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When in Gaul, do as the 'Romans' do? Shifting Health in Gaul during Late Antiquity (300-700 CE)

Leslie Quade

Abstract:

The fall of the Roman Empire has long been characterized as a period of regression and deterioration of living conditions across Europe– the 'Dark Ages'. The nature of the cultural and political environment during Late Antiquity (300-700 CE) and whether transitions might be considered as continuous or catastrophic has been a contentious source of debate. Analyses of health data from human skeletal remains have yet to be fully integrated into discussions of societal change in Late Antiquity, despite their informative potential. If catastrophic hypotheses of Late Antique life experiences are correct, the social and political instability would have had a discernible effect on the health and well-being of the populace.

The skeletal remains of 844 individuals from Roman and Late Antique Gaul were analysed for demographic data (age, sex), growth disruption (Height-for-Age Z scores, femur length), non-specific stress indicators (dental enamel hypoplasia, cribra orbitalia, tibia periosteal reaction), carious lesions and trauma to contribute to current understanding of Late Antique transition. A subset of 65 individuals were also included in a pilot study for the detection of cortisol in dental enamel and dentine.

Gallo-Roman samples demonstrated more skeletal signs of stress than either Late Antique sample. This suggests that social and cultural factors rooted in Roman lifeways were more deleterious to health than the process of transformation. Gallo-Roman individuals may have been more regularly exposed to stressors throughout the life course, as a result of overcrowding and insalubrity in urban settlement structures. Changes in mortality patterns between males and females from the Roman period to Late Antiquity suggested a differential transition experience based on sex and gender. Cortisol concentrations were detected from within archaeological tooth dentine and enamel, but results were insufficiently linked to other skeletal stress indicators or sex. Stress experience as indexed through cortisol analysis did not reveal differences between Roman and Late Antique samples.

When in Gaul, do as the 'Romans' do? Shifting Health in Gaul during Late Antiquity (300-700 CE)

Leslie Quade



Thesis submitted for the Degree of Doctor of Philosophy

Department of Archaeology

Durham University

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List of Abbreviations

ACTH- Adrenocorticotrophic Hormone
CAV- Centre Archéologique du Var
CCEL- Centre de Conservation et d'Etudes de Lorraine
Cm- Centimetre
CPR- Crude Prevalence Rate
CRAHAM- Centre de recherches archéologiques et historiques anciennes et médiévales
CRH- Corticotropin-releasing hormone
DEH- Dental Enamel Hypoplasia
dL- Decilitre
DOHaD- Developmental Origins of Health and Disease
ELISA- Enzyme-linked immunosorbent assay
GCs- Glucocorticoids
GC/LC/MS- Gas or Liquid Chromatographic Mass Spectrometry
GR- Glucocorticoid receptors
GRS- Gallo-Roman South
HAZ score – Height-for-age Z score
HCC- Hair Cortisol Concentrations
HPA- Hypothalamic-Pituitary-Adrenal
IRPA- Institut de Recherche sur la Provence Antique
Km- Kilometre
LAN- Late Antique North
LAS- Late Antique South
M- Metre
Mg- Milligrams
mL- Millilitre
mm- Millimetre
NBF- New Bone Formation
Nm- Nanometre
PACEA- De la Préhistoire à l'Actuel: Culture, Environnement et Anthropologie L'Anthropologie
PACA- l'Ostéothèque régionale Provence-Alpes-Côte d'Azur the
PRN- Post-Roman North
PRS- Post-Roman South
R- coefficient of reliability
RBCs- Red Blood Cells
Rpm- Rotations Per Minute
Sep- Sepulchre
SGP- Skeletal Growth Profile
Sk- Skeleton
TEM- Technical error of measurement
TMB- Tetramethylbenzidine
Tibia NBF- New Bone Formation located on the shaft of the tibia
TPR- True Prevalence Rate
µl -Microlitre
WHO-World Health Organisation

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To the pigeons who died in the process of this research.

Dedication

To Chris, for agreeing to this PhD before I did, for coming to England and for bringing your suit. Also, for your un-failing love and support, no matter what the circumstances. I could not have completed this process without you.

Ich liebe dich, je t'aime, I love you.

You're too dark, and you're not dark enough.

*You were close, right? Then it went sour
and propelled you into one extreme...and you into another extreme.
Two overlapping, fractured philosophies were born out of that one pain.*

-I Heart Huckabees

Chapter 1

Introduction

Life is pleasant. Death is peaceful. It's the transition that's troublesome.
— Isaac Asimov

1.1 Late Antiquity

Late Antiquity, here defined as 300-700 CE, has come to take on a special significance in the history of the western world, as an age little understood and yet nascent to modern countries and traditions. Adopted from art historians attempting to categorize transitional periods (Riegl, 1901), Late Antiquity is characterized and identified by processes of social and cultural metamorphosis. It is the transition from a large, integrated Roman world into smaller, less-connected Medieval kingdoms (Brown, 1971). Perhaps because of the ambiguity of transition, even the proposed dates of Late Antiquity vary from '200 to 476 CE' (Brown, 1971), '450-750 CE' (Halsall, 1995), '200-600 CE' (Jones, 2009), '400-900 CE' (Webster et al., 1997) and '250-800 CE' (Bowersock, 2001). With such nebulous foundations, little regarding the period is straightforward and broad characterisations are challenging, even contentious, varying greatly depending on the area or topic of research (Brown, 1971; James, 2008). A major theme of discussion surrounding Late Antiquity is the nature of its transformation; what actually changed, how transformation was experienced, by whom, and what elements of continuity or disruption characterise the period. Beginning as early as the 18th century (Gibbon, 1898), some scholars have suggested that the end of the Roman Empire was a dramatic rupture in the cultural, political and social fabric of the western world. However, other scholars have identified continuity from the Roman period through to the end of the Medieval era (Brown, 1971; Cameron, 2003, 1998; Dumézil, 2005; Goffart, 1980; Pirenne, 1922). Studies of human skeletal remains and their health and stress states have thus far played a comparatively small role in contributing to understandings of Late Antiquity, despite their ability to provide direct information about the larger population, including women and children.

1.2 Transition and Health

Human health is impacted by cultural and social transitions, suggesting that if Late Antiquity was defined by rupture and catastrophe, it is likely to be reflected in human skeletal remains. Assessment of population skeletal stress markers has unique potential to reveal the impact of

socio-political and cultural change on health, supporting hypotheses of collapse or continuity, and also signal potential changes in cultural values and priorities. The inclusion and examination of human skeletal remains can therefore help to elucidate gaps in knowledge, but can also challenge existing narratives and concepts (DeWitte, 2014; Perry, 2007). The impact of cultural and socio-political transitions on health is likely to be most visible through examinations of subdivisions of the population and in health during childhood, when health is most sensitive to environmental conditions (Lewis, 2007). This analysis focuses on Gaul, a geographic region that, despite its informative potential, has yet to be integrated into larger discussions of Late Antique health or transition. Although perpetually in flux, Gaul broadly encompasses areas that were deeply enmeshed with Roman lifeways, as well as frontier areas in the north and along the Rhine. This regional variability, adds additional complexity but also provides an opportunity for productive comparison, clarifying transition experiences. Gaul is thought to be broadly separated into northern and southern regions (Cartron et al., 2015; Ward-Perkins, 1996; Wood, 1992), and this division is used for working purposes in the present thesis. Northern areas may have experienced collapse or catastrophe during Late Antiquity and southern regions may have undergone a more continuous transition.

1.3 Stress and Health

‘Health’ is broadly understood to involve an absence of illness as well as physical, mental and social well-being and as such, is deeply complex to define and conceptualise (WHO, 1998a, 1998b). As this definition takes into account mental and social states that would be difficult, if not impossible, to assess from human skeletal remains, ‘stress’ is regularly used as a proxy for health (Goodman, 1993, 1991; Goodman et al., 1984). Also a somewhat ambiguous term, ‘stress’ encompasses stressors or stimuli, as well as the biological stress response in the body. ‘Stress’ and ‘health’ are profoundly linked, as extensively explored in modern clinical (Aizer et al., 2016; Avitsur et al., 2009; Baylis et al., 2013) and palaeopathology analyses (Goodman et al., 1984; Klaus, 2014; Temple and Goodman, 2014). The Hypothalamic-Pituitary-Adrenal (HPA) axis, a primary pathway in the biological stress response, is stimulated in response to stressors, producing the glucocorticoid hormone cortisol (Sapolsky et al., 2000). HPA activation is one pathway through which external environments become biologically internalised, impacting health and well-being. Within palaeopathology, stress is normally assessed through non-specific skeletal indicators, including growth disruption, dental enamel hypoplasia, cribra orbitalia and skeletal signs of infection

(Goodman et al., 1984). However, current methods for assessing stress are limited by preservation and methodological constraints that may mask the presence of 'stressed' individuals within a sample. As such, it is important to explore and understand how stress becomes manifested in the body. Through this, it has been revealed that it might be possible to evaluate cortisol concentrations from archaeological tooth structures, which would be an important contribution to bioarchaeological and modern research.

1.4 Research aims

To contribute to current understanding of Late Antique transitions, the present research has the following aims:

1. To address debates surrounding the transitions taking place during Late Antiquity through the recording of new data from skeletal stress indicators in individuals dated to the Roman and Late Antique Periods in Gaul
 - a. This includes analysis of skeletal collections or individuals that have not yet been studied and the application of additional methods to previously assessed individuals
 - b. This analysis focuses on a geographic region that despite its informative potential has yet to be integrated into discussions of Late Antique health or transitions
2. To consider and conceptualise how transitions (collapse or otherwise) become embedded in biology, health and skeletal stress indicators
3. To investigate potential differences in 'transition experience' between northern and southern regions of Gaul
4. To explore potential differences in subgroups of the skeletal samples (sex, age-at-death), contributing to the narrative of Late Antiquity (what changed) and for whom (distribution of vulnerability)
5. To deepen current understandings of stress within human skeletal remains

1.5 Research Questions

1. How was health and wellbeing impacted by the social, political and cultural transformations taking place during Late Antiquity in Gaul?

- a. Are differences in frequencies of skeletal stress indicators observed between Gallo-Roman and Late Antique skeletal collections?
 - b. Can observed health changes be attributed to societal transition- 'collapse' or a more gradual form of transformation?
 - c. Are differences between northern and southern samples observed? Do differences in health, as evidenced through skeletal stress indicators, follow regional trends suggested by archaeological and textual data?
2. Do frequencies of stress indicators suggest changing cultural or social priorities during Gallo-Roman and Late Antique periods, as reflected in the age and sex of those affected?
 - a. Are particular stages of development more affected by environmental stressors?
 - b. Are differences in health between males and females detectable, suggesting possible shifts in cultural roles or ideologies?
3. Can understandings of stress through skeletal markers be augmented through biochemical methods?
 - a. Can detectable cortisol concentrations be obtained from archaeological tooth structures?
 - a. Do cortisol concentrations vary based on sex?
 - b. Are there correlations between cortisol concentrations and skeletal stress indicators?

It was hypothesized that consistent or unchanging patterns of frequencies in health and stress indicators would suggest a gradual transition experience, whereas distinctive changes in prevalence of stress indicators, or differences in the age and sex of those affected could demonstrate more extreme forms of transformation, possibly collapse. To accomplish the aforementioned aims, the skeletal remains of 844 individuals dated to Roman and Late Antique periods in Gaul are assessed for demographic information (sex, age-at-death) and several skeletal stress markers (femoral growth, DEH, CO, tibial PR, carious lesions, trauma, dental cortisol concentrations). These indicators are examined in both non-adult and adult remains to understand how both survivors and non-survivors were affected. This choice also permits an examination of differences between the sexes and enables examination of health over the life course. In addition, the potential to examine cortisol concentrations from archaeological dental structures, as a novel stress indicator is explored for the first time in this research.

1.6 Thesis layout

To address the research aims and questions outlined above, this dissertation is structured into the following chapters. The primary results and discussion are encapsulated in five separate manuscripts, isolating certain important findings or contributions. The discussion chapter relates these findings back to the original research questions.

Chapter 2. Transition in Gaul during Late Antiquity. The aims of this chapter are to provide the larger context in which this research takes place, provides a brief history of Gaul during Late Antiquity to permit further discussion of transition and the socio-political impacts on the health of populations living during this complicated and tumultuous time period. There is a very complex historical narrative involving existing Roman structures and practices in Gaul, as well as the features that were transitioning during Late Antiquity. Gaul is a particularly interesting geographical and political location to examine Late Antique transformation because it provides regional variability within a relatively contained zone. The extant evidence of transformation during Late Antiquity in Gaul is discussed, focusing on written, archaeological and mortuary sources to demonstrate shifts in political, social and cultural structures. What emerges is a geographic divide, where transformation in northern Gaul appears to have occurred earlier and more aggressively than in southern, Mediterranean Gaul.

Chapter 3. Transition, Health and Stress. The cultural and socio-political environment has a pronounced impact on health and wellbeing, as evidenced through both past and contemporary societies. Therefore, health data may be uniquely suited to address some of the gaps in current knowledge regarding Late Antiquity and its transformations. However, even within modern contexts the relationship between health, cultural and socio-political stressors and environment is complex, and faces further limitations within past populations. It is, therefore, important to explore how health is impacted by socio-cultural environments and transitions so that health data from Roman and Late Antique Gaul can be appropriately interpreted and related to hypotheses of societal collapse or more gradual transformation. The impact of these socially and culturally constructed environments has its most profound and/or visible effects in early childhood, necessitating an investigation of health and growth during the developmental period. Stress has a significant impact upon health and wellbeing, particularly in the context of changing social conditions and priorities. As such, it is important to examine and understand how stresses external to the body become internalised within the body, affecting health and wellbeing. Cortisol, as a key

glucocorticoid hormone within the Hypothalamic-Pituitary-Adrenal (HPA) axis links outside stresses with internal, biological responses and health consequences.

Chapter 4. Materials. This chapter presents the skeletal collections and sites included in the present research. Contextual information includes the location, historical background and importance of geographical region to stated research questions. The excavation context, dating of individual sites and the methods of dating, special features or finds, organization of the necropoleis, number of individuals found and number of individuals are detailed.

4.1 Gallo-Roman Sites

4.1.1 South- Cirque Romain, Arles; La nécropole de la Rue de Jacques Brel

4.2 Late Antique Sites

4.2.1 South- La nécropole de la Grande Bastide de Cadarache; La Granède; La nécropole du Colombier, Vaison-la-Romaine; Les Clavelles; Saint-Martin, La Brillanne; Rues de Toulon

4.2.2 North- Le Clos des Cordeliers; Saint Martin de Fontenay; Ancienne Chambre des Métiers, Rue de Tombois; Fontoy Rue de l'église; Cutry

Chapter 5. Methods. This chapter includes a detailed description of all skeletal analysis methods used in the present research.

5.1 Demographic Data (Age-at-death, Sex)

5.2 Bone Preservation

5.3 Growth Disruption

5.3.1 Dental Enamel Hypoplastic defects (DEH)

5.3.2 Femoral length (Skeletal growth profiles, Height-for-age Z scores)

5.4 Non-specific Stress Indicators

5.4.1 Cribra Orbitalia (CO)

5.4.2 Periosteal reaction of the tibiae (Tibia PR)

5.4.3 Carious lesions (Caries)

5.5 Trauma (Exclusive to long bones)

5.6 Statistical Analyses

5.7 Cortisol Analysis

5.7.1 Tooth Preparation

5.7.2 Enzyme-linked Immunosorbent Assay (ELISA)

Chapter 6. Manuscripts.

1. Modelling Health during Societal Collapse: Can Recent History help our understanding of Post-Roman Gaul?

Abstract: Societal collapse results in structural breakdowns and instability, which can impact life expectancy and population health. Previous bioarchaeological studies have, however, sometimes struggled to identify correlations between socio-political changes and skeletal indicators of morbidity and mortality. Late Antiquity (c. 300-700 CE) has often been conceptualized as a period of socio-political rupture marked by the collapse of the Western Roman Empire and the transition to the Medieval period. The nature of this transition and whether it was marked by either catastrophic or more gradual change has been much debated. To date, bioarchaeological analysis has contributed little to these discussions. A model of the effects of societal collapse on health is generated from a modern example (The Soviet Union) and used to assess the bioarchaeological evidence. While contextually far removed from the Roman Empire, the Soviet Union is the only example of a large-scale union of multiple countries with a predominantly centralized economy and government for which clinical data relating to its collapse is available. Femoral lengths and height-for-age (HAZ) Z-scores from non-adult and adult skeletal remains (269 individuals) from northern and southern Gaul are analyzed as a proxy for health. Contrary to the Soviet model, results indicate a period of greater physiological stress during the Gallo-Roman period than the later transition. Differences in growth patterns suggest social and cultural factors rooted in Roman lifeways were manufacturing a non-traditional distribution of biological vulnerability, which was more deleterious to health than the process of transformation.

2. Height and Health in Roman and Post-Roman Gaul, a Life Course Approach

Abstract: Large-scale analyses of skeletal remains from the Roman period have often found an increased prevalence of growth stunting and reduced adult stature in comparison with preceding and later eras. However, when assessed from skeletal remains, small stature is indicative of childhood physiological stress, but can also reflect enhanced survivorship (an

adaptive response to stressors). This study explores growth and health in Roman and Post-Roman Gaul through an examination of non-specific stress indicators (femur length, dental enamel hypoplasia, cribra orbitalia, tibial periosteal reactions and carious lesions) in 844 skeletons. Rates of DEH and Tibial periosteal reactions were significantly higher in the Gallo-Roman sample and rates of CO and caries were significantly higher in Post-Roman samples. Small femoral length was not correlated with mortality in any of the groups. DEH presence was correlated with earlier mortality in the Gallo-Roman context, whereas CO presence was associated with earlier mortality in the Post-Roman samples. This suggests that Roman and post Roman populations included individuals that were affected by early life stressors, but these patterns manifested in different ways, presumably due to variation in biocultural environments. The intertwined and often synergistic relationships between early life environment, nutrition, settlement structure and social stress are highlighted.

3. Desperately Seeking Stress: A pilot study of cortisol in archaeological tooth structures

Abstract: Cortisol is a glucocorticoid hormone produced through activation of the Hypothalamic Pituitary Adrenal (HPA) axis. It is known as the ‘stress hormone’ for its primary role in the body’s stress response and has been the focus of much modern clinical research. Within archaeology, only a few studies have analyzed cortisol in human remains and these have been restricted to hair (Webb et al., 2015a, 2015b, 2010). This study examines the utility of dentine and enamel, which survive well archaeologically, as possible reservoirs for detectable levels of cortisol. Sixty-nine teeth from 65 individuals from five Roman and Post-Roman sites in France were tested via competitive ELISA to assess and quantify the cortisol concentrations present within tooth dentine and enamel. In both tooth dentine and enamel, detectable concentrations of cortisol were identified in multiple teeth. However, concentrations were low and not all teeth yielded results that were measurable through cortisol ELISA. Differences in cortisol values between dentine and enamel could suggest different uptake mechanisms or timing. These results suggest that cortisol is incorporated within tooth structures and merits further investigation in both modern and archaeological contexts. Analysis of the results through LC-MS would verify current results and might yield values that could be better integrated with published cortisol studies. Future studies of cortisol in tooth structures would greatly expand the research potential of cortisol in the past and could have implications for studies of human stress across deep time.

4. Cortisol, Stress and Paleopathology

Abstract: Stress impacts health and wellbeing through allostatic load, affecting morbidity and mortality. However, the relationship between stress, frailty, immunity and disease has generated interpretive challenges for palaeopathological analysis. Cortisol, known as ‘the stress hormone’, facilitates physiological response to stressors, thereby acting as a key pathway to bodily manifestations of adversity. Cortisol concentrations therefore have the potential to act as a direct indicator of stress and one that may not be subject to the same interpretive limitations as traditional skeletal stress indicators. Recent research has successfully detected cortisol concentrations in archaeological tooth structures. Here we review the pathophysiology of cortisol and its relationship with commonly recorded skeletal stress indicators (mortality, growth disruption, DEH, CO, periosteal reaction, carious lesions) and provide preliminary results of possible correlations in an archaeological sample of 29 individuals. Results did not reveal clear patterns between dental cortisol and skeletal stress markers, frustrating attempts to use them as a straightforward frailty indicator or signal of early life stress. Although too early for conclusive interpretations, this research illustrates how cortisol could be functioning within the formation of skeletal stress indicators, highlighting the complexity of cortisol’s many functions within the body. Future analyses should continue to consider how external stressors become embedded biologically and explore cortisol’s potential to reveal hidden heterogeneity in frailty.

5. Sex, Gender and Mortality in Roman and Late Antique Gaul

Abstract: Late Antiquity in Gaul (300-700 CE) is a period defined by cultural and socio-political transition. The impact of this transition on health and well-being is not yet well-understood, nor has the potential for differential effects on women and children been considered. This research examines how transitions occurring during Late Antiquity affected mortality in males and females by assessing age-at-death distributions in 13 skeletal collections (410 individuals) from Gaul dated to Roman and Late Antique periods through Kaplan-Meier survival analysis. Results demonstrate significant differences in age-at-death distributions and survivorship over time between Roman and Late Antique burial populations, with female mortality notably affected during the latter. Female survivorship in Late Antiquity significantly decreased both in comparison to Roman females and males from both periods. Environmental shifts, trade localisation, and cultural changes in Late

Antiquity could have placed new pressures on existing systems of structural inequalities, resulting in increased female mortality in early adulthood (18-35 years). This study suggests that gender-based inequities increased in Late Antiquity, resulting in greater resource restriction for women, and increased risk during reproductive years when metabolic and energetic needs would have been the greatest. Late Antique samples from southern Gaul had the largest degree of gender disparity in mortality, potentially supporting hypotheses of a more gradual transition, where female health and mortality was sacrificed to retain established cultural and social norms.

