burnby Lane	138	EM		U	A	N	NP	NP		
Burnby Lane	140	EM		U	OMA	NP	NP	NP		
Burnby Lane	141	EM		I	MA	Y	N	N		
Burnby Lane	144	EM		F	OMA	NP	NP	N		
Burnby Lane	145	EM		F	MA	N	N	N		
Burnby Lane	147	EM		?M	YMA	N	Y	Y	177.7	
Burnby Lane	152	EM		M	MA	Y	N	Y		
Burnby Lane	154	EM		F	MA	N	Y	N		
Burnby Lane	162	EM		?F	YMA	Y	Y	N		
Burnby Lane	164	EM		?M	YMA	NP	NP	N		
Sewerby	1	EM		M	YMA	N	N	NP		
Sewerby	8	EM		F	YMA	N	N	NP	170	
Sewerby	9	EM		M	OMA	N	N	N		
Sewerby	10	EM		?M	A	N	N	N		
Sewerby	11	EM		M	YMA	N	N	N		
Sewerby	12	EM		F	YMA	N	N	N	163	
Sewerby	13	EM		F	YMA	N	N	N		
Sewerby	15	EM		U	MA	N	N	N		
Sewerby	16A	EM		U	A	NP	NP	N		
Sewerby	16B	EM		U	A	NP	NP	N		
Sewerby	19	EM		?M	OMA	N	N	N		
Sewerby	23	EM		?F	YMA	N	N	N		
Sewerby	24	EM		?F	A	N	N	N		
Sewerby	25	EM		F	A	N	N	N	162	
Sewerby	26	EM		F	YMA	Y	Y	N	157	
Sewerby	27	EM		M	OMA	N	N	N		

Site Name	SK number	Period	Type	Sex	Age	CO	DEH	Rickets	Stature	Notes
Sewerby	29	EM		U	A	NP	N	NP		
Sewerby	31	EM		?M	A	N	N	N		
Sewerby	33	EM		M	A	N	N	N		
Sewerby	34	EM		?F	MA	Y	N	N		
Sewerby	35	EM		F	YMA	N	N	N	156	
Sewerby	37	EM		M	YMA	N	N	N		
Sewerby	38	EM		?M	YA	NP	N	NP		
Sewerby	40	EM		U	A	NP	NP	N		
Sewerby	41	EM		?F	OMA	N	Y	N	167	
Sewerby	44	EM		M	OMA	N	N	N		
Sewerby	45	EM		?M	MA	N	N	N		
Sewerby	46	EM		U	A	N	NP	NP		
Sewerby	47	EM		U	YA	NP	N	NP		
Sewerby	48	EM		M	YMA	N	N	N	171	
Sewerby	49	EM		?F	YA	N	N	N		
Sewerby	50	EM		U	YMA	N	N	N		
Sewerby	50A	EM		?M	YMA	N	N	N		
Sewerby	53	EM		U	YA	N	N	N		
Sewerby	57	EM		U	YMA	NP	N	NP		
West Heslerton	G6	EM		M	YMA	NP	N	N		
West Heslerton	G7	EM		U	YA	NP	N	NP		
West Heslerton	G12	EM		U	A	NP	N	NP		
West Heslerton	G13	EM		U	A	NP	N	NP		
West Heslerton	G14	EM		U	YMA	N	N	NP		
West Heslerton	G16	EM		M	YMA	NP	NP	N		
West Heslerton	G17	EM		U	A	NP	NP	N		
West Heslerton	G19	EM		U	A	NP	N	NP		
West Heslerton	G20	EM		U	YA	NP	N	NP		
West Heslerton	G21	EM		U	YA	NP	N	N		
West Heslerton	G22	EM		F	YMA	NP	N	N		
West Heslerton	G23	EM		F	MA	N	N	N		
West Heslerton	G25	EM		U	A	NP	N	NP		

Site Name	SK number	Period	Type	Sex	Age	CO	DEH	Rickets	Stature	Notes
West Heslerton	G27	EM		U	A	NP	NP	N		
West Heslerton	G28	EM		U	A	NP	N	NP		
West Heslerton	G31	EM		M	YMA	N	N	N		
West Heslerton	G34	EM		F	YMA	N	N	N		
West Heslerton	G35	EM		U	A	NP	NP	N		
West Heslerton	G36	EM		?F	A	NP	N	NP		
West Heslerton	G37	EM		F	OMA	N	N	N	171	
West Heslerton	G38	EM		M	YMA	NP	N	N		
West Heslerton	G62	EM		U	A	N	N	N		
West Heslerton	G67	EM		U	A	NP	NP	N		
West Heslerton	G68	EM		U	A	NP	N	NP		
West Heslerton	G70	EM		?M	A	N	N	N		
West Heslerton	G72	EM		M	YMA	N	N	N		
West Heslerton	G73	EM		U	MA	NP	N	NP		
West Heslerton	G74	EM		U	YMA	N	N	N		
West Heslerton	G75	EM		U	A	NP	N	N		
West Heslerton	G76	EM		?F	A	NP	N	N		
West Heslerton	G77	EM		U	A	NP	Y	N		
West Heslerton	G78	EM		F	YMA	N	N	N		
West Heslerton	G79	EM		U	A	NP	N	NP		
West Heslerton	G81	EM		?F	OMA	N	N	N		
West Heslerton	G82	EM		F	MA	N	N	N		
West Heslerton	G83	EM		U	A	NP	NP	N		
West Heslerton	G84	EM		F	YA	N	N	NP		
West Heslerton	G85	EM		U	YA	NP	N	NP		
West Heslerton	G86	EM		U	MA	N	N	NP		
West Heslerton	G87	EM		M	A	N	NP	N		
West Heslerton	G88	EM		F	YMA	N	N	N		
West Heslerton	G89	EM		F	YMA	N	N	N		
West Heslerton	G92	EM		F	A	NP	NP	N	168	
West Heslerton	G94	EM		?F	YMA	N	N	N		
West Heslerton	G95	EM		U	A	NP	Y	NP		