Chapter 7. Discussion. This chapter brings together the five manuscripts and addresses some smaller aspects of the research that could not be included or adequately discussed through the manuscript format. Limitations of the study are also discussed.

Chapter 8. Conclusion. Summary of the research findings and some future directions

Appendices

Bibliography

Chapter 2

Transition in Gaul during Late Antiquity

A transition period is a period between two transition periods.
— George Stigler

Transitions in Late Antiquity have been most often considered through a lens of the ‘decline and fall’ of the Roman Empire as immortalised by Gibbon in the 18th century. Major political, military and migration events along with changes in settlement structures, religious practices, trade networks, grave and burial rituals, all attest to large-scale transformations during Late Antiquity. However, there is also evidence for substantial continuity in cultural and legal systems. As a result, many aspects of transition remain poorly understood and hotly debated. Was Late Antiquity a period of dramatic rupture characterised by the collapse of the Roman Empire, or was transformation more gradual as important structures continued on in different, yet recognisable forms? To address debates surrounding the transitions taking place during Late Antiquity, this research examines skeletal stress indicators in burial populations from Roman and Late Antique Gaul. This analysis focuses on a geographic region that, despite its informative potential, has yet to be integrated into discussions of Late Antique health or transition. Archaeological and written sources attesting to transformation in Gaul are examined. Potential differences in ‘transition experience’ between northern and southern regions of Gaul are also investigated.

2.1 Decline and Fall?

Gibbon’s ‘The Decline and Fall of the Roman Empire’ (originally published from 1776 to 1789), written in the glow of Enlightenment thinking, spurred generations of scholars and the public to understand the end of Roman authority as a catastrophic and dramatic change, which plunged the world into the Dark Ages, only to be ‘re-born’ with the Renaissance. By portraying the end of the Roman Empire as a ‘decline and fall’, Gibbon established a dominant framework for research surrounding the period and instigated centuries of debate. Much recent research has rejected notions of decline and instead produced narratives of ‘continuity’ (Brown, 1971; Cameron, 2003; Goffart, 1980). These studies focus on cultural, legal and taxation systems, showing long term stability and durability throughout (and beyond) Late Antiquity (Brown, 1971; Cameron, 2003,

1998; Dumézil, 2005; Geary, 1988; Harrison, 2008; Noble, 2006; Pirenne, 1922). Within these frameworks, the Roman Empire did not fall, but merely ‘transformed’ into something else. However, it has been suggested that approaches prioritising ‘continuity’ are more reflective of current political and social environments, which favour multiculturalism and integration, than what might have existed in Late Antiquity (James, 2008). The concept and possibility of Late Roman decline, which has been downplayed over the past 40 years, is making a comeback (Ando, 2008; Esmonde Cleary, 2013a, 2011; Liebeschuetz, 2001; Marcone, 1997; Ward-Perkins, 1996; Wickham, 2005). ‘Decline’ has also received renewed attention from cutting edge interdisciplinary research exploring the interaction between climate change, disease and human action (Büntgen et al., 2016, 2011; Harper, 2017; Luterbacher et al., 2020; McCormick, 2015; Mordechai and Eisenberg, 2019). Liebeschuetz (2001) has stated that by denying the possibility of ‘decline’, the potential to identify and analyse ‘change’ has been withheld from historians, which is neither realistic nor productive. With no consensus in sight, many scholars have called for a re-orientation of research perspectives and questions; ones which are not so beholden to concepts of ‘catastrophe’ or ‘continuity’, but which instead prioritise global perspectives and regional variation (Ando, 2008; Heather, 2001; James, 2008). These shifts in thinking, strongly influenced by anthropological and global perspectives, as well as gender, resilience and complex systems theories, have yielded important new research (Bowersock et al., 1999; Cleymans, 2019; Izdebski et al., 2018; Lewit, 2020; Smith, 2000). However, despite the large strides this change in perspective has initiated, the respective nature of transition, whether ‘catastrophe’ or ‘continuity’, remains a dominant area of discussion and debate (Ando, 2008; Fischer et al., 2010; Jongman, 2007; Storey and Storey, 2017).

Because human health is impacted by cultural and social transitions, if the period, now known as Late Antiquity, was defined by ‘decline and fall’ with catastrophic effects, it is likely to be reflected in human biology and bodies. Palaeopathology can indicate if human health and well-being (as indexed through skeletal stress markers) changed during Late Antiquity or if similar patterns and trends were sustained throughout the period. Further, the inclusion of human skeletal remains within this debate offers a direct form of evidence of the lived experience that includes subsections of the population that are not often visible in textual and other archaeological sources. In this way, the inclusion and examination of bioarchaeological data can help to elucidate gaps in knowledge, but can also challenge existing narratives and concepts (DeWitte, 2014; Perry, 2007). This study can indicate on a large scale if population health differed between periods. Skeletal manifestations of health and well-being might indicate a diminution of resources, changes in culture or suggest normal fluctuations, rhythms and variations in lifeways. In this way, bioarchaeological analyses can

help to clarify Late Antique transitions (including and beyond elements of catastrophe or continuity). To address this debate and contextualise the evidence from human skeletal remains, it is important to understand what societal decline and collapse entail, as well as how the extant evidence for transition in Late Antique Gaul fits into this paradigm.

2.1.1 Collapse

That Late Antiquity encompasses change is not up for debate; it is a period defined by change. Socio-political and cultural transitions are to some extent a constant within human societies, and societal change can range from reorganization to collapse (Faulseit, 2016). The concept of societal collapse plays a key role within catastrophist views of Late Antiquity. Because skeletal stress indicators can be subtle and challenging to interpret in relation to societal transitions, it is prudent to frame the present research questions in terms of extremes (provides the best chance for a discernible outcome). ‘Collapse’ has multiple competing definitions and can be divided into different types and levels – systems, state, demographic, socio-political, cultural, socio-ecological (Middleton, 2017; Tainter, 1995; Temple and Stojanowski, 2018). For example, a ‘state collapse’ refers to a government’s loss of ability to provide its populace the necessary infrastructure, goods and services and authority that regenerated its own existence (Scheidel, 2017). State collapse may or may not have greater implications for a society and larger value systems, which can involve or spur other forms of collapse, such as demographic or cultural collapses (Storey and Storey, 2017, 2015). The collapse of complex societies, also referred to as societal or systems collapse, entails more than a political failure. As defined by Tainter, societal collapse is identified through ‘a rapid, significant loss of an established level of socio-political complexity’ (Tainter, 1988, p. 4–5)¹. Other key features include diminished social stratification, differentiation and division of labour, declines or decreases in spheres of trade and information, and a decline in investment in civilizational features such as monumental architecture, art, literature, and literacy. These developments accompany and interact with political disintegration that weakens or altogether removes centralized control functions and possibly elite classes (Renfrew, 1984). In some instances, the population as a whole contracts, settlements shrink or are abandoned, and economic practices regress to less sophisticated levels (Renfrew, 1984; Scheidel, 2017) (Table 2.1). Many aspects of

¹ For an extensive review of societal collapse see Tainter (1995), among others (Diamond, 2013; Renfrew, 1984, 1979).

societal collapse can therefore be visible archaeologically, including changes in and potential abandonment of settlement structures and monumentality (Faulseit, 2016; Renfrew, 1984).

Table 2.1 Features of collapse, adapted from Tainter, 1995

	Features of Collapse
1	a lower degree of stratification and social differentiation
2	less economic and occupational specialization, of individuals, groups, and territories
3	less centralized control; less regulation and integration of diverse economic and political groups by elites
4	less behavioural control and regimentation
5	less investment in the epiphenomena of complexity: monumental architecture, artistic and literary achievements etc.
6	less flow of information between individuals, between political and economic groups, and between a centre and its periphery
7	less sharing, trading, and redistribution of resources
8	less overall coordination and organization of individuals and groups
9	a smaller territory integrated within a single political unit

Systems collapse has become a prominent theme within archaeology and has been considered in relation to Late Roman or Late Antique periods (Faulseit, 2015; McAnany and Yoffee, 2010; Middleton, 2012; Redman, 2005; Storey and Storey, 2017, 2015; Tainter, 1988, 1995; Webster, 2002; Webster et al., 1997). Theories of systems collapse applied to several societies and time periods (Wari Empire, Classic Maya), highlight several features potentially applicable to Late Antiquity in Gaul (Table 2.2). In both Post-Roman (Late Antique) Britain and the collapse of the Wari Empire in the Andahuaylas in the 11th century, research has identified the displacement of living spaces, disintegration of road and trade networks, changes in goods production and utilized technologies and shifts in regional hierarchies (Esmonde Cleary, 2011; Kurin, 2016; Storey and Storey, 2017). Pronounced reductions in economic, social and cultural complexity, as reflected in reduced exchange of resources and a ‘flattening of the social hierarchy’ are demonstrated (Esmonde Cleary, 2011 p. 14). There are cultural and behavioural ramifications of large-scale transitions, including how people relate to one another and changes in social identity and inequities (Esmonde Cleary, 2011; Kurin, 2016). Several studies have identified heightened frequency of skeletal indicators of interpersonal violence (skull fractures) during the Wari collapse (Andrushko, 2007; Tung, 2008). Violence in response to collapse can derive from material deprivation or resource scarcity, large-scale migrations and socio-political instability (Kurin, 2016). Ways of managing and interacting with death are also affected by societal collapse (Kurin, 2016; Schiller, 2001). Therefore, burial rituals are likely to change in response to the disintegration of power authority and access to goods, services or locations necessary to perform certain burial rites

(Kurin, 2016). The presence of these features may suggest societal collapse in Gaul during Late Antiquity.

Table 2.2 Features of collapse for archaeological sites and populations

	Specifics of collapse
1	Different access to resources, trade, technology (can be evidenced through diet)
2	Migration (population movement)
3	Violence
4	Settlement structure changes
5	Material culture changes
6	Population (density)
7	Social stratification
8	Burial ritual and rite changes (Different engagement with death)

However, it has been stressed that while states and societies can collapse, cultures or civilisations merely transform (McAnany and Yoffee, 2010; Yoffee and Cowgill, 1991). This has caused many scholars to reframe questions around ‘resilience’, or the capacity of human societies to respond to or absorb external stressors by drawing on conserved energy or resources, or changing to maintain existing systems and structures (Faulseit, 2016; Harper, 2016; Redman, 2005). Reframed in this way, the features of collapse including migration, abandonment of monumentalism, changes in resource management and social organization can be seen as adaptation to a changing environment (Middleton, 2012). Concepts of resilience have become prominent in Roman history and archaeology, and are also a burgeoning topic within bioarchaeology (Martin et al., 2013; Reitsema et al., 2017; Temple, 2020; Temple and Stojanowski, 2018). This framework emphasizes human plasticity and adaptability, adding flexibility and complexity to understandings of behavioural change, cultural identity and transition (Temple and Stojanowski, 2018). Although interesting and worthy of investigation, it has been suggested that the concept of resilience may not always function or be appropriate for use in historical contexts or questions (as they were not developed for this use) (Middleton, 2017). Further complicating considerations of societal change during Late Antiquity, collapse and resilience/transformation can exist side by side, as evidenced in modern and archaeological examples, such as the USSR and the Wari civilization of Peru (Hammon, 2011; Kurin, 2016). This illustrates that elements of resiliency and collapse can coexist (Middleton, 2017; Redman, 2005; Storey and Storey, 2017).

Gaul offers critical evidence to the collapse-continuity debate through written and archaeological sources. Further, Gaul is a particularly interesting geographical and political location in which to examine Late Antique transformation because it provides regional variability within a relatively

contained zone. Recent analyses have focused on regional differences and variability in transition, where there can be evidence of collapse in one region and continuity in another (Ando, 2008; Heather, 2001; James, 2008). This adds necessary complexity to examinations of Late Antiquity and the transitions occurring within. The following sections provide a brief history of Gaul during Late Antiquity to permit discussion of transition and the socio-political impacts on the health of populations living during this complicated and tumultuous time period². The following sections also discuss the extant evidence of transformation during Late Antiquity in Gaul, focusing on written, archaeological and mortuary sources to demonstrate shifts in political, social and cultural structures. What emerges is a geographic divide, where transformation in northern Gaul appears to have occurred earlier and more aggressively than in southern, Mediterranean Gaul. This general trend has implications for understanding how health and well-being were impacted by the large-scale transitions taking place in Gaul during Late Antiquity.

2.2 Geography

To ground and contextualise the present research a brief description of the geography of Gaul is provided. Although Gaul encompassed several modern-day countries, this analysis is restricted to modern-day France. Although frontier boundaries were far from precise and often fluctuated, Roman and Late Antique Gaul is understood to have roughly comprised present-day France, Belgium, Luxemburg and parts of the Netherlands, Switzerland, Germany and Italy. Natural boundaries include the Atlantic Ocean to the North and West, the Pyrenees mountain range and Mediterranean Sea to the South and the Rhine river in the East (Fig. 2.1). The landscape is mostly made up of low-lying plains, broken up by several mountain ranges, including the Vosges and Jura ranges in the northern eastern quadrant, the Alps in the south-eastern quadrant and the Pyrenees along the southern border (Clout, 2013). The Massif Armorica and the Massif Central, are elevated regions in the north-west and south of France respectively, made up of mountains and plateaus. Six major rivers, the Seine, Loire, Garonne, Meuse, Moselle and Saône/Rhône run throughout the country (Fig. 2.1). Several climate zones, as defined by its oceanic, continental, Mediterranean and mountainous features create an excellent location for agriculture. Natural features, such as the Rhine River acted as rudimentary borders, separating Gaul from other regions,

² The narrative of events, key players and stakeholders in Roman and Late Antique Gaul is incredibly complex and a full description and analysis is beyond the scope of this work. The intention here is to provide enough context to understand the present research and questions. Several themed timelines are included in the appendix to augment this summary.

and contributing to internal physical and cultural divisions (Clout, 2013). Broadly speaking, these can be understood to include the division between France and its eastern and southern neighbouring countries, between northern and southern France and the region of modern-day Brittany in the north-western tip, known as Armorica.

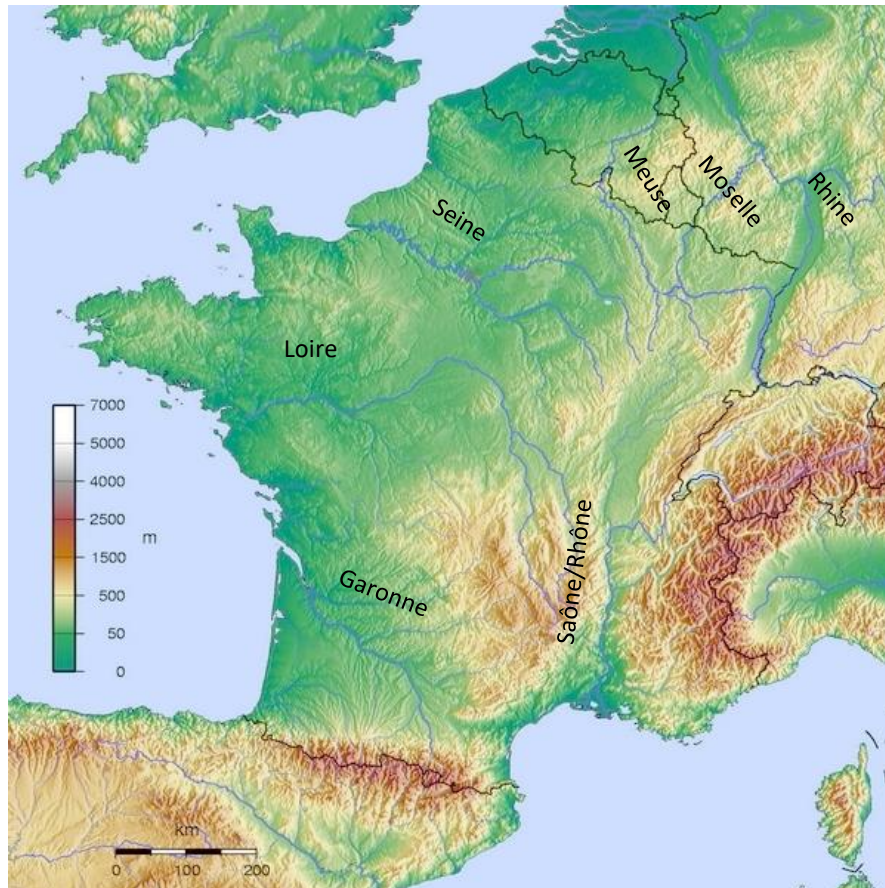


Fig. 2.1 Topographic map of Modern France (edited from Commons.wikimedia.org, 2017)

2.3 Sources

2.3.1 Written Sources

Although textual sources are challenging to interpret, they have constructed large portions of what is known about Late Antique Gaul. Consisting primarily of letters, poetry, chronicles, hagiographies and legislative texts, the written sources comment on contemporary interpretations and conceptions of events and society (Jones, 2009). Often, Late Antique sources are limited in quality or quantity, with relatively few yielding much more than small clues from which to construct a

history. Chronicles or short dated descriptions of events, for example, make up a large part of the written sources for the 5th century in Gaul, as no detailed histories survive (Drinkwater and Elton, 2002). More extensive narratives do not appear until the late 6th century with Gregory of Tours' *History of the Franks*, written from the mid-570s to the 590s (Wood, 1994). Despite their utility, written sources are subject to preservation filters and personal and cultural biases, which distort representations of past events. Late Antique Gallic sources were written almost exclusively by Gallo-Roman elite males, who often had very specific audiences and agendas in mind, meaning the texts cannot be interpreted as direct reflections of events (Drinkwater and Elton, 2002; Theuvs, 2009; Wood, 1992). Further, authors intentionally or otherwise, utilise various stylistic strategies to communicate their messages. These strategies need to be identified and understood in their proper context to be informative to modern readers (Murray, 2008; Theuvs, 2009). The voices of women, children, non-Romans and the poor or uneducated (the majority of the population) are largely absent from these texts (Goffart, 1980), severely limiting the possibility of reconstructing accurate pictures of life in Gaul during Late Antiquity. Still, these sources capture events that leave no archaeological trace, such as the Visigothic and Burgundian settlements in southern Gaul (James, 1979, 1977; Périn and Kazanski, 2011; Todd, 1997). Collectively, written sources enable only a fragmentary narrative of events to be reconstructed, primarily of political and military events and of ecclesiastical institutions.

Within the extant written evidence, sources illustrate societal transformation, but also geographical and cultural divisions. In the 5th and early 6th centuries, most written sources derive from southern regions of Gaul and display heavy 'Roman' influences, while texts from the North are so scarce that it has even been described as an almost 'proto- or pre-historic' period (Ward-Perkins, 1996, p. 6). Despite this geographic imbalance, major Roman centres in the North have revealed evidence of written culture (Sarti, 2013; Ward-Perkins, 1996). The city of Trier, a hub of Roman authority and culture near the northern Rhine frontier, contains 800, or almost one third, of the post-imperial inscriptions from Gaul, whereas the remainder of northern Gaul has thus far yielded only a few dozen such inscriptions (Halsall, 2007). This would seem to indicate that written works were not being produced or are not being preserved on the same scale from regions where Roman influence was weak. Texts from non-Roman peoples inhabiting Gaul during Late Antiquity are relatively scarce, especially from northern regions; however there are a few examples, such as the Salic Law, a legislative text written between 507 and 511 for the Merovingian king Clovis (Wood, 2014). A shift in the quantity and origin of texts emerges in the late 6th and 7th centuries, where more sources from central regions appear and many derive from the Merovingian north

(Sarti, 2013). By the 7th century, the north-west region of France (Neustria) became the best documented area of Gaul (Wickham, 2005). In this way, the changing geographic and cultural distribution of written evidence demonstrates social and political reordering (Esmonde Cleary, 2011; Halsall, 2007). The idea that Gaul was divided culturally and politically is not merely a construct of present historians, as evidenced through the *Querolus*, the only extant play from Late Antiquity, written in the 5th century (Murray, 2008). In the piece, the main character Querolus is instructed that the only way to pursue his base instincts is to leave his southern home and live at the Loire River, where there is anarchy.³ This division of southern Gallo-Roman civilisation in comparison with chaos beyond the Loire demonstrates a contemporary perception in Late Antiquity that the south was more stable than the north.

2.3.2 Archaeological Evidence

Archaeological sources are often the only evidence available for many regions in Gaul during Late Antiquity, providing critical insight into how cultural transformations took place. Although there is an inherent relationship between identity⁴, culture, and material culture, this connection is challenging to decipher, especially for past populations. When the internal manifestations of culture, or 'values, beliefs, code of conduct', undergo transition, the external manifestations of 'dress, cuisine, architecture, language and lifestyle' transition with it (Noble, 2006, p. 9). Yet the relationship between culture, identity and material culture is not direct or clear, making causal and unambiguous connections difficult to identify (Pohl, 2006). Late Antique settlement structures, material culture and burial trends have revealed conflicting evidence of decline and prosperity, disruption and continuity across Gaul. Where one community shows relative stability, the next shows 'complete devastation', confounding attempts to understand the period as a whole (Harrison, 2008, p. 34). Further complicating current research, few sites from Late Antique Gaul have been excavated in their entirety, omitting relevant information and potentially skewing

³ "Go and live on the banks of the Loire...In that place people live by the law of nations. There it's no trick. There, capital sentences are issued from an oak (tree) and written on bones. There, peasants conduct the pleadings and private persons act as judges. There all is permitted." (*The Querolus* cited in Murray, 2008 p 172-3).