Site Name	SK number	Period	Type	Sex	Age	CO	DEH	Rickets	Stature	Notes
West Heslerton	G96	EM		F	YMA	N	N	N		
West Heslerton	G102	EM		F	YA	N	Y	N		
West Heslerton	G103	EM		M	OMA	NP	N	N		
West Heslerton	G105	EM		?F	YMA	N	N	N		
West Heslerton	G107	EM		F	YMA	N	N	N		
West Heslerton	G109	EM		M	YA	N	N	N		
West Heslerton	G110	EM		F	YMA	NP	N	N		
West Heslerton	G111	EM		?M	YMA	NP	Y	N		
West Heslerton	G113	EM		F	YA	N	N	N		
West Heslerton	G114	EM		F	YA	Y	N	N		
West Heslerton	G115	EM		?M	YA	NP	N	NP		
West Heslerton	G119	EM		U	A	NP	N	NP		
West Heslerton	G120	EM		?F	YMA	N	N	NP		
West Heslerton	G123	EM		F	MA	N	N	N		
West Heslerton	G124	EM		F	MA	N	N	N		
West Heslerton	G125	EM		?M	A	N	N	N		
West Heslerton	G126	EM		M	YMA	NP	N	N		
West Heslerton	G127	EM		U	YMA	NP	N	NP		
West Heslerton	G130	EM		?M	A	NP	N	N		
West Heslerton	G133	EM		F	OMA	NP	NP	N		
West Heslerton	G134	EM		M	MA	N	N	N		
West Heslerton	G136	EM		U	YA	NP	Y	N		
West Heslerton	G139	EM		F	YMA	NP	N	N		
West Heslerton	G140	EM		U	A	NP	NP	N		
West Heslerton	G141	EM		U	A	N	N	N		
West Heslerton	G143	EM		U	A	NP	N	N		
West Heslerton	G144	EM		?F	OMA	N	N	N		
West Heslerton	G145	EM		M	A	N	N	N		
West Heslerton	G148	EM		M	YMA	NP	N	N		
West Heslerton	G149	EM		?M	OMA	NP	N	N		
West Heslerton	G150	EM		U	OMA	NP	N	N		
West Heslerton	G135	EM		U	A	NP	NP	NP		Excavated as separate grave but thought to have moved from

Site Name	SK number	Period	Type	Sex	Age	CO	DEH	Rickets	Stature	Notes
										G150
West Heslerton	G151	EM		U	YMA	NP	N	N		
West Heslerton	G155	EM		M	YMA	NP	N	N		
West Heslerton	G156	EM		U	YMA	NP	N	NP		
West Heslerton	G158	EM		M	OMA	N	N	N		
West Heslerton	G159	EM		F	YA	NP	N	N		
West Heslerton	G163	EM		?F	YMA	NP	N	NP		
West Heslerton	G164	EM		F	A	N	Y	N		
West Heslerton	G165	EM		U	A	N	NP	N		
West Heslerton	G166	EM		F	YMA	N	N	N		
West Heslerton	G167	EM		U	A	NP	N	N		
West Heslerton	G170	EM		?M	YMA	NP	Y	N		
West Heslerton	G171	EM		?M	YMA	NP	Y	N		
West Heslerton	G173	EM		U	A	NP	N	N		
West Heslerton	G174	EM		U	YA	NP	N	N		
West Heslerton	G175	EM		U	YMA	NP	N	NP		
West Heslerton	G176	EM		M	OMA	NP	NP	N		
West Heslerton	G177	EM		F	YMA	N	N	NP		
West Heslerton	G179	EM		?M	OMA	NP	N	N		
West Heslerton	G180	EM		U	A	NP	N	NP		
West Heslerton	G182	EM		?M	YMA	NP	N	N		
West Heslerton	G183	EM		U	YMA	NP	N	NP		
West Heslerton	G184	EM		?F	A	NP	NP	N		
Queen's Hotel	6064	EM		M	OMA	N	Y	N	168.5	
Queen's Hotel	7118	EM		F	MA	N	Y	N		
Queen's Hotel	7137	EM		M	MA	N	Y	N	179.9	
Queen's Hotel	7147	EM		F	YA	N	N	N	166.6	

Appendix 2: Vertebral neural canal data

Key

Measurement type

TR = Transverse diameter

AP = Anterior-posterior diameter

B = Vertebral body height

All measurements in mm

Vertebra type

C = Cervical

T = Thoracic

L = Lumbar

Cervical vertebrae

Site	SK no.	C1TR	C1AP	C2TR	C2AP	C3B	C3TR	C3AP	C4B	C4TR	C4AP	C5B	C5TR	C5AP	C6B	C6TR	C6AP	C7B	C7TR	C7AP
Cataractonium	SK20116																			
Cataractonium	SK20416	28.1	31.1	24.2	18.7	12.6	22.8	15.1	12.0				26.2					14.0	24.3	
Cataractonium	SK20585	26.9	29.8	22.0	16.2	11.9	21.1	14.7			14.7									
Cataractonium	SK20813	30.9	29.5																	
Cataractonium	SK20957			22.3	15.7	13.9	22.3	14.2		24.4	13.9	13.2	23.3	13.8		23.9	13.4		22.6	
Cataractonium	SK7182																			
Bainesse	G123	29.0		24.8	18.7	11.8			11.9										25.1	14.2
Bainesse	G13420	27.8	31.2	23.8																
Bainesse	G140			24.6	15.6	13.5	24.9	14.2	13.6	25.5	13.9	13.0	26.6	14.5		25.9				
Bainesse	G144	29.8	34.6	25.4	17.5															
Bainesse	G15	28.0	30.9	24.5	17.1	13.5	23.1	15.6		24.3	14.4	12.1	25.6	13.8	12.6	26.4	13.4			
Bainesse	G158			25.4	17.4	10.7	23.7	17.2	11.1	25.1	17.5	26.2								
Bainesse	G16	28.5	31.1																	
Bainesse	G17	25.3	29.4	23.7	16.1															
Bainesse	G173	28.5	30.6	23.9	17.0	14.2	23.7	13.7	13.8	24.8	15.0	12.7	26.2	16.2	13.4	26.1	16.7		24.2	17.0
Bainesse	G18	27.7	32.1	24.6	18.2															
Bainesse	G197A	27.7	28.7	24.5	17.1	15.3	24.9		14.5	25.6		13.5	24.9			24.0			22.5	14.7

Site	SK no.	C1TR	C1AP	C2TR	C2AP	C3B	C3TR	C3AP	C4B	C4TR	C4AP	C5B	C5TR	C5AP	C6B	C6TR	C6AP	C7B	C7TR	C7AP
Bainesse	G198			23.1	18.2	12.8		16.1	13.0			13.0	25.4	15.9	15.4	23.4	15.8			
Bainesse	G208	26.5	30.2	22.8	14.9		23.0	14.8		24.4	14.1		24.9	13.3		24.5	13.3	13.4	23.9	14.5
Bainesse	G209	28.2	27.2	23.3	15.0	11.5	22.4	14.2	10.9	23.2	13.6	10.8	23.6	12.6	10.5	24.5	12.7	11.9	24.0	13.1
Bainesse	G213	28.4	30.8	24.0	17.9	12.3	22.9	15.3	12.1	23.9	14.8	12.1	25.2	14.3	12.1	25.6	13.9	14.0	25.6	13.3
Bainesse	G22	32.6		23.6	17.1	14.0	22.5	15.4	13.4	22.7	14.6	13.1	23.3	14.4	12.6	23.4	14.1	13.2	23.1	14.2
Bainesse	G237					11.4	22.7		11.7	24.5	14.4	12.1	25.3		12.4			12.9	24.2	
Bainesse	G239			22.5	18.2	13.6	21.9	16.1	12.9	23.3	15.5	13.3	24.5	14.7		23.8	13.9			
Bainesse	G57	31.4	33.6	26.4	19.2	12.3														
Bainesse	G7			26.6	17.1															
Bainesse	G86	29.2		23.0	19.7					22.6	15.4		23.2	14.8	12.6	23.8	15.2			
Bainesse	G87	27.8	32.4																	
Dalton Parlours	1			22.3	15.9		21.2	14.9	12.7	23.2	14.8	12.0	23.0	13.5	11.6	23.0	13.3	13.2	22.8	12.7
Dalton Parlours	4	29.4		23.9	15.1					23.4	14.1		23.9							
Dalton Parlours	10	27.1	32.9	24.5	15.5	14.7	24.5	13.9	14.6	26.8	14.1		26.9	14.3	14.1	26.7	16.0	15.9	26.9	16.4
Healam Bridge	SK5016			26.6	20.4	13.3	25.1	19.1	13.5	26.0	18.2	13.6	27.2	17.7				15.1		
Healam Bridge	SK5026			27.9	20.1	12.3	28.5	17.5	13.3			14.8								
Healam Bridge	SK8126																			
Healam Bridge	SK8247			24.3	17.6	11.6			11.9			11.9			12.1			13.0		
Wattle Syke	SK1	30.7																		
Wattle Syke	SK2	29.2	31.4	24.5		12.3	23.1	14.7		23.9	13.0	12.2	24.7	13.2	12.9	24.0	13.1	14.0	22.6	13.8
Wattle Syke	SK3	30.5	29.7	23.7			24.3	13.8					25.8			24.8			21.2	14.0
Wattle Syke	SK4	22.9	29.9	22.9	15.5															
Wattle Syke	SK5															23.9	12.5			
Wattle Syke	SK7																			
Wattle Syke	SK29			24.8	16.7		22.7	16.0		25.3	16.5	13.5	25.4	16.7		26.2	16.7		25.1	17.1
Wattle Syke	SK30	31.1	30.4																	
Wattle Syke	SK39																			