⁴ Identity and not 'ethnicity' (see Theuvs and Alkemade, 2000 for an extensive review). The role of 'ethnicity' has a long history within the study of Late Antiquity, where some have looked for the presence of Germanic influences within Roman territories (Böhme, 1974; Werner, 1950). More complex conceptions of identity, a multidimensional, non-exclusive, fluid and mutable concept are perhaps more appropriate (Theuvs and Alkemade, 2000).

interpretations of the period. Many cities in modern-day France have their origins in Gallo-Roman and Medieval periods. Although urban development projects and frequent construction within cities often reveals archaeological finds, these important sites are often located in areas predominately inaccessible to large systematic excavation efforts. Further, some periods generate material culture that preserves better or remains more visible archaeologically than others (Harrison, 2008). In this way, archaeological analyses also suffer from biases which are challenging to overcome.

As with written evidence, archaeological sources demonstrate a geographic and cultural separation in the experience of transformation between northern and southern regions in Gaul. Reductions in the size and complexity of cities and villas and drastic changes in funeral practices in northern Gaul have suggested decline and rupture, while abundant sources from the south seem to reflect a more stable transition (Ward-Perkins, 1996; Wood, 1994). The conflicting evidence between the north and south of Gaul during Late Antiquity is so stark that some have suggested that Gaul cannot be discussed as a collective whole, but more-specific regions must instead be specified (Cartron et al., 2015). Providing support for this assertion, the following sections discuss how written and archaeological evidence of changing interactions between Romans and non-Romans, urban settlement patterns, villas, industry and trade networks and funerary practices display overall transformation during Late Antiquity, but also geographical divisions between the north and south of Gaul.

2.4 Political History and Boundaries in Roman and Late Antique Gaul

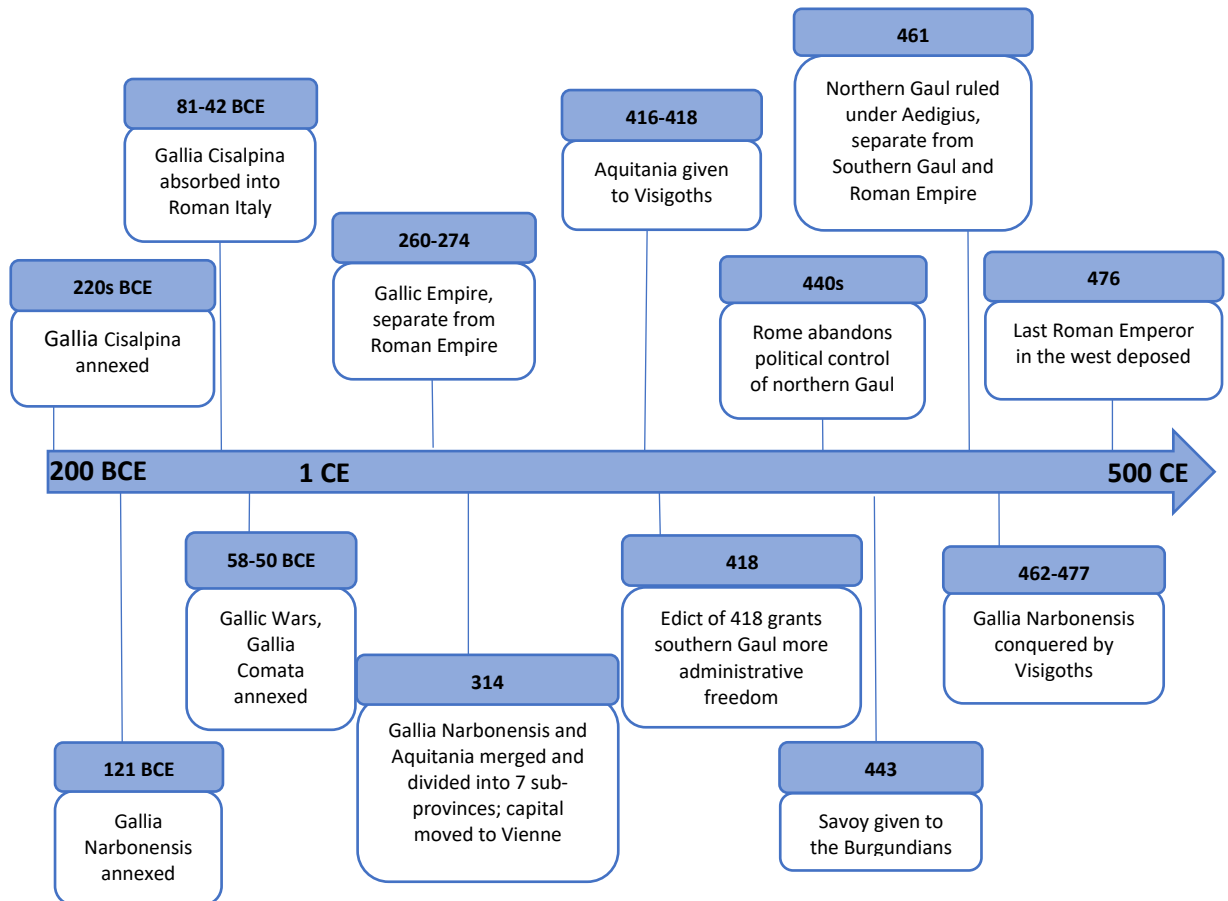


Fig. 2.2 Timeline of political boundaries in Gaul

Rome began its conquest of Gaul in the 2nd century BCE, establishing political borders, which also came to have important historical and cultural significance (Fig. 2.2). The Romans conquered south-eastern Gaul including modern-day Provence, the Languedoc-Roussillon and approximately half of the Rhone-Alpes (Gallia Narbonensis, or Gallia Transalpina), in as early as 121 BCE (De Planhol and Claval, 1994; Woolf, 1998). The remainder of Gaul, then known as Gallia Comata (long-haired Gaul), consisting of modern central France, Belgium, and parts of western Germany, was won from the Celts through the Gallic wars from 58 to 50 BCE. The Romans then divided Gallia Comata into three smaller provinces, Gallia Aquitania, Gallia Belgica and Gallia Lugdunensis (Fig. 2.3) (De Planhol and Claval, 1994). The Eastern border of Gallia Belgica, roughly following the Rhine river in the late 1st century, was an important natural and political boundary, as it effectively defined Gaul from the rest of barbarian lands (Drinkwater, 1992). The border between the Aquitaine and Lugdunensis

provinces, mostly following along the Loire river, would come to define the separation between northern and southern Gaul. During the crisis of the 3rd century, the Roman Empire suffered from significant instability, as a result of problems with succession, barbarian invasions and economic inflation. From 260 to 274 CE, Gaul along with parts of Spain and Britain formed the Gallic Empire, separate from Rome. However, the Gallic Empire (secessionist and not anti-Roman) was reincorporated into Rome when military and political stability was achieved.

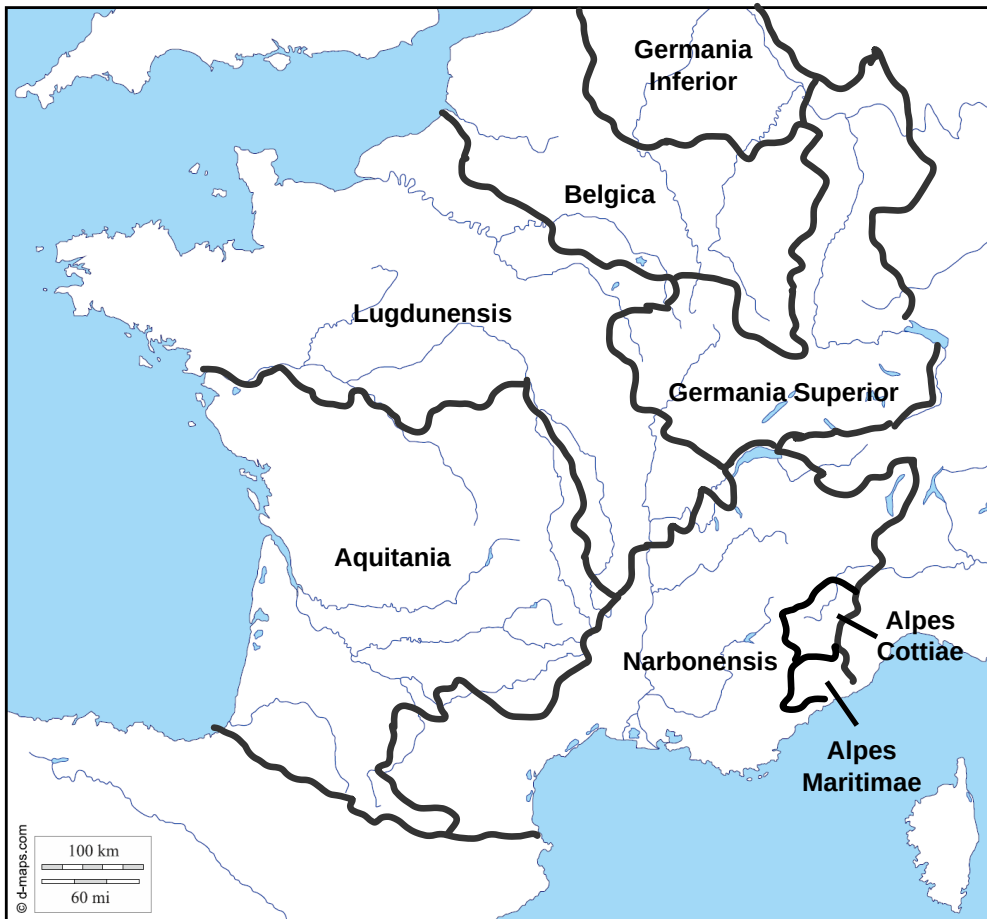


Fig. 2.3 Map of Gaul at approximately the 1st century BCE

From the 4th to the 6th centuries, administrative changes along with barbarian activities greatly altered the borders of Roman Gaul. In response to the difficulties of the 3rd century, Diocletian reorganized the administration of the Roman Empire, merging the southern provinces of Gallia Narbonensis and Gallia Aquitania into the *Dioecesis Viennensis* (Diocese of Vienne) (Fig. 2.4) (De Planhol and Claval, 1994). The name was later changed to *Dioecesis Septem Provinciarum* (Diocese of the Seven Provinces) and included *Aquitanica I*, *Aquitanica II*, *Aquitanica III*, *Narbonensis I*, *Narbonensis II*, *Viennensis* and *Alpes Maritimae* (De Planhol and Claval, 1994). In the mid-3rd century, the Gallic capital and imperial seat of the Western Empire was established in Trier on the

frontier in northern Gaul, providing greater protection and investment in the Rhine frontier. The presence of the emperor and the designation of a city as a capital brought with it the infrastructure necessary to Roman administration, along with wealth and prominence to the region (Bispham, 2008; Van Dam, 1985; Ward-Perkins, 1997). By moving the Gallic capital and the imperial seat to Trier, the emperor was able to shift the base of his power to a critical location for both resources and defence, changing the focus of the Western Empire from Rome itself to the periphery (Ward-Perkins, 1997). Throughout the late 4th and early 5th centuries, continuous barbarian threats on the Rhine frontier and revolts of the Bagaudae ('peasant' or 'bandit'), especially in the Armorica region, led to upheaval from both within and on the frontiers of Gaul (Drinkwater, 1992). In response, between 395 CE and 418 CE, the Gallic capital was moved again, from Trier to Arles in Southern Gaul, consolidating power in the south (Bispham, 2008; Geary, 1988; Halsall, 1999). Rome was in effect losing its hold on the peripheral regions (Drinkwater, 1998).

To regain control, Rome sought to placate and employ barbarian groups through improvements on various treaties. In 416/18, Gallia Aquitania (southwestern Gaul) was signed over to the Visigoths, establishing a barbarian kingdom within Roman territories and removing it from Roman control (Heather, 1998). Attempting to combat further losses within Gaul, the emperor Honorius signed the Edict of 418, which kept the southern Gallic provinces and aristocracy connected with Italy by granting them some autonomy. This edict eased the external administration and internal connection of the Seven Provinces, by allowing local elites from each province to govern as a dependent federation, which met every year in Arles, rather than having imperial governors imposed upon them. By the 440s, the Roman Empire had effectively lost political control of the northern regions of Gaul, with *foederati* (treated barbarian groups) established along the Loire to defend the new boundary (Halsall, 2007). In 443, the Burgundians were granted their own kingdom in Savoy, further limiting the extent of Roman physical, political and economic control in Gaul (Collins, 2001; Heather, 2001). In 461, problems with Roman imperial succession led to an official break between the northern and southern regions of Gaul, where the North had a separate leader, unaffiliated with Rome (Elton, 1992). After continuous sieges and raiding, Gallia Narbonensis was ceded to the Visigothic kingdom between 462 CE and 477 CE, effectively ending Roman political control in southern Gaul. In 476, the last Western Roman Emperor, Romulus Augustulus was deposed, which officially ended Roman control in Gaul, but also in the entire Western Empire (Geary, 1988).



Fig. 2.4 Map of Gaul around 400 CE (Commons.wikimedia.org, 2017a)

2.4.1 Problems with Succession

The imperial succession greatly affected the Gallic political atmosphere and was often heavily influenced by people and events in Gaul. Although dynastic changes are unlikely to have impacted the daily lives of the majority of the population, the repeated instability in imperial succession during Late Antiquity became an important factor contributing to political upheaval, leading to multiple civil wars as well as changes in barbarian relationships and interactions. Problems with succession exposed political power divisions and weakness, creating opportunities for Romans and non-Romans to obtain resources and power (Halsall, 2007). Late Antiquity had almost constant challenges to and interruptions of imperial succession. As emperors came, went, were usurped and assassinated, the office of emperor lost its position, authority and ultimately importance (Drinkwater, 1998; Fanning, 1992). The Gallic military and aristocracy became more actively involved with influencing the imperial succession when imperial grasp on control appeared to be waning. As the focus of the Empire began to shift away from the defence of the Rhine frontier through a military and bureaucratic retreat south, those with influence in Gaul asserted their authority where they could. Controlling who was emperor, was a relatively straightforward way of achieving this goal (Halsall, 2007).

The 3rd century had seen a rapid succession of emperors and usurpers (26 in a 50-year period), mostly promoted by the military and successful through violence, which undermined the central importance of the emperorship (Halsall, 2007). The emperor's authority, or at least the projection of dominance, was critical in the continuation of the Roman system (Kelly, 1997). In 293 CE, Diocletian formed the tetrarchy, which successfully regained control and stability of the office, but also divided the Empire into eastern and western halves, with a clear separation of power (Geary, 1988). Problems with succession began again shortly after Diocletian and Maximian abdicated the imperial seats of the Western and Eastern Empires to their constitutional heirs, Constantius and Galerius in 305 (Geary, 1988). Constitutional succession was heavily contested in both halves of the empire, and the following decades saw many quick and unstable reigns, as well as accompanying civil wars. Several struggles for power over the Western Empire were particularly impactful in Gaul, including Constantine from 306 to 312 and Constans between 350 and 353 (Halsall, 2004). The 5th century was politically chaotic in Gaul, with the promotion and deposition of several Roman and non-Roman emperors (Drinkwater, 1992; Fanning, 1992). Barbarians, already gaining in power, combined forces with an increasingly frustrated aristocratic class to usurp control and manoeuvre emperors and control territories within and outside of Gaul (Elton, 1992; Heather, 2001). Roman control of Gaul was ultimately confined to its southern regions in the mid-5th century (Elton, 1992). From this point onwards, Rome could only claim a tentative security in southern Gaul and none at all in the North (Elton, 1992). In 464/5, Syagrius continued an entirely separate reign from the Roman Empire in Northern Gaul. In 475 Romulus Augustulus was appointed western Emperor, only to be deposed by Odoacer (who was supposedly of non-Roman origins and leader of a *foederati* group in Italy) in 476 (Geary, 1988). From this point on there was no Western Roman Emperor.

Examining the history of Gaul and its relationship with the imperial succession reveals a complicated web of names, dates, and political agendas, which offered little political security. The longest stretch of time, which can claim any sense of stability, was during the reign of Constantine (312-337), a mere 25 years over the course of two centuries. Shifts in the locations of capital cities along with the seat of the emperor and his court altered core-periphery dynamics and geographical bases of power (Halsall, 2007). Difficulties with finances complicated systems of patronage and monetary tactics, which had been previously employed to manage military forces and to control borders (Geary, 1988). The nature of the military was also undergoing change, becoming a central aspect of aristocratic life, eclipsing civil responsibilities (Halsall, 2007). Barbarians and barbarian leaders also were deeply entrenched within Roman military organisation. These factors were often

interlinked, exacerbating the challenges each presented to the running of the Roman Empire and limiting Rome's options to combat them. As a result of the continual undermining of authority by internal and external threats, barbarian groups took advantage of the chaos, establishing their own kingdoms. In contrast with ineffectual and ever-changing emperors located at a distance, barbarian leaders were powerful, successful within their communities and in dealing with or escaping Roman bureaucracy and, most importantly, they were local. They were often physically present and invested in their surroundings.

2.4.2 Military Activity

During Late Antiquity, the military gained prestige and importance, due to increasing security needs and their influence over imperial succession and stability. Stemming from the 3rd century, the military had a strong influence on imperial succession through the assassination and promotion of emperors and usurpers of their choosing. Military and administrative activity during Late Antiquity is well-documented through sources such as the *Notitia Dignitatum* (Esmonde Cleary, 2013a). During the 4th and 5th centuries, military action instigated a series of civil wars surrounding the breaks, replacements and usurpations to imperial succession previously discussed. Several of these civil wars were particularly impactful in Gaul, especially Constantine's fight for power from 306 to 312; between 350 and 353 when his son Constans was assassinated and usurped by a Gallic general; and in the early 5th century when several Gallic usurpers were able to take control of Gaul with military aid (Halsall, 2000). These wars not only replaced figureheads, they affirmed that emperors could neither ascend to nor maintain control of the throne without the support of the military, increasing soldiers' social and political importance (Lee, 1997; Whitby, 2000). Economic factors also connected imperial succession and the military. A large proportion of Roman tax revenues were designated to the Roman army (Lee, 1997). As difficulties with succession continued, monetary gifts became increasingly important to ensure loyalties, but there was an ever-decreasing number of sources to draw them from (Heather, 2001). Some emperors and generals such as Stilicho and Aëtius could rally the army around them through their extreme charisma, but many were forced to raise taxes to pay for military needs, putting pressure upon landed citizens and furthering military and civilian differences.

During Late Antiquity, the military was called upon to quell increasing internal Roman revolts, which threatened the security of Roman rule. 'Bagaudae' or bandits, was the name given to a series

of revolts which took place within the Roman Empire by Roman citizens, often in the northern regions of Gaul beginning as early as the late 3rd century (Geary, 1988). Due to a lack of complete sources, much about the bagaudae remains a mystery, but they were a strong enough force to threaten Roman local control in Gaul and required extensive military attention during the 4th to the 6th centuries (Drinkwater, 1992; Geary, 1988). Originally it was thought that the Bagaudic revolts were the result of crushing tax obligations, forcing provincial peasants and lesser aristocrats into action against the Empire (Geary, 1988; Wood, 1997). However, this scenario is unlikely in the northern regions of Gaul, where the Bagaudae were the most active, but also where Roman authority and ability to enforce taxation were the weakest (Halsall, 2007; Van Dam, 1985). It would seem possible that the Bagaudae were in fact local individuals and aristocrats who illegally took control of regions where Roman power had receded (Van Dam, 1985). Supporting this interpretation, Bagaudae revolts appear throughout the 5th century in Gaul, springing up in rapid succession from 435 until 454, years when Roman control was seriously retreating to the South (Geary, 1988; Heather, 2001). Van Dam (1985) has argued that the Bagaudae did not revolt against traditional Roman political roles, but instead represent dissatisfaction with Rome's inability to keep existing pathways functioning. He suggests that the Bagaudae were not fighting to escape the oppression of Roman bureaucracy and taxation, but to remain connected to and under Rome's protection (Van Dam, 1985). That these revolts required Roman military meant that the army's attentions and resources were divided, limiting its ability to adequately address other threats to security.

Barbarian migrations, invasions and settlements were catalysts for military presence and change in Gaul during Late Antiquity. Repeated invasions by multiple nebulous barbarian groups in the 4th and 5th centuries required an increase in fortification and security, especially in northern Gaul. As security needs increased, the region became increasingly dependent upon soldiers, heightening not only their value, but their prestige within communities (Halsall, 2007; Marcone, 1997). Heightened military activity and presence in Gaul from the 4th to the 7th centuries increased the population's exposure to violent interactions, but also their reliance on military interventions (Sarti, 2013). This trend took on new gravity when masses of Vandals, Alans and Suevi crossed the Rhine in 406/7 and the imperial government was unable to provide sufficient troops or supplies to defend Gaul (Whitby, 2000). This raid was apparently so destructive that the emperor Honorius disregarded previous laws, which forbade citizens from owning weapons and encouraged local leaders and people to defend themselves (Whitby, 2000). Additionally, the Roman army itself was becoming increasingly composed of barbarian peoples and groups (Lee, 1997). Treaties with

neighbouring non-Roman populations (*foederati*) were often and regularly arranged to bolster the number of 'Roman' soldiers and ensure protection of the *limes* (Geary, 1988). This system of incorporating barbarian peoples into the Roman army was well entrenched in the Roman defence system by the 4th century, especially at the frontiers (Wood, 1997). However, during the 4th century the strategy and positioning of these *foederati* changed, as many barbarian forces were moved from the frontiers to major cities, increasing barbarian contact with Roman citizens (Geary, 1988). As treated barbarian groups increasingly made up the bulk of military forces at sensitive borders, it became clear that both their support and defensive capabilities would be necessary to retain stability (Heather, 2001; Lee, 1997). This encouraged and even forced people to look locally, rather than towards the central government for recourse, strengthening the interdependence of Roman citizens and *foederati* and transferring power on a practical level, from emperors to local leaders, who were now often barbarian military generals (Whitby, 2000).