Site	SK no.	C1TR	C1AP	C2TR	C2AP	C3B	C3TR	C3AP	C4B	C4TR	C4AP	C5B	C5TR	C5AP	C6B	C6TR	C6AP	C7B	C7TR	C7AP
Wattle Syke	SK44			26.2												24.2	15.7		23.0	16.6
Burnby Lane	15			25.3																
Burnby Lane	22	30.0		24.6	15.6		22.7	13.1	11.2	24.3	12.5								23.3	
Burnby Lane	49	27.8	30.0	26.8	16.3	12.5	25.4		12.8										26.5	
Burnby Lane	103	29.1	31.9	25.1	15.7														24.9	14.2
Burnby Lane	104																			
Burnby Lane	108	29.1	30.4	23.7	18.5		24.0	17.4		24.9	17.4		25.4	17.4		25.5			21.7	16.0
Burnby Lane	111	27.6	30.4	23.2																
Burnby Lane	128	30.0	29.8	23.8	16.5		23.2	14.8		24.2	14.1		24.8	14.6		25.4	13.8		24.4	14.2
Burnby Lane	131																	15.1		
Burnby Lane	132	24.8	28.4	22.2	14.7	12.0	21.4	13.6	11.2	21.9	13.9	10.9	22.2	15.1	11.4	22.7	14.4	11.5	23.4	14.4
Burnby Lane	145	28.1	29.0			13.3	23.0			24.0	12.4		25.6	12.0	13.1	25.8	11.4	14.9	25.6	12.8
Burnby Lane	147		35.9	25.2	20.9					24.6										
Burnby Lane	152	28.4	30.3	23.5	17.6															
Sewerby	8	28.1	34.4	23.6	18.9		21.3			22.9	16.3		24.5	15.3		24.4	14.6		22.6	14.1
Sewerby	9				17.3															
Sewerby	10			22.3											13.9	23.9	13.8	14.0	24.0	13.9
Sewerby	11	28.5	30.9																	
Sewerby	25			25.5	15.4		24.9			25.1										
Sewerby	26																			
Sewerby	34														14.5	26.1	14.5		25.7	16.7
Sewerby	35																			
Sewerby	37			25.7	19.9		24.4	18.5		24.6		13.5	26.8	16.8		25.9				
Sewerby	41																			
Sewerby	45																			
Sewerby	48			23.7	17.1		23.2	15.2		21.4			23.7	15.9		23.7	14.5	15.8	23.4	14.4
West Heslerton	G70						23.6	14.9												

Site	SK no.	C1TR	C1AP	C2TR	C2AP	C3B	C3TR	C3AP	C4B	C4TR	C4AP	C5B	C5TR	C5AP	C6B	C6TR	C6AP	C7B	C7TR	C7AP
West Heslerton	G76					12.7	23	15.5	12.4	24.9	15.9	12.9	25.4	15.9	13.1	25.1	15.7	13.9	24.0	15.1
West Heslerton	G78												26.2			25.3		11.7	26.2	14.1
West Heslerton	G89					13.8	23.1	14.8	13	24.4	15.5	12.6	25	15.4	13.1	25	13.9		24.6	14.2
West Heslerton	G102																			
West Heslerton	G103																			
West Heslerton	G109			23.4	15.5		22.6	13.8		24.7	13.4		25.7	13.1		25.6	13.2		24.8	14.1
West Heslerton	G111	30.6	30.1	23.2	14.9	14	24.5		14	26						26.6				
West Heslerton	G113					10.3	24.3	16.1	10	26	15.5	10.1	26.9	15.3	10.6	28.3	14.4	11.8	28.2	14.4
West Heslerton	G134	28.4	32	26.5																
West Heslerton	G145					12.4			12.4				25.6			25.8	14.4		24.7	14.3
West Heslerton	G158	29.5	32.2	25.5	17.6		25.1	14.8	15	26.7	15.4		27.5	16.3		27.6	15.1		25.5	16.0
West Heslerton	G164	27.9	27.9	23.3	16	12.5	21	15.5	12.6	22	14.4	13.3	21.9	12.6	13.6	22.6	14	14.3	22.4	13.4
West Heslerton	G166			23.6			22	14.9												
West Heslerton	G171			25	17.6	14.1	23.5	16.3				13.8	25	14.7	14.2	24.7	14.8	14.8	24.2	14.3
West Heslerton	G183																			

Thoracic vertebrae 1-6

Site	SK no.	T1B	T1TR	T1AP	T2B	T2TR	T2AP	T3B	T3TR	T3AP	T4B	T4TR	T4AP	T5B	T5TR	T5AP	T6B	T6TR	T6AP
Cataractonium	SK20116		16.2	15.5		16.3	15.4	18.7	17.5			16.3	16.5						
Cataractonium	SK20416					19.2			17.1	15.2		14.7			16.2	15.7		16.0	
Cataractonium	SK20585																		
Cataractonium	SK20813																		
Cataractonium	SK20957		19.1	14.3		16.6	15.1		15.3	13.9		15.2						15.1	
Cataractonium	SK7182																		
Bainesse	G123	16.0	20.7	14.6		18.1	14.0	15.7	16.8	14.1		15.3	13.3	18.2	14.9	13.5		15.1	14.1
Bainesse	G13420														15.2	16.6			
Bainesse	G140																		
Bainesse	G144	14.6	23.8	15.7	17.5	21.8	16.0	17.9	20.6	15.7		19.3			18.2	15.7			
Bainesse	G15																		
Bainesse	G158																		
Bainesse	G16										18.4				16.4	15.8		17.1	16.2
Bainesse	G17																		
Bainesse	G173																		
Bainesse	G18																		
Bainesse	G197A		18.7	13.9		16.6	15.0		16.0	15.0		15.2	15.2		14.4	15.3			
Bainesse	G198	18.3			18.5	18.2	15.4		17.2	15.5	17.6	16.5					21.2	16.4	
Bainesse	G208		20.5	15.1	14.9	17.0	15.3												
Bainesse	G209		21.4	13.4	14.8	18.7	14.0								15.8	14.9		15.5	14.8
Bainesse	G213	16.1	22.0	14.5	16.9	19.1	14.8												
Bainesse	G22		19.4	14.9	16.6	16.6	15.3	18.1	15.7	15.4									
Bainesse	G237	15.4	22.1																
Bainesse	G239		19.9	14.4		16.9	14.9	16.2	16.6	14.7	17.1	16.6	15.5	17.6			17.5		
Bainesse	G57																		
Bainesse	G7																		

Site	SK no.	T1B	T1TR	T1AP	T2B	T2TR	T2AP	T3B	T3TR	T3AP	T4B	T4TR	T4AP	T5B	T5TR	T5AP	T6B	T6TR	T6AP
Bainesse	G86																		
Bainesse	G87																		
Dalton Parlours	1	15.5	19.8	13.4		17.0	13.1		16.6	15.2	18.4	16.2	14.1	19.0	15.4	14.1		15.2	13.2
Dalton Parlours	4																		
Dalton Parlours	10	18.1	23.0	16.7	19.6	19.8	17.4	19.5			19.6	18.2	17.6	20.3	18.1	17.8			
Healam Bridge	SK5016	17.3	24.5	16.8		21.9	16.6		19.4	16.8									
Healam Bridge	SK5026	18.9	29.7	18.5	19.4	23.0	18.5	19.9	21.8	18.6	19.9	20.6	18.7	20.3	19.9	20.6	21.3	20.3	19.2
Healam Bridge	SK8126																		
Healam Bridge	SK8247																		
Wattle Syke	SK1																		
Wattle Syke	SK2	15.8	20.0	14.8															
Wattle Syke	SK3		18.1						16.6	16.1	18.3	16.0	14.7						
Wattle Syke	SK4																		
Wattle Syke	SK5		20.0			16.4	14.8												
Wattle Syke	SK7																		
Wattle Syke	SK29					19.8					19.2	17.3	14.7		15.8	15.3			
Wattle Syke	SK30																		
Wattle Syke	SK39																		
Wattle Syke	SK44		20.9	17.6		17.6	16.6		16.3	15.6									
Burnby Lane	15																		
Burnby Lane	22	15.1		14.3		15.9	14.9	16.1	15.1	14.8	16.8	14.3	14.9		14.3	156.0	17.6	13.4	15.4
Burnby Lane	49																		
Burnby Lane	103		22.0	15.8		18.1	16.4												
Burnby Lane	104																		
Burnby Lane	108		19.4			19.1													
Burnby Lane	111																		
Burnby Lane	128		20.5	12.8		17.4	15.2	18.9	16.6	14.5	18.4	16.0	14.7		15.0	14.6			

Site	**SK no.**	**T1B**	**T1TR**	**T1AP**	**T2B**	**T2TR**	**T2AP**	**T3B**	**T3TR**	**T3AP**	**T4B**	**T4TR**	**T4AP**	**T5B**	**T5TR**	**T5AP**	**T6B**	**T6TR**	**T6AP**
Burnby Lane	131	17.9			18.5			19.5											
Burnby Lane	132	14.0	19.9	14.7		16.5			15.4	14.8		14.5	15.4		14.3	15.5		14.0	15.0
Burnby Lane	145		21.4	13.9		18.4	13.4		18.0										
Burnby Lane	147																		
Burnby Lane	152																		
Sewerby	8	16.8	19.9	14		18.3	14.4		17.3	14.8	19.0	16.6	15.6		17.4	16.0		18.3	15.9
Sewerby	9																		
Sewerby	10	17.9	19.2	13.5	18.4	16.6	14.1												
Sewerby	11																		
Sewerby	25																		
Sewerby	26		19.5	13.3		16.6	13.6		15.2	14.2		14.4	13.4		14.9	13.5		14.7	13.8
Sewerby	34	17.4	22.0	14.8															
Sewerby	35																		
Sewerby	37																		
Sewerby	41																		
Sewerby	45																		
Sewerby	48	18.1	20.4	14.3		17.9	14.1		16.4	11.9		14.9	13.8		16.5	13.7		15.2	14.6
West Heslerton	G70																		
West Heslerton	G76	15.3	21.2																
West Heslerton	G78	16.7	21	15	18.6	18.1	14.5		17	15.3	19.7	15.6		19.6	15.4		19.2		
West Heslerton	G89	16.5	20.1	14.4		17.8	14.7	19.3	15.7	14.9	20	15.4	15	20.8	15.3	16		15.9	14.5
West Heslerton	G102								17.6			16.5			16.5	13.7		15.6	14.5
West Heslerton	G103																		
West Heslerton	G109		22.2	14.6											17.7			18.6	15.6
West Heslerton	G111		22.5	13.9		19.9	13.4		16.2	15.3		18.5	13.8		15.4			15.8	
West Heslerton	G113		20.6	16.2		20	16.4		18.1	16.7		17.7	16.8	16.6	17.8	16.9		17.8	16.6
West Heslerton	G134																		