2.5 Barbarian Interactions in Gaul

Interactions between Gallo-Romans and non-Romans changed substantially over the course of Late Antiquity, as the roles of 'barbarian' peoples evolved. Beginning as loosely banded groups living at or beyond Roman frontiers, barbarians became an integrated and important strategic element of the Roman military and ultimately, the leaders of separate kingdoms existing within and toppling Roman authority in Gaul. Although the role of barbarian invasions may have been overstated in the past (Gibbon, 1898), there is evidence that significantly more non-Roman groups were entering the Roman Empire beginning in the 4th century with a larger impact than before (Périn and Kazanski, 2011). However, their numbers were most likely quite small (80,000-100,000) compared to the millions of Roman citizens and landed individuals already established on Roman soil (Périn and Kazanski, 2011). It is thusly important to distinguish between barbarian groups who had treated relationships or settlements with the Roman Empire, those who entered slowly over decades and those who entered suddenly and *en masse* (Périn and Kazanski, 2011). The response of the populace to the shifting position of the barbarian in society bears an important witness to the transition from the Roman Empire to Medieval Kingdoms, providing insight into key junctures of change.⁵ Although sources are almost exclusively Roman, some distinctions in these relationships can be made and are used to present some of the more important events and trends

⁵ Although an analysis of how non-Roman peoples considered their new roles within Roman civilisation would be an important addition, the lack of non-Roman sources limits this discussion to the 'Roman' perspectives

that took place in Gaul from the 4th to the 7th centuries. Broadly speaking, it is possible to discuss barbarian movements and several key non-Roman groups in Gaul, the Visigoths, the Burgundians and the Franks.

2.5.1 Barbarian Movements

Barbarian invasions, migrations and settlements during the 4th to the 7th centuries had a large impact on Gaul. Although barbarians attacking and invading Gaul during times of weakness or distraction would become a theme throughout Late Antiquity, the situation was rarely simple. Groups and subgroups could form and dissipate, support and fight under Roman leaders to then quickly change factions, support a usurper or raid Roman cities (Wood, 1997). True invasions may not have been as common as once suspected, but they did occasionally occur and sometimes to tremendous impact. The Alamanni in 365/6 and the Franks in 389 attacked Gaul during another series of civil wars over succession, ultimately establishing new treaties with the emperor Valentinian and affecting the succession. Invasion of Roman lands was a tactic employed to apply pressure to the Roman government to obtain better treaties and access to new land (Goffart, 1980). During this period, barbarians seem to maintain their stereotypical role of invaders and destroyers as the emperor Julian writes in a letter in 356/7:

the barbarians then controlled on our side of the Rhine the whole country that extends from its sources to the ocean. Moreover those who were settled nearest us were as much as three-hundred stades from the banks of the Rhine, and a district three-times as wide as that had been left a desert by their raids; so that the Gauls could not even pasture their cattle there. Then too there were certain cities deserted by their inhabitants, near which barbarians were not yet encamped. This then was the condition of Gaul when I took it over (Julian, Letter to the Athenians, cited in Murray, 2008, p. 13).

Although Roman authority did not prevent this incursion, Julian impresses upon his reader that he is able to regain control, illustrating that the barbarians were problematic and even threatening, but tractable and ultimately still under the dominion of Rome.

Perhaps the most important invasion was in 406/7 when the Vandals, Alans and Suevi suddenly crossed the Rhine and attacked Gaul, causing panic in an already disquieted state over Constantine III's usurpation (Wood, 1997). Orientius wrote of the event 'All Gaul burned as a single funeral pyre.' (cited in Halsall, 2007). Confidence in Roman authority and ability to provide security was

severely shaken, as Rome could not defend Gaul against this incursion. From 411 to 413, Frankish, Alamanni and Burgundian peoples all rallied to support the Gallic usurper Jovinus against Honorius, causing a significant rupture between Gaul and the rest of the Roman world (Heather, 2001). As the political situation in Gaul continued to weaken, different barbarian groups and subgroups gained more ground with their attacks and could demand more from Rome in return for their peace or military services. After repeated raids in the South of Gaul, in 418, the province of Aquitaine was given to the Goths (Visigoths) in exchange for their help in defeating the Vandals, thus establishing a barbarian kingdom in Roman territory. In the 420s Franks, Alamanni and Burgundians continued to exploit military fragility in Gaul (Heather, 2001). Between 436 to 439, Aëtius, the commander of Gaul under Honorius defeated various barbarian groups entering and raiding Gaul, including the Franks and Burgundians, and expelled the Visigoths from Narbonne (Heather, 2001). In 450-451, the threat from the Huns was greatest and Aëtius was able to combine troops from the Burgundians and Visigoths to defeat Attila and the Huns at the battle of Catalaunian Plains (Collins, 2001; Heather, 1998). After these events, new treaties with these groups had to be formed (Heather, 1998).

2.5.2 Barbarian Groups

2.5.2.1 The Visigoths

The Visigoths, a subgroup of the Goths, had particular significance in Gaul. The Visigoths initially entered Gaul legally and slowly crossed the country over the course of 40 years, becoming ingrained in Roman defence systems (Périn and Kazanski, 2011). In 413, the Visigoths broke their treaty with Honorius and attacked cities in Southern Gaul, capturing Narbonne, Toulouse and Bordeaux. However, their assistance in defeating the Vandals who had taken control of valuable African provinces was rewarded between 416 and 418, when the Visigothic army was settled in the province of Aquitaine (Goffart, 1980; Heather, 2002). Although the basis and specifics of their settlement are unclear (there is argument whether this settlement was based on distributions of physical land or tax based), general information about how the Visigoths became integrated in Gaul is understood if not entirely agreed upon by scholars (Drinkwater and Elton, 2002; Todd, 1997; Wood, 1997). Local land-owning Gallo-Romans would have been forced to interact with the Visigoths or leave Aquitania (Heather, 2001).

The Visigoths remained an integral part of Roman defence systems, helping to defeat the Vandals again in 422 and 446, although this relationship was not always straightforward (Noble, 2008). On numerous occasions the Visigoths took advantage of the continuing weakened state of Rome. They attacked the Gallo-Roman capital of Arles in 425 and 430 to pressure the improvement of the terms of their treaty (Heather, 2002). They attacked Arles again between 436 and 439, and Narbonne in 436/7, where they were defeated by Aëtius and retreated back to Toulouse (Heather, 2001, 1998). Roman difficulties with the Franks, Burgundians and Huns improved the standing of the Visigoths, as the Roman military was otherwise occupied (Noble, 2008). After the Visigoths helped to defeat the Huns in 451, they gained even more influence in the west of Gaul (Noble, 2008). Gallo-Romans and Visigoths found a way to function together, where Gallo-Romans even participated in Visigothic government (Noble, 2008). By 458, Majorian led an army expelling the Goths from Arles, but they were granted Narbonne and its tax revenues in 461 in return for their support of the emperor Libius Severus (Collins, 2001; Heather, 2002). In 466, Euric became king of the Visigoths and initiated a major expansion of the Visigothic kingdom, gaining the majority of Southern Gaul from the Rhone to the Loire Rivers, including Narbonne, the Auvergne and Provence between 471 and 476 (Collins, 2001) (Fig. 2.5). From this point, Rome had no authority practically or officially in Gaul, leaving the barbarian successor kingdoms to fight amongst themselves for dominance. The Visigoths were eventually defeated by the Franks at the battle of Vouillé in 507, where they were pushed out of Gaul into their territories in Spain (Noble, 2008).

2.5.2.2 The Burgundians

The Burgundians were another barbarian group, which came to find settlement within Roman Gaul in the 5th century (Wood, 1997). There is relatively little information available about the Burgundians, but their role remains an important, if not altogether clear one. After the barbarian invasion of 406/7, the Burgundians established a kingdom in the frontier region of Mainz and supported the usurper Jovinus in 411—413 (Collins, 2001). The Gallic general Aëtius made a career of playing the barbarian groups against one another to achieve his aims and throughout the 430s, Aëtius controlled Burgundian expansion through the Huns (Collins, 2001). However, this tactic was reversed when the Burgundians were enlisted to help the Romans defend their territories in Gaul against the Alamanni in 369 and the Huns in the mid-430s (Heather, 2001; Wood, 1997). As a result of the conflict with the Huns, the Burgundians were forced to flee from their territory into Gaul. In response, Aëtius settled the Burgundians in Savoy in 442/3 (Collins, 2001; Wood, 2014). Like the Visigoths, the Burgundians provided military aid to the Romans and often they worked in tandem,

but as Roman control was shrinking, the Burgundians made plays to improve their treaties and expand their territories (Wilkinson, 2015). Gaining territories for their military support in 456 and 469, the Burgundian kingdom and power was expanding along the eastern border (Collins, 2001). The Burgundians joined the Franks to attack the Visigoths in 507 at the battle of Vouillé but were eventually conquered by Franks themselves in 533/4 (Collins, 2001). Importantly, some have suggested that the Burgundians had a particularly 'cooperative' relationship with Gallo-Roman elites and officials in comparison with other barbarian groups (Wilkinson, 2015; Wood, 2014). They often gained their territory through collaboration and co-defense, causing comparatively little violence and disruption, while maintaining many aspects of Roman culture and lifeways (Wilkinson, 2015; Wood, 2014).

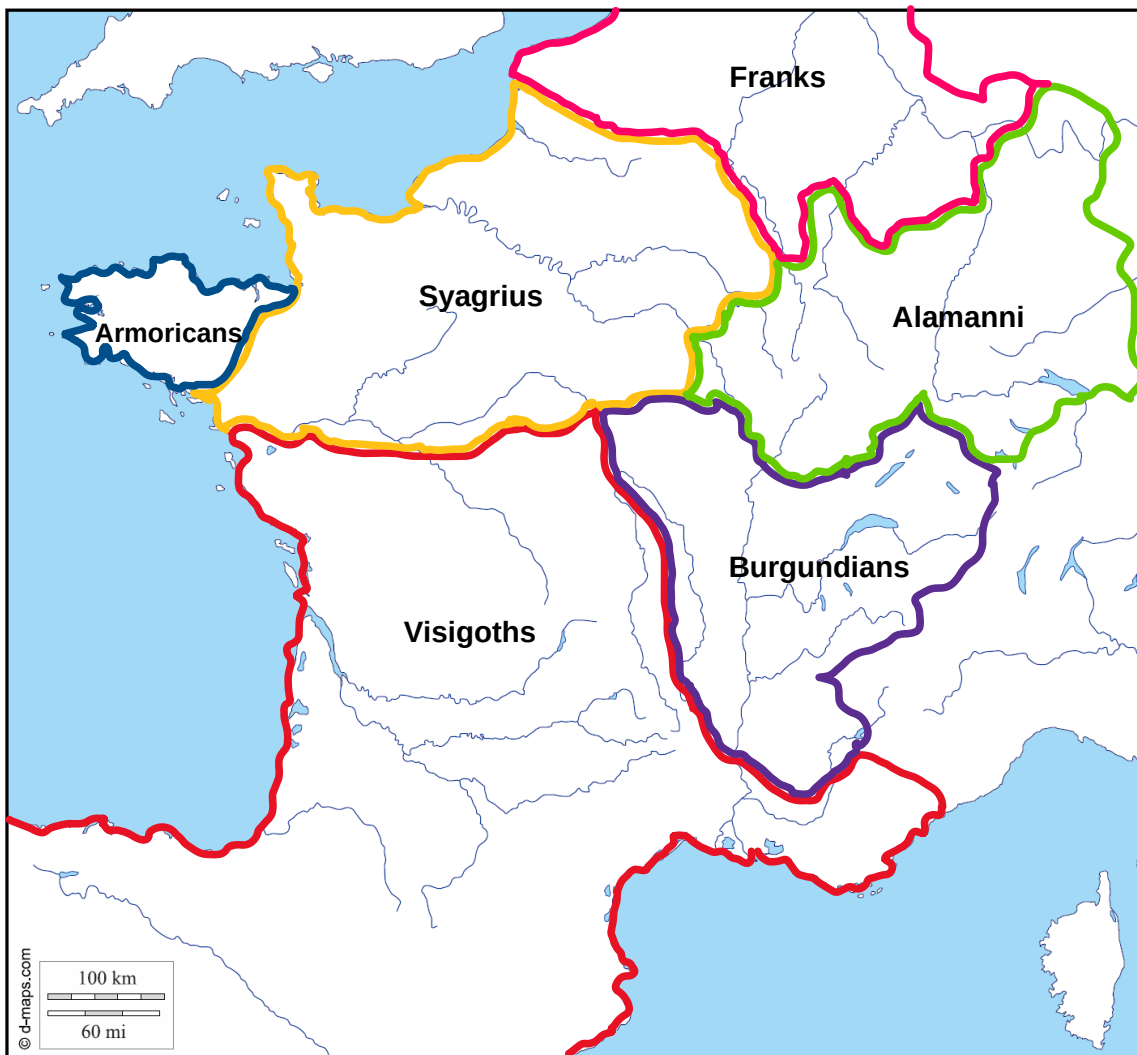


Fig. 2.5 Map of barbarian kingdoms in Gaul around 481 (modelled from Vidal de la Blache, 1894)

2.5.2.3 The Franks

The Franks ultimately became the most successful of all the barbarian groups in controlling power in Gaul, but their ascendancy was slow (Wood, 2014). The Franks were known to the Romans as early as the mid-3rd century and securely established themselves along the north-east border of Gaul in the early 350s (Collins, 2001). In several separate raids across the 5th century, the Franks sacked Trier (in 413, 428, 430, 440) (Todd, 1997). In the 450s the Merovingian dynasty came into power with Merovech, however his descendant Clovis would become the most important Merovingian leader (Noble, 2008). Clovis would come to defeat the last of the Roman rulers in the North of Gaul (Syagrius) at the Battle of Soissons in 486 and married the Burgundian Chlothild, merging their groups (Noble, 2006). In 507, Clovis campaigned against the Goths pushing them out of Gaul entirely and annexing their territories (Wood, 1994) (Fig. 2.6). In 523, The Franks invaded the Burgundian kingdom, defeating them and annexing their territories by 534. By the beginning of the 6th century, the Franks ruled most of Gaul, with a few critical changes. The capital of Gaul had been relocated to the North (Paris) and the international financial and political networks of the Roman Empire had been dramatically reduced, although the Franks maintained ties with the Eastern Empire which was still in existence (Noble, 2008). This transition shifted the cultural and political focus of Gaul from the south to the north (Halsall, 2007). Succession of the Merovingians was not smooth or stable (Noble, 2008). Clovis's sons and grandsons fought bitterly for power, in some ways echoing the struggles of previous centuries (Noble, 2008). When Chlothar I inherited the throne of his brothers' kingdoms in 548 and 558 respectively, he became the first Merovingian ruler to preside over all of Gaul (Halsall, 2007). In 613, Chlothar II gained control of the Frankish kingdoms, then divided into Neustria, Austrasia and Burgundy (Noble, 2008). In this system all sons inherited parts of the land and kingdom, resulting in constantly shifting borders and struggles between siblings and heirs, which even came to define political life in Gaul during the 6th century (Collins, 2001; Yoon, 2016). Frankish rule of Gaul (and beyond) lasted from the 460s until 751 (Yoon, 2016).

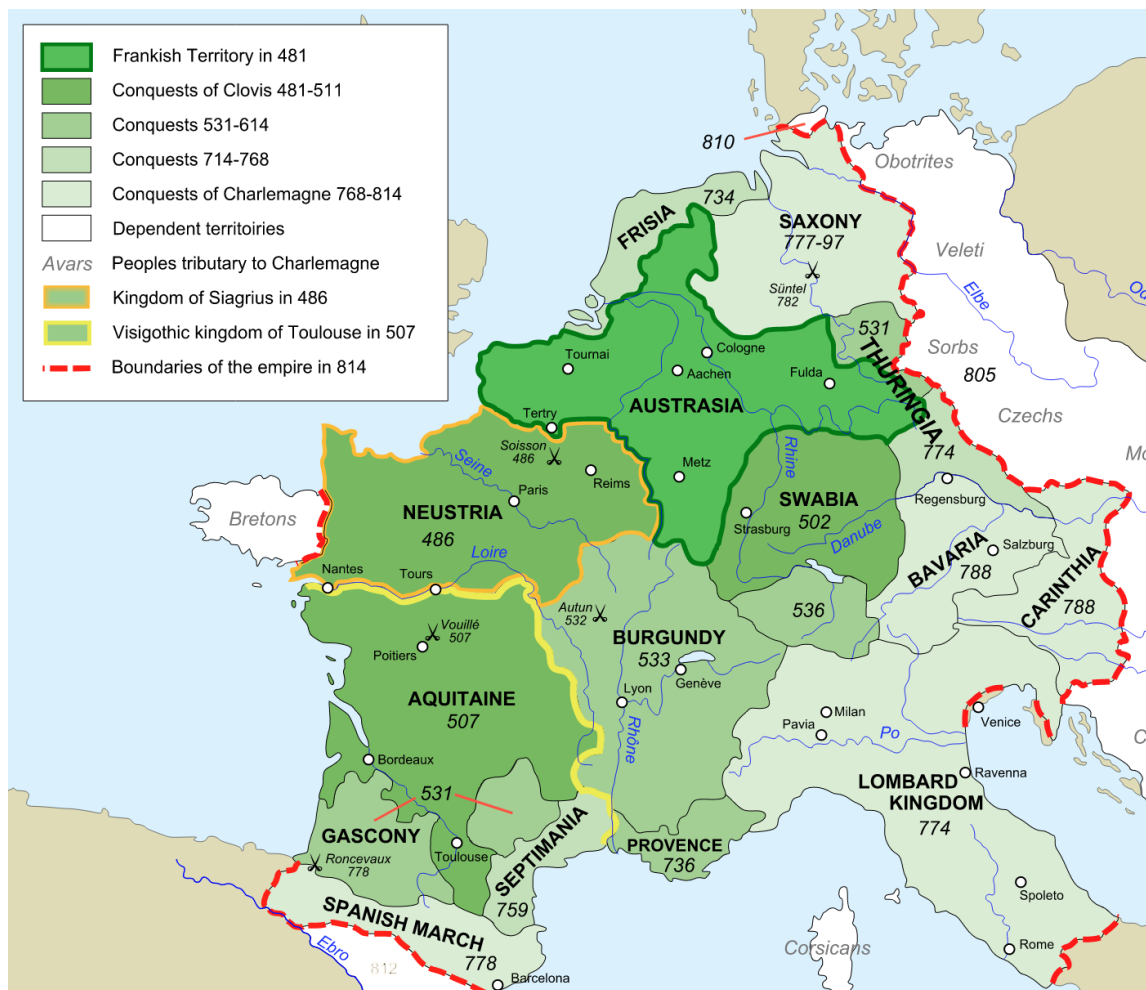


Fig. 2.6 Map displaying the development of the Frankish Empire from 481 to 814 (Shepherd, 1911)

2.5.3 Roman response to barbarians

In the early 5th century, in response to large numbers of barbarian peoples crossing the Rhine frontier, poems and letters describe a drastic shift in Gaul from a stable and peaceful region to one defined by suffering, violence and chaos (Cameron, 1998; Sarti, 2013). Some writers interpreted these events as so significant that it demanded a re-conception of the world order (Sarti, 2013; Wood, 1992). The rising prevalence of Christianity provided an outlet and method to do precisely this, where power could be shifted away from attackers to the attacked, by suggesting that these raids were the god-sponsored punishment for the sins of Gallo-Roman cities and citizens. Salvian writing in the 440s, posits that misfortune and destruction occurred in Gaul because it was God's punishment for Roman wrongdoing.

“Why does he allow us to be conquered by the barbarians? Why does he allow us to be subject to the law of the enemy? ...He allows us to bear these evils because we deserve to suffer them” (Salvian, On the Governance of God, Book IV, cited in Murray, 2008 p. 115).

Changes in material culture (construction of city walls and new defences) during this time period also suggest that the almost constant stream of war during the 5th century impacted the daily lives of people living in Gaul (Sarti, 2013). As Roman protection dwindled throughout the 5th century, civilians were forced to deal with violence themselves or seek aid from more local sources of authority, including wealthy individuals of Roman or non-Roman status (Sarti, 2013). Military structures changed with the transition from Roman to Merovingian leadership, where Roman armies had been largely professional and paid by the state, Merovingian armies were not (Liebeschuetz, 2001). Soldiers were instead dependent upon war booty, sometimes as their only pay, making devastation and destruction of local property and resources more strategic and increasing collateral damage to local populations (Sarti, 2013). In this way, soldiers, whether friend or foe, became dangerous for local populations. Sidonius Apollinaris, a Gallo-Roman aristocrat from southern Gaul, commented:

“We are located between rival forces, a pitiful prey to them, held in suspicion by the Burgundians and near neighbours of the Goths; we are spared neither the fury of our attackers nor the envy of our defenders” (Sidonius Apollinaris, a letter to Magnus Felix, cited in Murray, 2008, p. 234).