Site	SK no.	T1B	T1TR	T1AP	T2B	T2TR	T2AP	T3B	T3TR	T3AP	T4B	T4TR	T4AP	T5B	T5TR	T5AP	T6B	T6TR	T6AP
West Heslerton	G145		22.6	15.8	17.4	20	15.9	17.6	18.6	15.6									
West Heslerton	G158		21.4	16.4	19.9	19.1	16.7												
West Heslerton	G164		20.2	14.1		17.7	14.1		17.4	15.1		16.6	14.1		16	14.9		15.7	14.2
West Heslerton	G166		23.4	15.2		20.2	14.9		17.7	14.6	16.9	17	15.2	17.2	17.1	15	18.1	16.7	14.6
West Heslerton	G171	17.8	22.4	14.6		19.8	14.3	19.9	18.5	14.6	20.5	16.8	15		17	15.4		17.1	16
West Heslerton	G183																		

Thoracic vertebrae 7-12

Site	SK no.	T7B	T7TR	T7AP	T8B	T8TR	T8AP	T9B	T9TR	T9AP	T10B	T10TR	T10AP	T11B	T11TR	T11AP	T12B	T12TR	T12AP
Cataractonium	SK20116																		
Cataractonium	SK20416		16.1		21.2	17.0	13.9	21.3	17.0	13.3	22.1	17.8		24.9	18.1	15.4	25.2	20.7	18.5
Cataractonium	SK20585																		
Cataractonium	SK20813																		
Cataractonium	SK20957		15.3			15.2													
Cataractonium	SK7182																		
Bainesse	G123		15.2	14.3		15.2	16.2		15.1	15.0		16.3	14.9	24.6	17.7	16.0	26.2	20.5	17.3
Bainesse	G13420																		
Bainesse	G140																		
Bainesse	G144																		
Bainesse	G15														18.7	14.6		20.7	14.7
Bainesse	G158																		
Bainesse	G16		17.3			17.6	16.5												
Bainesse	G17																		
Bainesse	G173																		
Bainesse	G18																		
Bainesse	G197A		13.5	15.4		13.9	15.3		14.8	15.7		15.5	13.1		17.5	13.2		20.6	15.0
Bainesse	G198	22.4	16.2	15.2	22.7				16.4										
Bainesse	G208																		
Bainesse	G209		15.0	15.9		15.6	15.7		16.3	15.7		17.2	15.8		18.7	16.2	23.0		
Bainesse	G213														17.4	16.1		20.2	16.3
Bainesse	G22	21.9	14.4	14.7	21.8	15.0	14.7		15.9	15.9		16.5	14.7		18.6	15.2		21.2	16.4
Bainesse	G237											17.8	15.6	23.4	19.1	15.2	24.5	22.2	17.2
Bainesse	G239	18.6			19.2	17.6	15.9	20.4	17.8	15.8	22.0			23.1	18.6	16.3		21.2	
Bainesse	G57																		
Bainesse	G7																		

Site	SK no.	T7B	T7TR	T7AP	T8B	T8TR	T8AP	T9B	T9TR	T9AP	T10B	T10TR	T10AP	T11B	T11TR	T11AP	T12B	T12TR	T12AP
Bainesse	G86														17.6	14.9		19.4	16.4
Bainesse	G87																		
Dalton Parlours	1	20.9	15.5	13.5		16.0	13.6	21.7	16.7	13.2	24.0	16.7	12.9	26.1	18.5	13.4	26.9	20.3	14.1
Dalton Parlours	4																		
Dalton Parlours	10	21.3						21.8	18.4	17.0	23.8	17.7	16.0	25.5	17.8	15.4	27.1	21.1	16.9
Healam Bridge	SK5016		17.1	16.2		18.0	15.3		18.8	14.4		19.0	15.5		20.0	16.9			
Healam Bridge	SK5026		19.9	18.7	23.1	20.7	18.3	23.8	20.3	18.3	25.8	20.3	19.3	26.6	20.6	20.5	27.8	22.8	20.4
Healam Bridge	SK8126													25.0	18.7	16.4			
Healam Bridge	SK8247																		
Wattle Syke	SK1																		
Wattle Syke	SK2																		
Wattle Syke	SK3																		
Wattle Syke	SK4																		
Wattle Syke	SK5																		
Wattle Syke	SK7																		
Wattle Syke	SK29										22.2	17.1	15.0	22.9	17.9	15.1		19.9	16.4
Wattle Syke	SK30																	22.8	
Wattle Syke	SK39																		
Wattle Syke	SK44																		
Burnby Lane	15																		
Burnby Lane	22		13.3	14.9		13.5	14.3	18.1	13.1	14.4	19.7	13.3	15.2	22.0	14.5	16.6		17.2	17.4
Burnby Lane	49																		
Burnby Lane	103																		
Burnby Lane	104										24.0	18.5		26.6			28.5	24.5	18.5
Burnby Lane	108																		
Burnby Lane	111																		
Burnby Lane	128	18.4	15.4	14.7		14.4	14.7		15.1	14.3	22.5	16.5	15.3		17.9	16.4	25.9	20.2	18.2

Site	SK no.	T7B	T7TR	T7AP	T8B	T8TR	T8AP	T9B	T9TR	T9AP	T10B	T10TR	T10AP	T11B	T11TR	T11AP	T12B	T12TR	T12AP
Burnby Lane	131																		
Burnby Lane	132	19.3	14.1	14.0		14.9					22.2	14.1	14.7		15.3	15.8		18.8	
Burnby Lane	145																		
Burnby Lane	147																		
Burnby Lane	152					15.1			15.9	12.8		16.5							
Sewerby	8		18.8			18.7	16.5		17.9	14.9		17.9	15.1		18.9	16.8		23.2	17.9
Sewerby	9																		
Sewerby	10																		
Sewerby	11																	19.3	16.8
Sewerby	25																		
Sewerby	26	19.9	15.0	14.5	21.0	15.0	14.6		15.0	14.2		15.3	15.0					17.4	16.8
Sewerby	34																		
Sewerby	35																	14.1	
Sewerby	37																		
Sewerby	41								19.0	17.2		18.4	17.4		19.7	16.5		23.2	
Sewerby	45																		
Sewerby	48	20.7	15.2	14.1		15.3		22.3	14.7	13.6		15.3	14.1		17.1	15.9		19.8	16.5
West Heslerton	G70																		
West Heslerton	G76																		
West Heslerton	G78	19.7			19.1	16.3	14.7					16.8	15.7	24.4	18.8	14.9	26.9	22.4	16.9
West Heslerton	G89	19.8	15.8	14	19.4	16.1	14.4	20.8	16.7	15.4	22	17.2	14.7		18.2	14.8		21.4	14.4
West Heslerton	G102		16	15.2		15.8	15.4		16.4	14.3		17.4	14.9		18	15.4	21.7	18.3	15.5
West Heslerton	G103																		
West Heslerton	G109		18.1			17.6			18						17.3	16.8			
West Heslerton	G111		15.7	15.3															
West Heslerton	G113		18.8	16.7		19.4	17.3	18.8	19.5	17.4					21.3	17.7		24.4	18.8
West Heslerton	G134																		

Site	SK no.	T7B	T7TR	T7AP	T8B	T8TR	T8AP	T9B	T9TR	T9AP	T10B	T10TR	T10AP	T11B	T11TR	T11AP	T12B	T12TR	T12AP
West Heslerton	G145																		
West Heslerton	G158											15.8			17.8	15.3	25.6	21.5	13.7
West Heslerton	G164		15.9	15.4		16	15.5		16.7	14.6		17	15.8		16.9	15.1		19	14.5
West Heslerton	G166	18.7	16.4	14.6															
West Heslerton	G171		16.2	15.6															
West Heslerton	G183														19.1			21	16.1

Lumbar vertebrae

Site	SK no.	L1B	L1TR	L1AP	L2B	L2TR	L2AP	L3B	L3TR	L3AP	L4B	L4TR	L4AP	L5B	L5TR	L5AP
Cataractonium	SK20116															
Cataractonium	SK20416	27.4	23.6	18.4	28.0			27.3			27.0	24.6		26.7	25.2	14.5
Cataractonium	SK20585															
Cataractonium	SK20813															
Cataractonium	SK20957															
Cataractonium	SK7182							24.9			24.5	23.6				
Bainesse	G123	27.0	20.3	15.8	25.4	21.2	13.8	26.3	19.8	12.6	25.5	18.2	12.9	23.9	21.9	13.5
Bainesse	G13420					25.0			25.5			25.4				
Bainesse	G140															
Bainesse	G144															
Bainesse	G15		23.1	15.8		22.5	15.9		23.1	14.1		24.1	26.6			
Bainesse	G158															
Bainesse	G16															
Bainesse	G17															
Bainesse	G173															
Bainesse	G18															
Bainesse	G197A		21.4	18.0		21.8	16.4	28.7	21.5	14.8		24.1	15.0		26.2	17.1
Bainesse	G198								22.3	13.9		22.4	16.1			
Bainesse	G208															
Bainesse	G209		22.0	17.0	25.1	22.9	17.8	27.1	23.3	17.8						
Bainesse	G213		21.7			22.5	16.3	27.9	22.5	14.0	26.1	22.8	15.8		24.2	17.5
Bainesse	G22	28.9	23.3	16.4	27.3	23.4	16.2	26.8	25.3	18.3	27.4	26.6	20.7	27.5	27.7	
Bainesse	G237	26.4									27.0					
Bainesse	G239		26.2	22.1	25.8	22.1	17.0	26.0	21.8	13.8	26.5	21.8	14.4	25.6	23.9	16.9
Bainesse	G57															
Bainesse	G7														23.6	