Despite the grim image of Late Antique Gaul described by some, others appear to have been less affected by barbarian incursions or changes in their roles. Writing from Marseille, the furthestmost southern and Mediterranean area in Gaul in the 5th century, Prosper of Aquitaine believed neither Gaul nor the Roman Empire was much affected by the barbarian incursions over the Rhine or internal strife (Muhlberger, 1992). Ausonius of Bordeaux portrays Gaul as a thriving area, with extensive trade and a cosmopolitan atmosphere in the 5th century, and much archaeological data supports this assertion (Sarti, 2013). From these and other similar accounts, it would appear that northern Gaul's problems were not mirrored for those living in the south (Muhlberger, 1992). However, for an anonymous Chronicler in Marseille writing in 452, the barbarian incursions were some of the most important events in living memory, which had significant consequences for people in both northern and southern Gaul (Muhlberger, 1992). Other authors too noted a reduction in Roman authority, including Hydatius who almost completely associated Gaul with the

Goths after 456 (Burgess, 1992). Sidonius Apollinaris saw the end of Roman authority in Gaul and fall of the Roman Empire in the west at 476 (Harries, 1994).

This transformation of Roman and non-Roman positions within society indicates a changing sense of the conception of 'self' in dialogue with the 'other'. How and when this boundary fluctuates demonstrates a profound shift in culture, society and even identity. Sidonius Apollinaris (430c-489) and Gregory of Tours (538-594), the most important authors of the 5th and 6th centuries respectively, both came from prominent Gallo-Roman aristocratic families. Both authors, despite their chronological separation, share a desire to portray themselves in a 'Roman' style, even though they both lived in barbarian kingdoms (Wood, 1994; Yoon, 2016). In the face of other writings from the first half of the 5th century, which express a response to calamitous change and social and religious upheaval, Sidonius Apollinaris stresses continuity with 'the imperial past' (note past, not present) (Wood, 1994). Gregory too expresses continuity of identity with the Roman past and a sharp division between social groups in the *History of the Franks* (Wood, 1994). His introduction to the work is as follows:

The cultivation of liberal letters is declining or rather dying in the cities of Gaul, since some things that are good and some that are wicked are taking place, and the savagery of the barbarians is on the loose; the anger of the kings is sharp; the churches are under threat from the heretics, and are protected by the Catholics.... (Gregory of Tours, History of the Franks, cited in Murray, 2008, p. 289).

Perhaps Gregory stresses difference and opposition (barbarians vs. Romans, Catholics vs. heretics) because of the blending and blurring of contradictions in his own life, of inhabiting an amalgamated world. He identifies as Gallo-Roman but lives in a barbarian kingdom and serves barbarian kings, many of whom adopted Roman symbols of power and authority themselves (see burial of Childeric). The 5th century ushered in a golden age of elite writing in Southern Gaul, especially in the form of artful letters (Cameron, 1998; Drinkwater and Elton, 2002). Several scholars have suggested that these hyper-stylized writings were in fact a reaction to or even a compensation for the changing circumstances of the elites in Southern Gaul (Harries, 1994; Jones, 2009). If no longer able to act as strong political forces, elite individuals could demonstrate their 'Roman-ness' by exaggerating elements of traditional Roman culture (Halsall, 2007). Although this form of response to loss of control and access to power may not be entirely accessible to modern readers, writing letters and poetry became an important way for elite Gallo-Romans to maintain and re-assert their identity as Romans of the elite classes in the 'barbarian era' (Jones, 2009). With the increasing

importance and status of barbarians within the Roman world, 'Roman-ness' was being lost, but so was 'barbar-ism'. By the end of Late Antiquity, Gauls were not Roman anymore, but they weren't barbarians either. By 550, new identities were being spawned, such as Goths, Franks and Saxons and by the seventh century, these new identities were fully formed (Halsall, 2007).

2.6 Economy and Trade

The economic history of Gaul is an important contributing factor to the transitions which took place during Late Antiquity. Gaul was, from its very beginnings, a region primarily based on agriculture (Geary, 1988). Cereals were the most prolific and important produce, followed by viticulture after it had been introduced by the Romans (Geary, 1988). This meant that although Gaul was important for its produce, a great deal of its value came from the tax revenues based on the land and its production (Whittaker and Garnsey, 1997). These tax revenues were crucial for the continued functioning of systems within and around the Western Roman Empire, but as territories in Gaul were threatened, ceded to, or settled by barbarian kingdoms, the Empire lost its abilities to collect the tax revenue from these regions (Heather, 2001). As taxes largely went to pay for military defence, a problematic cycle was introduced (Whittaker and Garnsey, 1997). By 410, the Roman Empire had lost taxes from Britain and Spain (Heather, 2001). Between 410 and 430, most of Gaul would also not have been able to produce the necessary tax funds (Heather, 2001). Due to the extensive loss of tax revenues, in the 440s the Roman state could no longer fund their military needs. As a result, new taxes were introduced, tax corruption was attacked and bureaucratic tax exemptions were eliminated, risking the alienation of aristocratic classes, who were so important to maintaining control (Heather, 2001). Those regions still under Roman authority then suffered under the increasing burden, where it has been estimated that in 440 western tax rates were twice as high as those in the east even a century later (Cooper, 2007). Although the impact of the tax burden is debated, some have argued that faced with the inability to meet new tax requirements, an estimated 20% of arable land was abandoned by peasants and landlords alike (Geary, 1988). The populace began to find that it was more beneficial to ally themselves with nearby barbarian kingdoms, which continued to erode Roman power in the provinces and encouraged more localised political and economic exchange (Cooper, 2007).

2.6.1 Trade and Industry Networks

Northern and southern Gaul are understood to have formed a minimum of two separate and distinct economic areas, stemming from the geographical, political and cultural differences between the regions (Cartron et al., 2015). The production and trade of pottery and ceramics in Late Antique Gaul depict some of these economic differences resulting from political and cultural transformation. In northern Gaul, ceramic and pottery production underwent a recession in the 5th century, as reflected by a reduction in the quality and variety of form and decoration (Ward-Perkins, 1996; Wickham, 2005). Although not as extreme as in Britain (Wickham, 2005), the decline in technique sophistication has been interpreted by some as a representation of a tangible reduction in quality of life (Ward-Perkins, 1996). Argonne ware, an orange or grey fine sigillata, and Mayen courseware were common in northern Gaul around 400, but their range of trade contracted substantially in the 5th century (from a 400km radius to 200km), likely as a result of political upheaval (Whittaker and Garnsey, 1997; Wickham, 2005). Not all pottery production stopped, as local wares were produced across northern Gaul (Wickham, 2005). One example, biconical vessels in a black fine ware with roulette decoration, became a popular grave good in the furnished burials in Gaul around 500 (Wickham, 2005).

Southern Gaul remained closely entwined with the Mediterranean economic system, continuing trade with Greece, Turkey, Egypt, Palestine and other regions (Drinkwater and Elton, 2002; Yoon, 2016). Evidence from shipwrecks in the 4th and 5th centuries reveal perhaps an even greater expansion of long-distance trade in southern Gaul than was possible in the 3rd or 7th centuries (Hitchner, 1992). Excavations of 6th century sites from southern Gaul have revealed amphorae containing olive oil, wine, fish sauce and various types and styles of pottery imported from other Mediterranean lands (Bonifay et al., 1998; Démians d'Archimbaud, 1994). African red slipware, oils and cooking ware were still being traded into the Languedoc and Provence areas until the 6th and 7th centuries (Sivan, 1992; Wickham, 2005). Marseille, a large and important port city in Gaul, appears to have been the main port of entry for imports and maintained trade networks until well into the 7th century (Wickham, 2005). It remains unclear how far this trade extended into other regions of southern Gaul, where evidence would suggest that imports declined rapidly after 550 and most sites only reveal evidence of local ceramics (Bonifay et al., 1998; Démians d'Archimbaud, 1994; Yoon, 2016). Where trade stopped or was considerably reduced, local products appear to have emerged, although the quality of these items was markedly inferior (Wickham, 2005). *Dérivées des sigillés paléochrétiennes*, a type of grey slip ware largely coming from Provence and Narbonne was widely distributed in the mid-5th to early 6th centuries, eventually overshadowing

the presence of African Red Slipware in Marseille (Wickham, 2005). The changes and reductions in the manufacture and trade of ceramic goods are a strong signal of contraction from the extensive trade routes of the Roman Empire to a world much more dependent upon local goods and craftsmen.

Industry, trade and communication networks contracted during Late Antiquity to create more insular and localised worlds (on a general level) (Ando, 2008). Within Gaul, communication systems deteriorated dramatically between 395 and 500 (Wilkinson, 2015). The regular communication between Gallo-Roman and Roman elites, which had been common at the beginning of the 5th century, was lost sometime after 420 (Mathisen, 1992). This reduced not only their sphere of political influence, but also opportunities to hold offices connected to the rest of the Empire, which was moving decidedly eastwards. Beginning in the late 5th century, Roman imperial coins were no longer being issued in Gaul and multiple more localised nobilities were minting their own coins (Sarti, 2013). By the 6th century, coins produced by Merovingian and Visigothic kings, no longer referred to the emperors in Constantinople, clearly indicating a changed political arena (Yoon, 2016). However, mints in Provence retained reference to the Byzantine emperors by keeping their names on the coins throughout the late 6th and into the early 7th centuries, until coins from Northeast Gaul slowly overwhelmed them (Uhalde, 2001; Yoon, 2016). A pattern of decline in quantity and quality in various industries including metalworking, tile-making and stone quarrying has been interpreted as a fragmentation and reduction of the northern Gallic economy, similar to that of Britain (Halsall, 2007). The deterioration of these industries would have made it challenging to maintain previous Roman modes and ways of living, such as constructing stone buildings, the art of mosaics and fine imported pottery (Halsall, 2007). However, systems of trade continued to function with some degree of complexity, even if these did not match those of previous centuries (Härke, 2001; Wickham, 2005). Although southern Gaul remained more directly connected with traditional Gallo-Roman pathways, through evidence of fine sculptures and mosaics (Noble, 2006), it has been argued that by 700, the entirety of Gaul (as well as the rest of the Mediterranean) displayed markedly decreased wealth, social complexity and distant communication networks (Ando, 2008; Wilkinson, 2015).

2.7 Settlement Patterns

Along with shifts in borders and political control of land, types of settlement structures changed over the course of Late Antiquity. This is reflected in both urban living structures, as well as rural settlements, including *villae*.

2.7.1 Urban Structures

Gallo-Roman cities (and all Roman cities) connected the Roman Empire through communicative, administrative, military and social functioning. In many ways, how urban areas developed and adapted throughout Late Antiquity is particularly informative about transitions in society (Noble, 2006). As the empire became increasingly bureaucratized in the 4th century, lists of Roman provinces and cities were drafted, providing detailed information about the number and location of urban centres (Harries, 1978). The *Notitia Galliarum*, lists the seventeen Gallic provinces, including 115 major cities and lesser *civitates* divided into two dioceses (Galliae and Quinque Provinciae) in existence in the late 4th- early 5th century (Fig. 2.7) (Harries, 1978). During the height of the Roman Empire, Gallo-Roman cities had relatively uniform administrative hierarchies and settlement structures, with most containing a forum, baths, circus, amphitheatre, temples and aqueducts, drainage systems and paved roads in larger cities (Esmonde Cleary, 2013a). However, throughout Late Antiquity, this structure and regularity was replaced with increasing regional variability and new defensive systems, indicating the shifting needs of the community.



Fig. 2.7 Map of Metropolitan cities, Civitates and Castra (Kenworthy, J. in Harries, 1978).

From the mid-3rd to the 6th centuries, many urban areas contracted in size and surrounding defensive walls were constructed in response to outside invasions and military instability (Esmonde Cleary, 2013a). Traditional methods of Roman construction and planning were abandoned, and Roman buildings were re-used for the construction of new structures (Harrison, 2008). City layouts were re-oriented away from the emphasis on geometric street patterns focused on the forum to what would become a more medieval structure with cathedrals at the centre (Harrison, 2008). In Arles and Tours, Gallo-Roman amphitheatres were transitioned into and used as fortresses (Clout, 2013). Defensive walls were constructed out of debris from destroyed buildings, monuments, temples and possibly even gravestones, in what some have interpreted as a hurried attempt at defence and protection (Clout, 2013; Sarti, 2013). However, there is also evidence that the walls were built with thorough and carefully constructed design, meaning they could not have been put together quickly in desperation, but instead reflect a more considered approach to defence (Halsall, 2007). The presence of walled cities had been uncommon in the Roman period, but in Late Antiquity they were so ubiquitous in Gaul that they developed into a defining element of Late

Antique urban areas until after the 6th century (Sarti, 2013). The style of fortification was also new, where strongholds were built on hilltops, providing viewpoints with an extensive range, as opposed to those of previous centuries, which had largely been oriented toward a single side (Sarti, 2013). Although cities and towns constantly evolve as a result of the dynamic expression of the people living within them, the observed changes in urban structures and functions between 300 and 700 were more than mere shifts within regular development, and instead reflect a tangible shift in culture (Christie and Loseby, 1996, p. 1; Ward-Perkins, 1996, p. 4).

Divisions between northern and southern Gaul were pronounced with respect to changes in urban settlement structures (Esmonde Cleary, 2013b; Ward-Perkins, 1997). In the north, closer to frontier lands and farther away from the influence of Roman traditions and authority, there is more evidence of defensive walls and substantial reduction or abandonment of urban areas (Esmonde Cleary, 2013b; Wickham, 2005). In northern Gaul *civitates* degraded, as many urban areas lost their importance as market and manufacture centres or were abandoned entirely due to local violence or declines in the population (see emperor Julian quote above; Halsall, 2007). Other cities, such as Paris and Cologne, continued to function with changes in orientation or on more limited scales (Wickham, 2005; Yoon, 2016). Tours, only 9 hectares in its walled Late Roman form, has revealed very little archaeological evidence of occupation outside its walls during the 4th/5th centuries. Only 'simple' hand-made ceramics have been found within city walls, despite extensive excavations. This may suggest that the city ceased to function as an urban centre in the 3rd century (Galinié, 1997; Wickham, 2005). Paris, by contrast, reoriented its centre from the Roman left bank to l'Île de la Cité, where there is evidence of continued urban functioning through construction projects and the extensive presence of pottery (Wickham, 2005). Wickham (2005) argues that the period between 450 and 600 should 'probably be seen as a general nadir for urbanism' in northern Gaul, with little signs of recovery until the 7th and 8th centuries (p 677). However, there are exceptions to this characterization. Trier, located along the northern Rhine border, was an imperial residence and the seat of the Gallic Prefecture in the 4th century and its prominence kept it connected to Roman power, authority and resources (Ward-Perkins, 1997). Throughout southern Gaul, and Aquitaine in particular, cities remained centres for cultural and economic activity and tended to survive better than in the north (Esmonde Cleary, 2013b; Ward-Perkins, 1997; Yoon, 2016). Several towns, namely Arles, Marseille and Bordeaux provide evidence of a flourishing political and cultural state during the 5th century (Bachrach, 2010; Drinkwater and Elton, 2002; Heijmans and Sintès, 1994; Loseby, 1998; Sivan, 1992). Urban church building programs are seen in Provence, Lyon and Geneva (Rouche, 1979). Written sources in the 4th and 5th centuries further suggest that Gallic cities

were highly regarded, as their citizens were sought as teachers or politicians in Rome and Constantinople (Harries, 1978). Despite their importance to Late Roman social and political structures and continuity, it is important to bear in mind that cities contained only about 10-15% of the population, meaning that the majority of people would have experienced a life outside of urban centres (Cheyette, 2008; Garnsey and Whittaker, 1998).

2.7.2 Villas

A villa, a country estate or farm (Fig. 2.8), was a critical rural element of the Roman settlement system, as it provided a type of social and administrative connectivity, agricultural resources and tax revenue to the Empire. Although the size and style of *villae* could vary greatly, these rural estates could employ hundreds of individuals and provided a type of local Roman centralisation despite the often large distances between them (Wickham, 2005). Gallo-Roman *villae* were widely distributed across Gaul, with high concentrations around Lyon, throughout modern Burgundy up to the Seine, in Aquitaine and south-eastern areas of Gaul (Clout, 2013). Even at the height of Roman power, southern *villae* were larger and wealthier than those in the north, which were small to middling in size (Halsall, 2006; Peytremann, 2003). Excavations have presented evidence of large scale abandonment of many *villae* (between one quarter and one half) in northern Gaul over the course of the 3rd century and early 4th century, with no evidence of *villae* in the south after the 7th century (Cheyette, 2008; Halsall, 2006; Wickham, 2005). The pattern of decline in the villa system follows a geographical divide, where regions of Gaul north of the Loire changed earlier, more quickly and more drastically than regions in Mediterranean Gaul (Cheyette, 2008; Halsall, 2006; Van Ossel, 2006; Van Ossel and Ouzoulis, 2000; Whittaker and Garnsey, 1997). The presence of villas in the north decreased continuously after 350 and almost none were constructed of stone or brick after 450 (Wickham, 2005). In southern Gaul and the area surrounding Trier, the villa system appears to have been more successfully maintained and perhaps even prospered, likely as a result of its status as an imperial capital (Halsall, 2006). In and around Bordeaux and Toulouse, people continued to inhabit and invest in *villae*, even furnishing them with sophisticated mosaics (Halsall, 2007; Harrison, 2008). The seemingly large-scale abandonment of the villa system did not impact Mediterranean Gaul until the 6th and 7th centuries, when few *villae* are found afterwards (Wickham, 2005). It is hypothesized that retention of the villa system went hand in hand with the power of the Gallo-Roman aristocracy, which maintained Roman lifeways and traditions insofar as was possible (Wickham, 2005). The slower pace of change and abandonment of the villa system in

southern Gaul suggests that the cultural change there was also slower and more temperate than in the north (Wickham, 2005).

What happened to abandoned *villae* is unclear, as there is some evidence of a reduced form of occupation in the 4th century, and agricultural production may or may not have completely stopped (Theuvs, 2009; Van Ossel, 2006; Van Ossel and Ouzoulias, 2000; Whittaker and Garnsey, 1997; Wightman, 1985). Some have suggested that people moved from villae to settlements on hills and mountain tops (Harrison, 2008). It is certainly possible that arable land was abandoned as a result of wars and military action particularly around the frontiers, such as north-eastern Gaul (Whittaker and Garnsey, 1997). If and where different types of settlements replaced abandoned *villae* in the 5th and 6th centuries, they have been challenging to identify archaeologically (Härke, 2007). *Villae* could have been repurposed into churches, monasteries or developed into the centres of village settlements, obscuring some of their visibility to archaeologists (Harrison, 2008; James, 1979). There also appears to have been a switch in building materials, especially in northern Gaul, where wood rather than stone was used for the construction of smaller, simpler structures and sunken-featured huts, known as Grabenhäuser (Halsall, 2007; Härke, 2007; Harrison, 2008). The transition to wood construction, even for large-scale elite projects during the 4th century indicates a significant cultural shift, as this building material had formerly only been used for peasant homes (Wickham, 2005). Härke (2007) has used this shift in building materials to draw parallels between the end of Roman authority in Gaul and the collapse of the Soviet Union in 1991. He argues that in both cases, changes in material culture took place, which might appear invisible to archaeologists due to the very nature of the change and its impact on preference for certain materials, which may be subject to different preservation factors.



Fig. 2.8 Baths of a Gallo-Roman villa at Langrolay-sur-Rance, Brittany 1st century (Paitier, 2016)

2.7.3 Demographic Decline

Multiple sources have suggested a substantial population decline (potentially even a crisis) during Late Antiquity, possibly explaining the abandonment of land and contraction of urban settlements (Ando, 2008; Bachrach, 2007; Jongman, 2007; Kron, 2019). Arable land that had been previously worked for agriculture was converted into pasture and forests began to re-establish themselves (Cheyette, 2008; de Beaulieu et al., 1988; Raynaud et al., 1990). This has been interpreted as an indicator of depopulation, where less people were available to work the land and/or less food was required for subsistence or sale (Cheyette, 2008). Alternatively, reforestation has also been interpreted through a lens of resiliency, where a silvo-pastoral based economy was not evidence of depopulation, but was instead a better strategy for survival under the existing conditions (Harrison, 2008). A series of volcanic eruptions in the 530s and 540s and subsequent clouds of volcanic dust led to a period of cooler and wetter weather throughout the 6th and 7th centuries (Büntgen et al., 2017, 2016; Newfield, 2016). This shift in climate, known as the Late Antique Little Ice Age, likely contributed to changes in land use and agriculture, potentially leading to famine and population decline (Büntgen et al., 2017, 2016, 2011; Harper, 2017; McCormick et al., 2012; Newfield, 2016). Predating extreme weather events, Hydatius wrote about famine sweeping Gaul in 409 and 410:

“Severe hunger spread so that human beings, compelled by hunger, consumed human flesh. Mothers even fed upon the bodies of their own children, whom

they had killed and cooked with their own hands....” (Chronicle of Hydatius, cited in Murray, 2008 p 87).

Although this quote should probably not be taken literally, it does suggest a certain extremity in the perception of events occurring during Late Antiquity. Gregory of Tours also describes a seven-year famine spanning across all of Gaul beginning in 585, with particularly damaging effects in Provence (Riché, 1967). This famine was supposedly so extreme that grain had to be sent from Italy into Gaul (Riché, 1967).

Illness accompanied climatic events and famine, with potentially severe consequences for the population in Gaul during Late Antiquity. Now widely accepted to have been *Yersinia pestis*, the Justinianic Plague, reached Gaul around 541 to 544, with periodic reoccurrences over the course of the following two centuries (Feldman et al., 2016; Harbeck et al., 2013; Keller et al., 2019; Mordechai et al., 2019; Mordechai and Eisenberg, 2019; Wagner et al., 2014). The Justinianic Plague has alternatively been interpreted as a major catastrophe directly linked to mass casualties and even precipitating the ‘decline and fall’ of the Western Roman Empire (Feldman et al., 2016; Harbeck et al., 2013; Harper, 2017; Little, 2007; McCormick, 2015, 2007; Meier, 2020; Russell, 1968; Sallares, 2007; Sarris, 2002) or as an illness with relatively insignificant consequences on long-term demography and socio-political events (Bachrach, 2007; Eisenberg and Mordechai, 2019; Mordechai et al., 2019; Mordechai and Eisenberg, 2019; Russell, 1968). Thought to travel along trade routes and waterways, southern Gaul was particularly affected (Provence and the Rhone valley) (Harrison, 2008; McCormick, 2007). Occurrences in 543 and 588 were commented on by Gregory of Tours (Riché, 1967; Sallares, 2007). Maximalist interpretations suggest mortality rates of between 25 to 60% of the estimated population, or mortality in the tens of millions across the Late Roman Empire (Harper, 2017; McCormick, 2015; Mordechai et al., 2019). Although population numbers and the degree of demographic decline have been estimated, these calculations are problematic and difficult to substantiate (Harrison, 2008). The effects of climate change and potential demographic decline were not necessarily uniform across all regions of the empire (Newfield, 2016; Sessa, 2019). Despite the considerable evidence of plague in southern Gaul, evidence for population decline is most strongly reflected in Britain and northern Gaul (Cheyette, 2008; Eisenberg et al., 2019; Wickham, 2005). The decline in population has been interpreted as another sign that quality of life declined from the 4th to the 7th centuries (Ando, 2008).

2.8 Mortuary Practices

Cemeteries and burial evidence have made up a considerable proportion of the archaeological data in the study of Late Antique Gaul. Changes in mortuary rites and customs have been associated with cultural transitions as funerary rituals generate, legitimize and re-enforce societal values through community-shared symbols and actions, which serve to link the living with the deceased (Effros, 2003). Mortuary practices are particularly advantageous in studying cultural and political change because they act as physical embodiments of social and political power, identity and legacy (Blaizot, 2018; Härke, 2001; Symonds, 2009). As with other forms of evidence, a general geographic divide is observed, where southern regions display greater continuity with Gallo-Roman funerary practices and regions north of the Loire developed different funerary rituals and rites.

2.8.1 Gallo-Roman Mortuary Evidence

Although there is considerable sub-regional variation, burial practices in Gaul during the Late Empire and in southern Gaul during Late Antiquity show several significant similar features. By the end of the 3rd century, inhumation was the primary funerary rite across Gaul, with cemeteries located nearby established settlements or churches (Blaizot, 2018; Dierkens and Périn, 1997; Duchesne, 2015; James, 1977; Pearce, 2008). Individuals were buried directly in the ground, in stone coffins or elaborately carved sarcophagi, the latter of which could be buried or remain above-ground in mausoleums or churches (Dierkens and Périn, 1997; Duchesne, 2015; James, 1977). The placement of grave goods within these burials was quite rare, although coins in the form of Charon's Obol and small ceramic or glass vessels are sometimes found (Theuws, 2009). Sarcophagi and stone coffins were frequently re-used multiple times, as has been seen in Trinquetaille, a cemetery near Arles where some stone sarcophagi were used as many as six separate times (Effros, 2003; Halsall, 1995; James, 1979). As a result, it has been argued that the lack of grave good evidence might instead reflect the effects of re-use or grave robbing on sarcophagi (Duchesne, 2015; Effros, 2003, 2001; James, 1979).

Throughout Late Antiquity, necropoleis south of the Loire tended to retain typical Gallo-Roman features, continuing the use of established burial locations, sarcophagi with very few grave goods and little in the way of burial dress (Halsall, 1995; James, 1977; Todd, 1997). The cemeteries could be quite large and graves seem to be laid out head to foot, side by side or often lack clear organisation (Fig. 2.9) (Halsall, 1995). Bodies were often buried in a supine position with variations

in limb placement (Halsall, 1995; Pearce, 2008). The use of sarcophagi for burial remained particularly common in the southwest of Gaul, with the most elaborately designed sarcophagi found in the most southern regions (Halsall, 1995; Todd, 1997). Although design aesthetics from previous centuries were largely retained, the quality of sarcophagi declined in the 4th and 5th centuries (Effros, 2003; James, 1977). This indicates that although Gallo-Roman rituals were still valued, their practice may have been complicated by other surrounding factors. Despite the general continuity of late Roman burial practices in southern Gaul, several cemeteries in Charente including Herpes and Biron displayed burials similar to those of northern Gaul, including grave goods of weapons and jewellery, which are discussed in the following section (Effros, 2003; James, 1977). The use of sarcophagi or stone slabs appears to have been abandoned within these rural cemeteries, and bodies were placed in rows with grave goods (but in a smaller quantity than those seen in northern Gaul) (James, 1977).



Fig. 2.9 Merovingian cemetery (5th-8th c) in Civaux displaying proximity to church and sarcophagi

2.8.2 Northern Gaul Mortuary Evidence

North of the Loire, an overtly different form of burial appeared during the late 4th century, where graves were dug in series of regular rows and often contained a greater and more varied selection of grave goods than Gallo-Roman customs (Böhme, 1974; Effros, 2003; Halsall, 1992; Werner, 1950). These row-grave cemeteries, or *Reihengräberfelder*, began as small numbers of burials found within larger necropoleis, which largely retained Roman burial traditions (Effros, 2003). As

settlements in north-western Gaul were systematically abandoned over the course of the 5th century, *Reihengräberfelder* were newly established in more rural areas, on or in close proximity to abandoned Roman buildings including *villae*, temples and baths (Blaizot, 2018; Effros, 2003; James, 1979; Todd, 1997). The cemeteries could be small (from about twenty graves) to quite large (thousands) (e.g. Audun-le-Tiche) and grave orientation could be on either west-east or north-south axes (e.g. Frenouville) (Fig. 2.10) (Buchet, 1978; Effros, 2003). Within the row-grave cemeteries, burials could vary a great deal with different sizes and depths of grave-cuts, styles of inhumation, positioning of the body and even presence or absence and quality of grave goods (Effros, 2003; Halsall, 1992). Bodies were buried in funerary clothing which ranged from a simple shroud to ornate garments, as evidenced through the presence of brooches and other accessories (Halsall, 2007). There is evidence of feasting at the grave site, from nearby pits and within the graves themselves; ash, bone and broken pottery have been found (Halsall, 1998). However, Roman style graves (sarcophagi, multiple burials, or graves with no grave goods or just pottery) are often also found within row-grave cemeteries, indicating some connection with Roman traditions (James, 1979; Pearce, 2012). *Reihengräberfelder* are thought to have originated in the north-east of Gaul, where they show the highest concentrations, but had spread across northern Gaul by the late 6th century (Effros, 2003; Halsall, 2007). New forms and locations of burials represent a profound shift in culture in the early 5th century in northern Gaul (Todd, 1997).

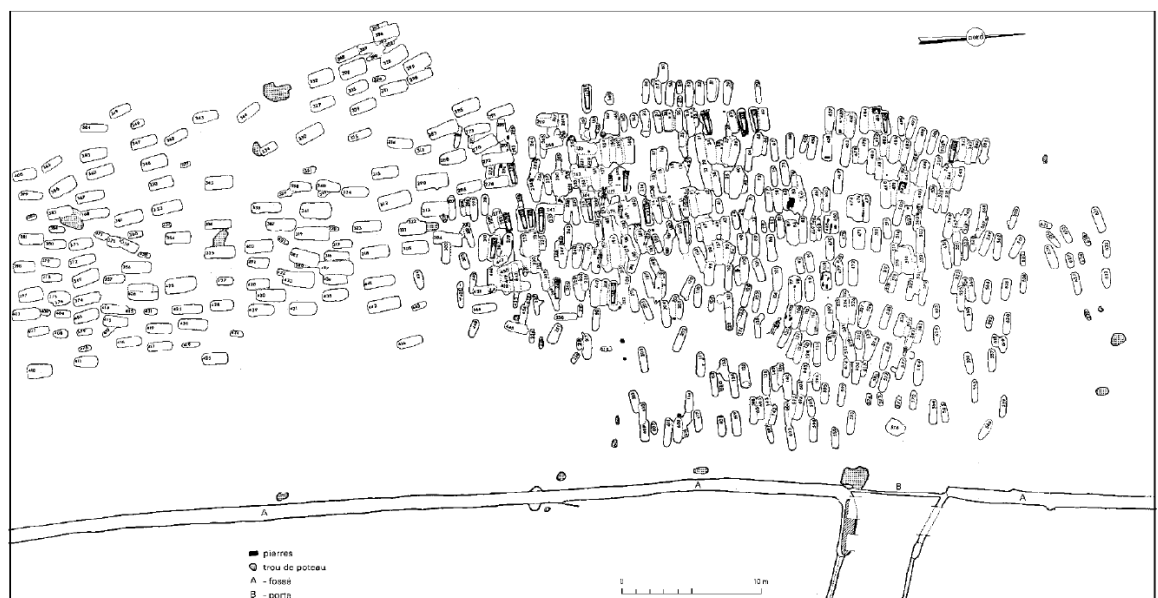


Fig. 2.10 Burial plan from Frénouville, Caen (3rd-8th c) (Pilet, 1980, p. 5)

2.8.2.1 Burial Objects

Beyond the location and organisation of the graves, the presence and type of grave goods incorporated into the funerary rituals north of the Loire during Late Antiquity are a crucial element of the observed discontinuity with Roman practices. By the end of the 4th century, dressed inhumations accompanied by more elaborate grave goods such as weapons, jewellery and buckles began to appear (Fig. 2.11) (Effros, 2003; Halsall, 2007). These furnished graves tended to be focused around the north-western areas of Gaul, in particular surrounding the towns and *villae*, which had declined around 400 CE (Halsall, 2007). Grave goods have often been considered in relation to gender (James, 1979; Périn and Kazanski, 2011). However, there have been few anthropological studies of human skeletal remains verifying if supposedly gendered grave goods are indeed reflective of the biological sex of the interred individual. ‘Feminine’ grave goods mainly consisted of jewellery in the form of necklaces, hair pins, and various brooches, the most famous of which are the *tutulus*, or trumpet *fibulae* (Fig. 2.12) (Böhme, 1974; James, 1979; Theuvs, 2009). ‘Masculine’ grave goods are typically associated with the military, including decorated military belts, brooches and weapons such as axes, spears and shields (Fig. 2.13) (James, 1979; Périn and Kazanski, 2011). The grave goods themselves appear to be a combination of forms new to Gaul and others that refer back to Roman authority in design or symbolism (Halsall, 2007). The *tutulus fibulae*, along with other styles of jewellery have been previously associated with ‘Germanic’ traditions (Todd, 1997), although this interpretation remains problematic. Late Roman official belts have been found alongside weaponry in many graves, indicating a reference to Roman authority, further complicating interpretations (Esmonde Cleary, 2011; Halsall, 2007; Pearce, 2015). The most famous furnished burial belongs to Childeric, the first known Merovingian ruler of Gaul. Discovered in Tournai in 1653, the grave contained large amounts of remarkable grave goods, including weaponry, clothing, gold, a horse harness, a golden military brooch and his inscribed signet ring, identifying the grave (Todd, 1997). Although lost to history in the 18th century, drawings of the goods have revealed both weaponry, which represented foreign influences, and symbols of official Roman office authority, such as the crossbow brooch (Halsall, 2007; Todd, 1997). The proportion of burials with weapons or jewellery within a cemetery could range greatly, from seven to 90 percent and many graves within row-grave cemeteries had no grave-goods at all (James, 1979). Further, there appears to be sub-regional variation where burials were more elaborately furnished further north from ‘centres of Merovingian power’ in and around Paris, creating differences between regions between the Loire and the Seine and regions north of the Seine (Halsall, 1995).



Fig. 2.11 Merovingian buckle from Noisy-le-Grand, 5-6th century (Jacquot, 2009)



Fig. 2.12 Merovingian *Tutulus fibulae*, Saint-Aubin-des-Champs, Normandy. 5th-7th c (Thomann, 2014). 6th c Merovingian grave goods from Artres, Nord (Trustees of the British Museum)

2.8.2.2 Weapon Burials

Within the ornately furnished burials found north of the Loire during Late Antiquity, weapon burials display perhaps some of the most extreme divergence from traditional Gallo-Roman practices. Weaponry had been forbidden to Roman citizens unconnected to the army, suggesting some type

of profound shift in the meaning or purpose of using armament as a grave good. From the middle of the 4th century, weapon depositions, usually axes, lances, bows and arrows, became more common (Theuws, 2009). One individual from Saint-Aubin-des-Champs in Normandy in the 5th-7th centuries was found buried with over 20 objects, including an axe, spear and a dagger (Thomann, 2014). Weapon burials have been found in the Meuse, Somme and Marne valleys, with the highest concentration of graves in the upper Moselle valley and just south of the Ardennes (Theuws, 2009). Weapon graves are rare outside of these areas with few south of the Seine river and even fewer south of the Loire river, despite signs of inhabited settlements (Theuws, 2009). The distribution of weapon graves does not adhere to the location of military activity and is associated with various living contexts, including forts, urban, rural and villa cemeteries, suggesting that the burials cannot be thought of as merely the graves of soldiers (Halsall, 2007; Theuws, 2009). Further, weapon burials are found in cemetery contexts which include women and children, indicating family, rather than soldier burial grounds (Theuws, 2009). Excluding sword burials, Theuws (2009) calculates approximately 100 weapon burials during the 4th and early 5th centuries in northern Gaul, yielding approximately one weapon burial per year, demonstrating that they must have been a rare and special event. Burials with swords and shields have been considered a sub-section within weapon burials, as they follow slightly different and more specific patterns (Fig. 2.14). Burials with swords and shields appear only after 390, and only twenty to thirty from northern Gaul are known (Theuws and Alkemade, 2000). These are located along the Rhine, in the Meuse Valley and Picardy and seem to disappear around the mid-5th century. Such a rare and limited distribution would seem to suggest that the ritual was only employed in situations of considerable importance (Theuws and Alkemade, 2000). Interestingly, sword burials are found only in regions where there was no known clear source of authority and are absent from north-western France where the Salian Franks were established; the Moselle valley and Gaul south of the Loire, where Gallo-Roman senatorial classes (and Burgundians?) remained strong (Theuws and Alkemade, 2000). Based on this distribution, it has been argued that sword burial may reflect attempts by local elites to reinforce relationships of power (Theuws and Alkemade, 2000).



Fig. 2.13 Tomb from Saint-Dizier (Haute-Marne) dated to 525-550 displaying original burial and found grave goods (Truc et al., 2009) and a proposed reconstruction of how the burial might have looked (Juhel, 2010)



Fig. 2.14 Merovingian sword fragment from the 6th-7th centuries from Champagne, Ardenne, France (Trustees of the British Museum)

The practice of elaborately furnished burials and row grave cemeteries declined over the 6th and 7th centuries, disappearing almost entirely from northern Gaul by 700 (Effros, 2003; Halsall, 1995). During the 7th century, in both northern and southern Gaul, cemeteries became smaller and more focused on individual communities and churches. The quantity and type of grave goods interred with the deceased was reduced and became more standardized (Effros, 2003; Halsall, 1996).

Several contentious hypotheses have evolved to explain variation in funeral practices in northern Gaul during Late Antiquity and Gallo-Roman traditions. These theories offer substantially different perspectives on what was taking place in Gaul during Late Antiquity and the dominant forces at play. Although an exhaustive review is beyond the scope of the current work, a brief discussion of Christianization, ethnicity and social struggle hypotheses is provided⁶.

2.8.3 Christianization

Although not overtly discussed in this chapter, the increasing importance of Christianity throughout the western Roman world, including Gaul, has been a recurrent theme. Christianity had been practiced within the Roman Empire for decades but took on new importance from the 4th century onwards (Brown, 1998; Geary, 1988). With imperial support, Christianity developed through traditional Roman bureaucratic and political pathways (Halsall, 2007). Individuals from elite families could access position and control by climbing the clerical ladder, and by the 5th century it was commonplace for elites to adopt a religious route to power (Geary, 1988). Although it is tempting to suggest that the observed changes in burial practices relate to the increasing Christianization of the population of Gaul, the patterns do not match either chronologically or geographically (Halsall, 1995; Pearce, 2012). Inhumation, including bodies laid supine and in an east-west orientation, was well established in Gaul prior to the 4th century, when Christianization was gaining in popularity (Duchesne, 2015). The grave goods buried with individuals do not follow known Christian symbolism, but instead transform during the 4th century from goods focused on the deceased (food and wine offerings, Charon's Obol- coins placed on the eyes or mouth) to those which display status and wealth (weaponry, jewellery) (Duchesne, 2015; Young, 1977). Further, the church and church doctrine had yet to become involved with burial or grave good customs in Late Antiquity, meaning there is no record of the church attempting to actively change funerary practices until later periods (Geary, 1988; Pearce, 2012). Although Christianity was widely present in Gaul by the 4th century, the majority of citizens were not baptized until the 6th century and burial practices were yet to be prescriptive under Christianisation (Crubézy and Catafau, 2015). However, in the 7th century, a preference for burial location within churches and small cemeteries appears, which shows a much clearer relationship with Christianity (Effros, 2003). Although religious practice may have impacted funerary ritual during Late Antiquity, the textual and archaeological

⁶ Other forms of evidence, including funerary epigraphy and sculpture provide important contextual data (see Carroll, 2013), but are not discussed as inhumations are the focus of this analysis.

evidence does not support hypotheses which suggest it was the primary driving force (Esmonde Cleary, 2011; Halsall, 1995).

2.8.4 Ethnicity and Mixed Population Hypotheses

The most controversial explanation for new burial practices during Late Antiquity is that row graves and grave good depositions represent Germanic peoples, *laeti* (Werner, 1950) or *foederati* (Böhme, 1974), entering Roman territories, bringing with them their funerary rituals and customs. This concept has been widely criticised (Dierkens et al., 1986; Effros, 2003; Halsall, 1992; James, 1979; Périn, 1981; Theuws, 2009), but has formed a significant segment of the literature and has shaped much of the discourse⁷. There is, firstly, a chronological discrepancy; although the *laeti* began settlement in Roman territories around 300 CE, the first 'row graves' do not appear until late in the 4th century (Halsall, 1992). This rupture between time and practice does not follow a culture looking to preserve important cultural rites in a new land. The row-grave cemeteries also appear in association with various contexts, including forts, urban and rural areas, which does not always correlate with where *laeti* or *foederati* were established (Halsall, 1992). Further, there are other locations such as Toxandria or Aquitaine, where it is known that *foederati* were established and yet no row-graves have been found (possibly with the exception of Herpes) (Halsall, 1992). Perhaps the most problematic though, is that this type of burial system is not found in areas where Germanic peoples are thought to have lived before they arrived in northern Gaul. This suggests that these practices were not introduced from elsewhere, but were newly established (James, 1979). However, some rituals, such as burials under tumuli or horse burials, have been found in barbaricum, which potentially indicates 'Germanic' roots and demonstrates that not all of the new burial practices can be considered together (Périn and Kazanski, 2011). Despite some continuing debate, it has been widely accepted that the presence of row-graves or grave goods alone cannot be used to identify the presence of Germanic communities in Gaul (Halsall, 2007; Harrison, 2008; Symonds, 2009; Theuws and Alkemade, 2000).

In response to the difficulties with and critique of the 'ethnicity' hypothesis, some scholars (Maurin, 1971; Todd, 1997; Young, 1975) have suggested the shift in mortuary culture was born of the mixing of civilisations in northern Gaul. This hypothesis does not entirely abandon the concept of

⁷ Racist and eugenic ideals have used some of this literature as its basis, further complicating an already charged concept.

ethnicity impacting burial customs, but instead posits that the reason there is no trace of similar practices as antecedents, is that the practices are new and represent a 'melded culture' that non-Romans and Gallo-Romans formed through interaction and progressive reliance upon one another. There is some evidence to support this interpretation. In some cemeteries such as Neuviq-Montguyon (Charente-Maritime, 6th century), sarcophagi with inscriptions were found accompanied by grave-goods (Maurin, 1971). In this example, the placement of Charon's obol and ceramics within a grave represented the Roman traditions and bodies buried in dress represent the Germanic influence (Effros, 2003; Young, 1975). However, Effros (2003) has cautioned that 'funerary symbolism' cannot be so literally translated, as it was a constantly changing dynamic, which may have had innumerable meanings to the contemporary community. Moving this hypothesis beyond the socially and politically charged term 'ethnicity', Dierkens and colleagues (1986) have reoriented grave goods along cultural and social lines, as opposed to ethnic ones (Effros, 2003). Similar interpretations have also been made for Anglo-Saxon burial practices in Britain (Dickinson, 2011; Lucy, 1998). This suggestion better aligns with research on other cultures and time periods, which suggest that shifts in burial practices are associated with social identity and changes rather than ethnic ones, further degrading an ethnicity-based hypothesis (Halsall, 1992; Lucy, 1998; Pearce, 2012; Theuws, 2009; Young, 1975).