Site	SK no.	L1B	L1TR	L1AP	L2B	L2TR	L2AP	L3B	L3TR	L3AP	L4B	L4TR	L4AP	L5B	L5TR	L5AP
Bainesse	G86		23.3	16.7					23.0	16.0		23.9	18.0			
Bainesse	G87															
Dalton Parlours	1	27.3	21.3	14.8	26.3	20.8	13.0		20.9	11.7	25.5	21.0	12.1	26.1	24.8	11.5
Dalton Parlours	4															
Dalton Parlours	10	29.0	24.2	17.4	28.5	25.3	14.4	28.1	25.0	14.2		25.0	16.9	28.6	27.9	17.8
Healam Bridge	SK5016	25.7			26.3	27.8	17.4	26.9	26.1	16.7	26.2	26.8	16.5	28.2	29.1	18.3
Healam Bridge	SK5026	29.0	25.8	20.0		25.0	20.2		25.8			26.8				
Healam Bridge	SK8126															
Healam Bridge	SK8247															
Wattle Syke	SK1							27.2			27.1			28.4		
Wattle Syke	SK2								24.2		25.6	25.9	20.6		30.0	19.5
Wattle Syke	SK3					22.5	15.0		22.1	12.8					28.1	14.4
Wattle Syke	SK4													30.1	25.9	
Wattle Syke	SK5															
Wattle Syke	SK7							27.9	22.3	15.4	26.6	22.7	15.1	26.7	26.2	14.0
Wattle Syke	SK29	26.8			25.7	24.8						21.6	14.6			
Wattle Syke	SK30		25.1			24.4										
Wattle Syke	SK39				26.3	20.4	19.2	26.6	19.8	15.4	25.5	21.2	15.0			
Wattle Syke	SK44															
Burnby Lane	15															
Burnby Lane	22		19.8	16.9		20.6	17.2		20.8	15.7	25.7	21.2	15.9		22.9	17.1
Burnby Lane	49					23.0	16.5					23.6				
Burnby Lane	103															
Burnby Lane	104	28.4	24.8	16.6	26.8	23.5	15.3	27.5	23.7		26.9	23.2	13.2		28.6	16.0
Burnby Lane	108															
Burnby Lane	111															
Burnby Lane	128		21.3	17.8		21.8	16.3	27.9	22.1	16.1	28.4	23.6	17.7		28.9	

Site	SK no.	L1B	L1TR	L1AP	L2B	L2TR	L2AP	L3B	L3TR	L3AP	L4B	L4TR	L4AP	L5B	L5TR	L5AP
Burnby Lane	131	25.5				23.3	17.1									
Burnby Lane	132	24.5	19.0	16.8	26.4	19.7	15.9	25.1	19.5	14.1	23.0	20.2	13.9	222.0	21.6	15.1
Burnby Lane	145											26.5				
Burnby Lane	147					21.1	15.4	25.9	21.6	13.7						
Burnby Lane	152															
Sewerby	8		24.4	17.2		23.9	15.6		24.1	15.1		23.6	16.2	25.7	27.8	16.8
Sewerby	9															
Sewerby	10	28.2	21.5	16.1		21.7	17.1								25.1	
Sewerby	11		22.7	17.1		22.8	16.9								21.8	
Sewerby	25															
Sewerby	26		18.7	17.1		19.8	15.5		20.5	15.1	24.9	21.5	14.5	25.1	25.0	15.3
Sewerby	34															
Sewerby	35		17.8			19.8	17.1		20.2						22.3	13.3
Sewerby	37															
Sewerby	41					25.9	18.4		26.0	19.0					25.2	17.4
Sewerby	45					23.5	15.8		22.6	16.0		21.0	14.7		22.4	14.6
Sewerby	48		21.6	15.7		21.6	15.2		22.8	13.9						
West Heslerton	G70															
West Heslerton	G76															
West Heslerton	G78	27.5	23.1	18	28	23.2	16.9	28.9	23.6		26.7	23.6			27	16
West Heslerton	G89		23	14.2		22.1	15.6	26.8	22.2	15.7		21.6			23.5	14.7
West Heslerton	G102	21.9	21.8	15.8		21.9	17		21.7			21.4			22.5	
West Heslerton	G103											21.8	12.4		24.1	15.4
West Heslerton	G109															
West Heslerton	G111															
West Heslerton	G113		23.2	18		23.1	16.9		23.3	17.6		25	19.2		29.3	
West Heslerton	G134															

Site	SK no.	L1B	L1TR	L1AP	L2B	L2TR	L2AP	L3B	L3TR	L3AP	L4B	L4TR	L4AP	L5B	L5TR	L5AP
West Heslerton	G145															
West Heslerton	G158		24	14.5		22.8	13.3		22.6		28.7	23.3	13.1	28.7	26.3	
West Heslerton	G164											20.9	14.1		22.5	15.6
West Heslerton	G166															
West Heslerton	G171															
West Heslerton	G183								22.2	12.3		21.8	12.8		22.9	14.7