2.8.5 Social Struggle

Focusing on social causes for changes in mortuary practices, another hypothesis for the presence of new inhumation customs in northern Gaul is that they reflect the re-negotiation of local power conditions (Effros, 2003; Halsall, 2007, 1992; Theuws and Alkemade, 2000; Wickham, 2005). The relationship between elaborate grave displays, gift-giving and societies with unstable social hierarchies has been fleshed out in other archaeological and contemporary societies (Härke, 2001; Pader, 1979). This establishes a precedent of association between exaggerated funereal rites and attempts to retain or institute social power within a community (Effros, 2003). However, the inhumation practices north of the Loire not only show a change in the quantity of grave goods, they also display a change in form and symbology, which further suggests transformation of cultural or social factors. Where Roman authority receded, symbols of Roman power could not have maintained the effects of previous centuries, necessitating the development of a new way of asserting power, which did not necessarily depend on traditional Roman pathways or symbols (Halsall, 2007). The presence of weaponry and other symbols of military activity, including the new cultures which had been slowly integrated into that military structure, indicates a shift in the base

of power, no longer aligning solely with the Roman civil service or the barbarian army (Sarti, 2013). The seemingly greater focus on differentiating gender in the burial practices in northern Gaul has also been associated with an un-stable or un-clear social hierarchy in other Late Antique and Medieval communities (Härke, 2007, 2001). However, as mentioned earlier, many grave goods did continue to make reference to Roman modes of authority and were often in the same graves as symbols of other forms of power. This suggests that the transitions taking place were not simple and which, demonstrates a complex, shifting dialogue, where authority could come from multiple places (Halsall, 2007).

Championing this hypothesis, Halsall (Halsall, 2007, 2006, 1996, 1992) has argued that the presence of grave good depositions in northern regions of Gaul, Belgium and Eastern Germany and their distinct absence in the south is reflecting the geographical difference in Roman power and authority. He argues that northern Gaul dealt with a more serious power vacuum when Roman authority lost its capacity to hold or assert their dominance, resulting in the competition of local elites who fought for immediate control. Lavish burial displays may have been an effective means for expressing pre-eminence and authority when an important individual died (Halsall, 1992). That many sites containing furnished graves are located in the proximity of urban areas and villas showing serious decline in the 4th and 5th centuries, is strong support for this hypothesis (Halsall, 2007; Theuws, 2009; Theuws and Alkemade, 2000). Further, the presence of these new burial customs are sparse or non-existent south of the Loire and surrounding Trier, where Roman continuity was stronger (Halsall, 2007). This would seem to fit with other evidence of instability and localisation in northern Gaul and is reflected in other regions where there was a reduction Roman authority, such as lowland Britain and provinces north of the Alps, who also adopted elaborate mortuary displays (Dickinson, 2011; Halsall, 2000; Lucy, 1998; Pearce, 2012; Theuws, 2009). That the practice of furnished inhumations disappeared during the 7th century has been interpreted as a result of Christianisation, but also may reflect the 'decreasing necessity of social competition' (Effros, 2003, p. 130). Importantly, changing and special burial rituals in the late 4th to 7th centuries are bounded in space and time.

2.9 Evidence for collapse in Late Antiquity?

Based on written and archaeological evidence, some of the features of systems or societal collapse are evident during Late Antiquity, potentially lending support for catastrophist hypotheses (Table

2.3) (Kulikowski, 2013a; Marcone, 1997; Ward-Perkins, 2006). Halsall (2007) argues that cultural transitions taking place were ‘complex and dramatic’. He suggests that as Roman culture and identity became less popular or prevalent in the Late Antique world, particularly in Britain and northern Gaul, ‘a single lifetime could experience a shift from a complex urban, monetised, Romanised society, with villas, finewares and long-distance exchange to an unremittingly local and rural society with no towns and no manufacture, craft specialisation or long-distance economic connections’ (Halsall, 2007 p. 498). Cities were a deeply important structure in Roman culture and administration, but changed dramatically in Late Antiquity, as evidenced through the abandonment of public building works and rejection of Roman city planning; abandonment or repurposing of residences and civic structures (villas, baths, arenas turned into shops, fortresses, churches or burial areas); reduction and eventual abandonment of water and sewer systems (Bailey, 2016; Cheyette, 2008; Porter, 1999; Storey and Storey, 2017). Trade and military factions become more localised, were smaller and more independent (Renfrew, 1979; Storey and Storey, 2015; Ward-Perkins, 2006). New burial rites were formed, especially within north-eastern Gaul (Effros, 2003; Theuws, 2009). Even the reduction in archaeological evidence in comparison with preceding periods has been interpreted as a feature of systems collapse during Late Antiquity (Renfrew, 1979).

Table 2.3 Features of collapse for archaeological sites and populations assessed in Gaul

	Specifics of collapse	Late Antique South	Late Antique North
1	Different access to resources, trade, technology		X
2	Migration (population movement)	X	X
3	Violence		
4	Settlement structure changes	X	X
5	Material culture changes	X	X
6	Population (density)	X	X
7	Social stratification		
8	Burial ritual and rite changes		X

X= evidence of feature present

However, much of the discussed evidence can be (and regularly is) interpreted in multiple, antithetical ways. Where some see decline and catastrophe as axiomatic (Ando, 2008; Ward-Perkins, 2006), others observe transformation, focusing on adaptation and resiliency (Brown, 1971; Goffart, 1980). Were urban settlements and villas abandoned or merely repurposed? Did retraction in trade represent a fundamental simplification of lifeways for the majority of the population or just elites? Was the Justinianic Plague an epidemic of huge proportion and consequence or just one of many diseases affecting an already struggling population? Heterogeneity in transition is also evidenced, where northern regions could have experienced collapse and southern regions may

have experienced continuity. Health data from human skeletal remains have unique potential to contribute to and address these debates, providing direct information about the lived experience during Late Antiquity.

2.10 Summary

In this chapter, the complex historical narrative of Late Antiquity in Gaul and the nature of the extant evidence for transformation have been presented. This (far from comprehensive) review of key events, trends and evidence from Late Antique Gaul highlights several points related to hypotheses of continuity and/or collapse. There is evidence of overall political instability and changing power sources with implications for social conceptions of self and social roles; decline in wealth, trade networks, industry; changes in settlement structures and differential burial rites in some regions. These features, taken at surface level, could be suggestive of societal collapse, according to criteria discussed. However, there is also evidence of substantial continuity. Transitions appear to follow a geographic divide, where northern Gaul experienced transition more dramatically and could potentially be considered collapse. As also presented in this chapter, the available data can be differentially interpreted, leading to disparate conclusions about continuity or collapse during Late Antiquity. Population level health can be deeply affected by political and cultural priorities and transitions and as such, may be a beneficial line of evidence to consult.

Chapter 3.

Transition, Health and Stress

'The greatest wealth is health' -Virgil

Historical and archaeological evidence present an incomplete, complex and sometimes conflicting image of transformation occurring during Late Antiquity. It is not clear if the shifts in political and religious authority, cultural practices and modes of life that can appear dramatic to modern scholars were profound or barely noticeable to Late Antique people. In both past and living populations, health, as defined by the biocultural approach, is shaped by the interplay of social, cultural, political and biological influences (e.g. Goodman and Leatherman, 1998; Leatherman and Goodman, 2011; Stinson, 2012). Therefore, health data collected from archaeological human remains may be uniquely suited to address some of the gaps in current knowledge regarding Late Antiquity and its transformations. Even within modern contexts the relationship between health, cultural and socio-political stressors and environment is complex. There are further limitations when studying these relationships in skeletal remains from past populations. Because of these limitations, it is important to explore and discuss how health is impacted by socio-cultural environments and transitions. This provides a framework for how to appropriately interpret and relate health data from Roman and Late Antique Gaul to hypotheses of societal collapse or more gradual transformation. Within this chapter, the ways in which external environments and socio-cultural factors become internalised and affect health are discussed. There is a focus on structural violence, health during childhood and 'stress' as a mechanism through which external factors can dictate or mediate health outcomes.

3.1 Determinants of Health

Even within modern populations, health as a concept is deeply complex and complicated to define, assess and operationalise. Being in good health includes an absence of illness, but also encompasses 'complete physical, mental and social well-being' (WHO, 1998a). Various factors and conditions contribute to individual and population level health status. As defined by the biocultural approach, health states are created through a complicated and constantly shifting/evolving interplay between multiple intrinsic and extrinsic factors. These include genetic heritability,

nutritional and immunological states, political and cultural practices, living and working conditions, climate and degrees of social cohesion and integration (Archaeological studies- Cole and Packer, 2016; Goodman and Leatherman, 1998; Clinical studies- McDade, 2002; Rogoff, 2003; Tanner and Team, 2014; Worthman and Kohrt, 2005). Although the influence of biological factors (genetic predisposition, pathogen exposure, metabolic requirements) on health receive extensive clinical attention, cultural and political manipulations of resources and environments are crucial determinants of health status (Fig. 3.1) (Dahlgreen and Whitehead, 1992; Marmot, 2015, 1996; Nesse et al., 1995). Access to adequate nutrition, healthcare, suitable and salubrious living and working conditions and social support is distributed according to cultural and socio-political value systems. These systems, therefore, differentially manufacture or mediate health and disease states.

Extensive research in both clinical (e.g. Barker et al., 2002; Baxter, 1875; Boas, 1912; Bowditch, 1879; Crews et al., 2014; Hobdell et al., 2003; Kuzawa and Sweet, 2009; McDade, 2002; Panter-Brick et al., 2008; Shapiro, 1939) and archaeological (Agarwal, 2016; Edes and Crews, 2017; Gowland and Knüsel, 2006) settings have demonstrated the importance of socio-cultural and political influences on health and health disparities from at least as early as the 19th century. In the early 20th century, Franz Boas examined body size and shape in immigrants in New York City. He identified that body size and shape were correlated with social and cultural environments during development, demonstrating plasticity rather than exclusively genetic heritability (race at the time) (1912). This foundational work (although not without controversy) (Gravlee et al., 2003a, 2003b; Sparks and Jantz, 2002), illustrated proof of human biological plasticity and indicated the importance of maternal and childhood environments on health. Given the complexity of health status, it is important in the present research to examine health indicators that are sensitive to and thereby informative about cultural and socio-political conditions. The impact of cultural and socio-political influences on health is particularly apparent through structural inequalities between subgroups of a population and during childhood, when health is the most sensitive to environmental stressors (Farmer, 2004a, 2004b). As such, health during childhood and between subgroups of the samples are important axes of this work. Societal transitions often expose existing social and cultural influences on health, but can also impact health, as social and cultural determinants shift, change or are replaced with new value systems (McDade, 2002).



The Determinants of Health (1992) Dahlgren and Whitehead

Fig. 3.1 Visual representation of the determinants of health (Dahlgren and Whitehead, 1992)

3.1.1 Structural Violence

The impact of socio-political factors on health becomes markedly visible through structural violence and inequities, or how culturally and politically dictated belief systems and actions disenfranchise a segment of the population on a systematic level (Farmer, 2004a). By examining subgroups within a population through the lens of structural violence, it becomes possible to identify certain value systems and priorities. Structural violence can take the form of reduced access to or exclusion from vital resources (food, shelter, healthcare, social support) based on economic groupings, age, sex, race, ancestry, sexual orientation, etc. (Farmer, 2004a; Lauderdale, 2006; Panter-Brick et al., 2008). The effects of even subtle cultural, social and political practices on health can be quite dramatic. In the 1980s, Wallace and Wallace (1990) examined increasing rates of tuberculosis, homicide, suicide, gonorrhoea, salmonellosis, drug abuse, elderly and infant mortality and low birthweight within certain regions in New York City. When these indicators, typically viewed independently by different city departments were considered simultaneously, large scale patterns emerged, which could be linked to the deterioration of urban housing and community services as a part of New York City's municipal divestment plan (Wallace and Wallace, 1990). In this case, politicians stopped investing resources in selected parts of the city, which then had extensive negative behavioural and health consequences for residents. This example of structural violence demonstrates how political and economic choices, dictated by cultural values can enter the biology of the public and create health disparities. This has also been evidenced most

recently in the differential experience of SARS-CoV-2 morbidity and mortality based on social and economic status (Kim and Bostwick, 2020; Wang et al., 2020).

Although informative about cultural value systems and priorities, examining structural inequities in archaeological skeletal samples faces several challenges. Within archaeological studies, the ability to identify and define subgroups of the population is limited. Past perceptions of social roles, priorities and potential inequities have to be inferred from historical textual and archaeological data (Knudson and Stojanowski, 2008). Cultural priorities are rarely stated outright and require nuanced interpretation. Further, modern researchers bring their own biases in the analysis of sources and this can be particularly challenging to override in examinations of more abstract ideas (e.g. culturally appropriate gender roles) (Weiss-Krejci, 2011). Even when 'subgroups' are explicitly identified, it can be challenging to map social identities on to individuals (Agarwal and Glencross, 2011). In terms of this research, many cemetery samples from Late Antiquity are quite broad in their dating and provide limited information about specific individuals or contemporary perceptions. However, for most individuals, it is possible to estimate age-at-death and sex from skeletal remains. Conceptions of sex and gender in the Roman and Late Antique worlds have received contemporary and recent attention, revealing certain inequities (Allason-Jones, 1989; Halsall, 2004; Smith, 2000). As such, divisions based on biological sex may be a particularly informative subdivision for identifying potential structural inequalities (Hollimon, 2011), and thereby for revealing information about Late Antique transitions. Individuals who died during childhood (non-survivors) and those who lived into adulthood to various ages (survivors) also represent a potentially useful division of burial samples (Gowland, 2018). Non-survivors are a subgroup of the population that were unsuccessful in reaching maturity, already representing a subsection of the population that faced hardship or disadvantage. Further divisions can sometimes be made based on grave goods, as a proxy for status. However, these divisions may not always be appropriate depending on the context from which individuals derive (grave robbing; re-use of graves; lack of association between grave goods and status). Importantly, the effects of transition are most likely to be identified (and least likely to be missed) if subgroups are considered and examined.

3.1.2 Health during childhood and development

The growing bodies of children are particularly susceptible to adverse cultural, political and environmental stressors (Lewis, 2007; Stinson, 1985). Normal growth and development processes compel children's bodies to continually adapt to their current environment, capturing traces of environmental and cultural 'exposures' (phenotypic or developmental plasticity) (Agarwal, 2016; Gowland, 2015; West-Eberhard, 2003). Therefore, factors such as inadequate nutrition, illness, or poor living conditions impact growth and development, potentially leading to delays in growth or maturation as the body prioritises survival (Bogin, 1999a; Goodman, 1991; Stinson, 1985). Accordingly, there is a well-known correlation between health and relative growth, where growth disruption, stunting, wasting and declines in population stature are often used to assess health trends in modern populations (Leonard et al., 2002; Stillman, 2006; Stinson, 2012). Several archaeological studies have made specific links between growth stunting and poor child health in response to structural inequities (e.g. Burroway, 2011; Cardoso et al., 2019). Cardoso and colleagues explored growth stunting in non-adult individuals thought to be African enslaved children in 15th-17th century Portugal (2019). They compared growth patterns with other populations exposed to different forms of socio-cultural pressures, or structural inequities (Raymond Dart and Hamann-Todd collections). Similar rates of stunting were observed between populations, suggesting that the consequences of enslavement and institutionalised racism were identifiable in the growth stunting of these children (Cardoso et al., 2019). Because childhood health is a sensitive indicator of cultural, socio-political and environmental conditions, it forms an important component of the present research. The effects of transition may only be visible in skeletal remains through childhood health and growth indicators.

3.1.2.1 Developmental Origins of Health and Disease (DOHaD)

Poor childhood environments can also have life-long effects, resulting in increased risks of disease and reduced life expectancy in adulthood (Archaeological studies- Agarwal and Beauchesne, 2011; Armelagos et al., 2009; Clinical studies- Barker et al., 2002). The Developmental Origins of Health and Disease (DOHaD) hypothesis argues that early life stressors force an organism to prioritise needs for survival in the present, potentially at the expense of health outcomes in the future (Barker et al., 2002; Barker, 2012a; Kuzawa, 2005; Worthman and Kuzara, 2005). Recent clinical research into the DOHaD paradigm suggests that reduced adult stature and poor health is closely linked to adversity early in life, specifically during the first 1000 days after conception (Barker,

2012b; Barker et al., 2002; Kuzawa and Quinn, 2009). Early life stressors force the body to prioritise energetic demands for immediate survival ahead of investment in other bodily structures and processes, including growth and maturation. This metabolic rationing can come at the expense of future health outcomes (Barker, 2012b; Barker et al., 2002; Kinnally, 2014; Kuzawa, 2005; Worthman and Kuzara, 2005). For example, within this framework, growth disruption can be thought of as a 'trade-off', reflecting adaptive plasticity and energetic or physiological constraint, two key concepts within DOHaD (Agarwal, 2016; Barker, 2012b; Barker et al., 2002; Temple, 2019; Worthman and Kuzara, 2005). In the presence of a stressor, the body initiates an adaptive response by diverting energy away from growth to survive the immediate threat (adaptive plasticity). Because resources are limited or constrained (physiological constraint), this diversion of resources means that other bodily structures and processes are not being developed or maintained, potentially leading to negative health outcomes in the future (Agarwal, 2016; Temple, 2019). This concept has been extensively explored in longitudinal studies of pregnant women affected by the Dutch Hunger Winter in 1944. This research demonstrated the impact of famine during the first trimester of foetal life resulting in individuals with a higher rate of obesity and coronary heart disease later in life (Painter et al., 2008; Ravelli et al., 1998; Roseboom et al., 2001, 2000b, 2000a). Analyses of the DOHaD hypothesis in bioarchaeological contexts have identified relationships between skeletal evidence of early life stressors (enamel defects, cribra orbitalia, porotic hyperostosis) and adult health and mortality (Amoroso et al., 2014; Armelagos et al., 2009; DeWitte and Stojanowski, 2015; Gowland, 2015; Roberts and Steckel, 2018; Temple, 2014; Watts, 2013, 2011).

Exposure to high levels of stress and allostatic load during early childhood have also been found to negatively affect immune response and mortality in adulthood (Armelagos et al., 2009; Garland, 2020; Rodney and Mulligan, 2014) and is thought to be one mechanism through which environmental conditions impact health intergenerationally and from childhood into adulthood. Childhood health, therefore, reflects experience during the developmental period but also provides a useful proxy for the effects of cultural, socio-political and environmental conditions on the wider population, as evidenced in both past (Gowland, 2015; Schug and Goldman, 2014) and contemporary societies (Barker, 2012a; Cole and Packer, 2016; Tarlov, 1999; WHO, 1998b). Importantly, the relationship between childhood and adulthood health adds another layer of analysis to the effects of transition in Late Antiquity. Looking at childhood health indicators in the

remains of 'survivors' also permits the examination of health divisions and potential structural inequities based on sex, as sex cannot reliably be determined from non-adult remains¹.

3.1.3 Transitions and Collapse

Societal transitions expose populations to new and different cultural and socio-political factors, often outside or beyond their control. As a result, transitions can affect health in significant ways, as evidenced in both modern westernized (Liebert et al., 2013; Marmot, 1996; McDade, 2002; Panter-Brick et al., 2008; Stillman, 2006; Tanner, 2014; Virchow, 1958) and past populations (Klaus and Tam, 2009; Larsen et al., 1995; Larsen and Milner, 1994; Saunders and Hoppa, 1993; Schug and Goldman, 2014). Although societies are to a varying extent always in some form of transformation, large scale transitions, such as the agricultural transition, colonialism, industrialisation and globalisation, have resulted in substantial, wide-ranging and far-reaching effects on health (Armstrong et al., 2005; Liebert et al., 2013; Santos and Coimbra Jr, 1998). Modern examples of societal collapse, such as the Soviet Union in the early 1990s, represent the most extreme form of socio-political and cultural transformation and have resulted in marked negative health outcomes (Brainerd and Cutler, 2005; Costa-Font and Kossarova, 2019; Leonard et al., 2002). These included dramatic spikes in excess mortality (decreased life expectancy) (Brainerd and Cutler, 2005; Leon et al., 1997; Mackenbach, 2013; Shkolnikov et al., 1996, 1998; Stillman, 2006); high rates of growth disruption, stunting and wasting during prenatal development and childhood (Adserà et al., 2020; Mironov, 2007; WHO, 1998b); increased morbidity and mortality from infectious and parasitic diseases (Tragakes and Lessof, 2003; WHO, 1998b); increased psychosocial stress and diseases associated with stress (cardiovascular and ischaemic heart disease, cirrhosis) (Carlson, 2000; Field, 2000, 1995; Leonard et al., 2008, 2002; Stillman, 2006) and increased interpersonal violence and accidents (Stillman, 2006). This suggests that if societal collapse was occurring during Late Antiquity, it is likely to have had a significant impact on the health of the population and may be detectable in human skeletal remains, particularly due to the inter-generational nature of health effects as elucidated through the DOHaD framework. Although extreme examples of change (such as societal collapse) would theoretically be the most evident in skeletal remains, more gradual forms of transformation may also be observable, especially through examinations of subgroups within the samples (e.g. structural inequities or childhood health).

¹ New biochemical techniques assessing peptides in tooth enamel are poised to overcome this limitation (Stewart et al., 2017)

3.2 'Health' in Palaeopathology

Assessing 'health' in relation to cultural and socio-political influences is complicated in modern populations and becomes even more challenging in skeletal remains (Temple and Goodman, 2014). As previously stated, 'health' comprises mental, social and physical or biological well-being (WHO, 1998a, 1998b). This comprehensive definition in some ways precludes the assessment of 'health' from human skeletal remains, as palaeopathologists are limited to analysis of the skeletal manifestations of physical, mental and social states (Temple and Goodman, 2014). Because many of these states, as well as certain pathological conditions are difficult to assess through skeletal markers, it has been argued that investigations of 'health status' in the past are in reality assessments of 'stress' (Reitsema and McIlvaine, 2014; Temple and Goodman, 2014; Wood et al., 1992). Although often used as a proxy for health in past populations, stress comes with its own terminological problems (see section 3.3 Stress) and has an imperfect relationship with health and wellbeing (Piperata et al., 2014; Reitsema and McIlvaine, 2014; Tanner, 2014). There are hidden heterogeneities in frailty, or susceptibility to morbidity and mortality that influence health outcomes, complicating interpretation of skeletal stress markers and their significance for larger patterns of stress experience in the past (the osteological paradox)(Cohen et al., 1994; Marklein et al., 2016; Wood et al., 1992). However, understanding stress and health in response to differing social and environmental conditions and transitions are primary goals within bioarchaeology and generates considerable research (Cardoso et al., 2019; Goodman et al., 1984; Goodman and Leatherman, 1998; Huss-Ashmore et al., 1982; Larsen and Milner, 1994; Temple and Goodman, 2014). With this shift in terminology, it is possible to assess the relationship between cultural and socio-political transition and 'stress' (as a proxy for health) in human skeletal remains to address questions about transitions occurring during Late Antiquity.

3.2.1 Collapse in Palaeopathology

Bioarchaeological studies have sometimes struggled to identify correlations between socio-political changes and skeletal indicators of morbidity and mortality during periods of supposed societal collapse (Jennings, 2010; Kurin, 2016, 2012; Schrader and Buzon, 2017; Wright, 1997a, 1997b; Wright and White, 1996). This is counterintuitive as collapse is the most extreme form of societal transformation (Storey and Storey, 2017), and thereby should demonstrate severe responses, as have been recorded in studies of living populations. Prominent examples of bioarchaeological analyses of societal collapse and stress include the collapse of the Classic Maya

(c 900 CE) (Wright, 1997a, 1997b) and the archaic Andean Wari Empire in Peru (c 1000 CE) (Kurin, 2016, 2012). In both cases, several features of societal collapse were identified through archaeological evidence of rapid changes in settlement and subsistence patterns, a reduction in trade networks and goods production and increased evidence of violence and isolation (Andrushko, 2007; Tung, 2008). To identify changes in cultural and socio-political contexts and better understand and characterise the human experience of these important transitions, Wright (1997a,b) and Kurin (2012; 2016) examined skeletal stress markers (dental enamel defects, porotic hyperostosis, cribra orbitalia, skeletal injury) and stable isotope analysis. They hypothesized that if collapse was catastrophic, it would be reflected by changes in the frequency of skeletal manifestations of stress. For both societies, no significant differences in the frequencies of stress, trauma or diet (isotopic signatures C, N) markers were identified (Kurin, 2016, 2012; Wright, 1997a, 1997b). However, both authors noted more subtle changes within their data. Wright (1997a) identified a shift in the timing of the enamel defects during the collapse of the Classic Maya. This finding supported hypotheses that suggested cultural and political origins of the collapse, rather than ecological factors. Based on isotopic data, Kurin (2016) identified shifts in the subgroups of the population that had access to certain food resources during the Wari collapse. These findings reflect shifts in distribution of vulnerability, but the results are subtle for what was hypothesized to be a societal collapse that should have exerted notable impact on the 'stress' state, or health and well-being, of the populations.

Several features of societal collapse would likely affect health and stress, including rapid loss of established socio-political structures (authority), changes in social stratification, settlement patterns, technologies and rituals, declines or decreases in spheres of trade and information (access to resources), and population declines (due to migration or death) (Härke, 2007; Scheidel, 2017; Tainter, 1995). Wright and White (2006) and Kurin (2016) explored migration, diet and violence in detail, but there has not yet been a specific focus linking health or stress outcomes with societal collapse. A critical examination of how collapse effects health and how these effects might manifest in the skeleton could be beneficial to future analyses. Modern examples could provide a framework to better understand skeletal stress data and augment the interpretation of more subtle shifts in pathological conditions found in previous analyses (Wright, 1997a,b; Kurin, 2016; 2012). A potentially interesting option would be to explore the role of 'stress' in societal collapse and health outcomes. Psychosocial and physiological stressors accompanying rigid hierarchical structure with greater degrees of inequality/social stratification may play a role in mediating health outcomes in modern (Brainerd and Cutler, 2005; Panter-Brick et al., 2008; Thayer and Kuzawa,

2015) and past populations (DeWitte and Bekvalac, 2011; Redfern, 2008; Redfern and DeWitte, 2011a; Roberts and Cox, 2003). Although challenging to assess in skeletal remains, stressors stemming from larger political, economic and ideological systems do physically manifest in ways that are quite pronounced (Edes and Crews, 2017; Panter-Brick, 2002; Panter-Brick et al., 2008). In Afghanistan for example, this is reflected in higher blood pressure and Epstein-Barr Virus antibodies, as well as poor mental health in females (Panter-Brick et al., 2008). Early spikes in mortality were associated with the increased stress and 'reduced social cohesion' that occurred during the Soviet collapse (Brainerd, 2010; Brainerd and Cutler, 2005; Leonard et al., 2008; Stillman, 2006). Other studies have also highlighted stress as a key pathway for the embodiment of socio-economic and cultural influences on health, especially during childhood (McDade, 2002; Nyberg et al., 2012; Rodney and Mulligan, 2014). Examining the specific role that stress plays in mediating health outcomes (and producing skeletal stress markers) could be an important contribution to understanding health in relation to societal collapse.

3.3 Stress

'Stress' is a primary way in which external environments become internalised in both childhood and adulthood. As a result of its pervasive use in conventional conversation, media, scholarly and clinical research, 'stress' as a term is often ambiguous in its definition and interpretation (Beehner and Bergman, 2017). The terms 'stressor' and 'stress response' have been adopted to clarify and delineate often conflated ideas of stimulus and reaction (Beehner and Bergman, 2017). Specific to biological systems, a stressor is a disruption to an organism's homeostasis and a stress response is the combination of physical actions taken to either reduce the impact of the stressor and/or return the organism to homeostasis as quickly as possible (Dhabhar, 2011). Importantly, 'stress' is an interaction; a stressor affects an organism by causing physiological changes (a response) within the body. When examining stress markers, it is this interaction that is being observed, highlighting the importance of both stressor and bodily stress response. Stressors can be psychological/psychosocial (public speaking, social subordination), physiological (temperature extremes, nutritional scarcity or deficiency, infection), 'real' (harmful event occurring) or perceived (harmful event anticipated) (Edes and Crews, 2017; Sapolsky et al., 2000; Selye, 1950). The stress response is non-specific in its attempt to neutralise disruptions to homeostasis, stimulating similar pathways whether a stressor is real or perceived, psychological or physiological (general adaptation syndrome) (Sapolsky et al., 2000; Selye, 1950). Both stressors and stress responses can

be acute (minutes to hours) or chronic (hours daily, weekly, monthly), according to their duration and intensity (Dhabhar, 2011). There is variation within and between individuals in when, how and for how long a biological stress response is activated. This illustrates the importance of understanding how the body responds to stressors and how this response system can become dysregulated (allostatic load). Measuring dysregulation of the stress response is an important tool in examining health and stress in modern populations and has relevance for examining stress and societal transitions in past populations.

3.3.1 Allostatic Load

When functioning properly, the stress response is an adaptive system, promoting survival through the facilitation of physical reaction and adaptation to avoid or cope with danger. In the presence of a 'stressor', the biological stress response prepares the body to counter the stressor's negative effects and regain homeostasis (Selye, 1950). This process of moving in and out of homeostasis to address a threat in an efficient manner is known as 'allostasis' (McEwen and Wingfield, 2003). Allostasis is a protective mechanism, allowing bodily systems to be flexible and adaptable to many different types of stressors with minimal or controlled damage to the organism (Beehner and Bergman, 2017; Dhabhar, 2011). However, in the presence of repeated or excessive exposure to stressors, 'set points' for homeostasis can become altered, changing the minimum threshold, timing or degree of the stress response (Fig. 3.2) (Evans and Kim, 2012; Lee et al., 2015). These changes can result in negative health consequences from overexposure to stress hormones or ineffective stress responses, leaving the organism vulnerable to stressors. The accumulation of wear and tear on homeostatic and stress response setpoints is known as allostatic load (Edes and Crews, 2017; McEwen, 2012). Allostatic load is regularly used to measure 'stress-related physiological dysregulation' in response to socio-political and cultural influences and health disparities in modern populations (Worthman and Panter-Brick, 2008), and may represent one mechanism through which repeated exposure to stressors functionally effects health outcomes (Edes and Crews, 2017). Allostatic load can be measured in multiple ways, including blood pressure, heart rate, body fat percentage and cortisol and catecholamine concentrations (Edes and Crews, 2017; Russell et al., 2012). Dysregulated cortisol levels are the most often used marker of allostatic load in modern populations and have been found in association with war, chronic pain and illness (Greff et al., 2019).

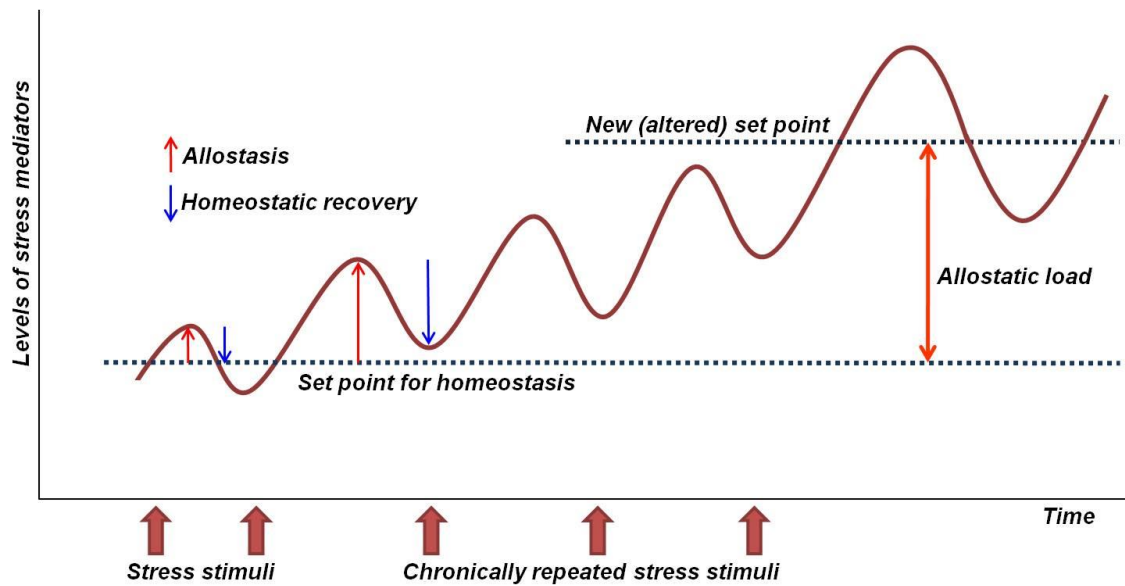


Fig. 3.2 Visual representation of allostasis and allostatic load (Lee et al., 2015). If stress stimuli are excessive and repetitive, recovery to the original homeostatic levels may be incomplete.

3.3.2 Biological stress response

The biological stress response involves several bodily systems, although the Hypothalamic-Pituitary-Adrenal (HPA) axis is among the most important for the assessment of allostatic load/stress. When a stressor is encountered, the sympathetic nervous system generates immediate responses, such as elevated heartbeat, quickened breath and sensory acuity through catecholamine (epinephrine, norepinephrine) production (Sapolsky et al., 2000). The parasympathetic nervous system, including the HPA axis, works in concert, taking minutes rather than seconds to produce and secrete glucocorticoid hormones (Sapolsky et al., 2000). The HPA axis consists of the hypothalamus and pituitary glands in the brain, the adrenal glands located just superior to the kidneys and the various chemical messengers, or hormones they produce. When a stressor is encountered, structures in the prefrontal cortex (thalamus and prefrontal lobes) evaluate the stressor and pass signals to the emotional centre of the brain, the limbic system (amygdala and hippocampus), stimulating the HPA axis (Dickerson and Kemeny, 2004). Paraventricular cells in the hypothalamus synthesize and secrete corticotropin-releasing hormone (CRH) into the blood stream to the anterior part of the pituitary gland. In the presence of CRH, the anterior pituitary gland produces adrenocorticotrophic hormone (ACTH), which is sent throughout the body in the blood stream. The ACTH is then picked by hormone-specific receptors located in the adrenal gland, instigating the synthesis of glucocorticoid hormones, of which, cortisol is the most abundant.

Cortisol travels through the bloodstream in both active (unbound) and inactive (bound to the protein transcortin or albumin) forms (Gow et al., 2010). From the blood stream, unbound cortisol passes through cell membranes to activate glucocorticoid receptors in the cytoplasm, where the complex is translocated into the cell nucleus, binding to glucocorticoid-response elements and modulating the transcription of target genes (Gow et al., 2010; Greaves et al., 2014). Although free or unbound cortisol makes up only a small proportion of total cortisol, usually 10% or lower, it is the free cortisol that acts upon and regulates systems within the body (Dallman and Hellhammer, 2011). Upon arrival in the pituitary gland, the production of ACTH is halted and thereby also bringing the production of cortisol to a stop, completing a negative feedback loop (Fig. 3.3) (Dickerson and Kemeny, 2004). Apart from the influence of stressors, the HPA axis has a natural rhythm of glucocorticoid secretion, which is episodic and circadian (Dallman and Hellhammer, 2011). The HPA axis is typically activated the most intensely approximately 30-45 minutes after waking, producing high levels of circulating cortisol, which then decrease throughout the day, reaching their lowest levels during sleep (Fig. 3.4) (Dallman and Hellhammer, 2011).

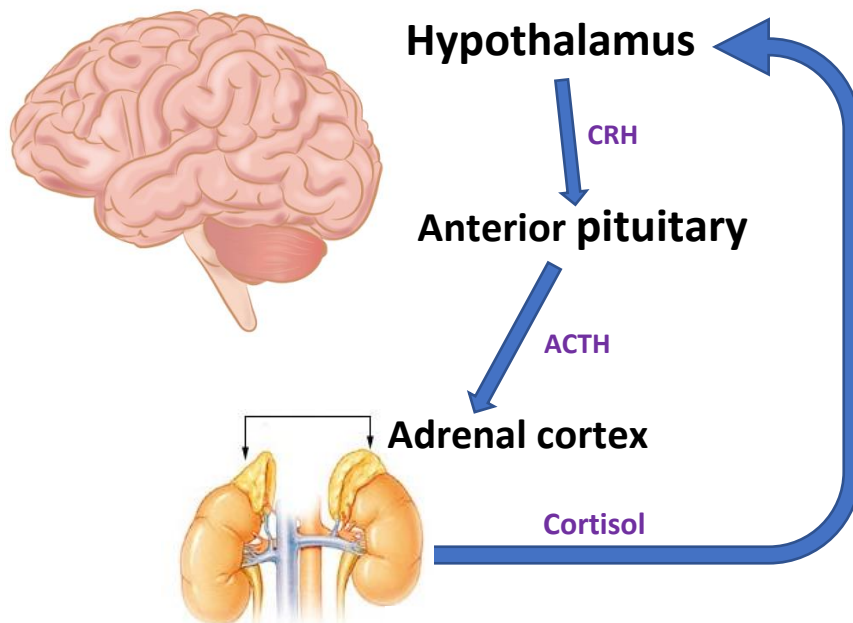


Fig 3.3 Negative feedback loop of the HPA Axis

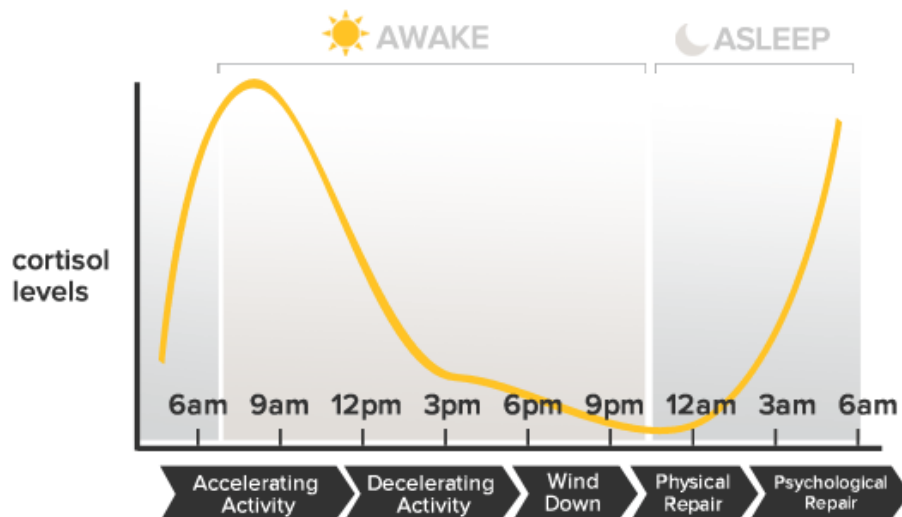


Fig. 3.4 Diurnal pattern of HPA axis and cortisol secretion

3.3.3 Cortisol

Biochemical tests of cortisol concentrations are routinely performed to assess stressors, the stress response and their health consequences in modern human and animal populations. Cortisol, often referred to as the ‘stress hormone’, is the primary chemical messenger produced by the adrenal cortex in response to stressors. Although the HPA axis is a critical response pathway for stress, it also has significant regulatory functions in metabolic, immunological and cardiovascular systems (Dallman and Hellhammer, 2011; Fraser et al., 2010). This means that cortisol is present and necessary in the body even in the absence of stressors, affecting various tissues by up- or downregulating their actions to maintain homeostasis (Greff et al., 2019; Scheschowitsch et al., 2017). Of particular relevance to bioarchaeologists, cortisol exerts a large influence on skeletal tissues and is known to play a considerable role in growth suppression and osteoporosis in the presence of chronic HPA overactivation.

Due to its presence throughout the body, cortisol concentrations can be obtained from multiple tissue types, including blood serum, saliva, urine and hair. Obtained cortisol values are analysed with reference to established ranges, indicating normal or dysregulated HPA axis function. Serum tests allow for the examination of bound and unbound or free cortisol levels, providing the most complete picture of HPA axis function (Wilson and Thayer, 2017). However, the blood drawing process itself can be stressful, increasing cortisol levels and potentially biasing results (Fraser et al., 2010). Cortisol in both saliva and urine reflect only free cortisol concentrations but have been

successfully correlated with free cortisol levels in blood serum (Fraser et al., 2010). Saliva samples are less invasive to collect and store, but samples need to be collected multiple times a day or at consistent times to understand the influence of diurnal fluctuations in cortisol concentrations (Greff et al., 2019). Urine samples can be less complicated or biased to collect than blood, and concentrations reflect free cortisol from approximately 24-hour periods, averaging some of cortisol's diurnal secretion pattern (Beisel et al., 1964). Because testing cortisol in blood, urine or saliva generates cortisol concentrations related to relatively short periods of time (1- 24 hours) (Greff et al., 2019), these tissues are not practical for assessment of chronic HPA dysregulation. One solution has been to look at chronic stress through cortisol concentrations in hair, which reflect a much longer period of time (weeks to months) (Raul et al., 2004; Van Uum et al., 2008; Wosu et al., 2013). Through this, diurnal rhythms are averaged out over time and a diachronic view of stress can be observed and tested (Van Uum et al., 2008). Correlations between hair cortisol and urine have been established, but not between hair cortisol and serum or saliva, likely as a result of daily fluctuations captured in serum and saliva tests (Van Uum et al., 2008).

3.3.3.1 Hair Cortisol Concentrations (HCC)

Assessing chronic stress from hair cortisol concentrations (HCC) is increasingly utilised in multiple fields, generating a staggering amount and breadth of research. Although not yet fully understood, it is hypothesized that similar to other hormones and drugs, free cortisol diffuses into the hair follicles through the blood stream during periods of hair growth (Novak et al., 2013; Van Uum et al., 2008). Once incorporated into the hair shaft, cortisol is thought to remain fixed within its deposited position, suggesting that sections of hair reflect discreet periods of time (Novak et al., 2013; Webb et al., 2015a). There is, however, natural variability in the timing of hair growth within and between individuals that needs to be considered in comparisons of HCC (de Kruijff et al., 2020; Stalder et al., 2017). Infants have a slower hair growth rate until the age of 2 years and as such their HCC would reflect a different period of incorporation than in an adult (de Kruijff et al., 2020; Russell et al., 2012). HCC is affected by washing (even just with water), colouring and exposure to natural sunlight (32% reduction after only 40 hours of exposure) and UV radiation (50% reduction after 40 hours) (Greff et al., 2019; Kirschbaum et al., 1992; Wester et al., 2016). Some studies (but not all, see- Sharpley et al., 2012) have found that cortisol concentrations decrease after the most proximal 3 cm from the scalp, which suggests a within individual variability that is not yet understood (Stalder et al., 2017). Hair cortisol concentrations have been obtained from archaeological samples of hair dating from 1-1000 CE (Webb et al., 2015a, 2015b, 2010). This important discovery demonstrates that cortisol can be preserved over the course of centuries,

recording physiological stress in the past for analysis in the present. Although there have been relatively few analyses of archaeological hair cortisol levels to date, the technique has yielded exciting and encouraging results, as the values obtained were quite high (Webb et al., 2015a, 2015b, 2010).

Recently, Nejad and colleagues (2016) successfully obtained and analysed cortisol concentrations from modern tooth dentine. Tested on a small sample of permanent third molars from 21 individuals, this first analysis of cortisol from within dental structures suggests that cortisol is present within dentine. However, as with HCC, it is not yet clear how cortisol might be incorporated into tooth structures. Cortisol could be deposited into dentine during the development of the tooth, reflecting stress during a discrete period of time. Alternatively, cortisol could enter dentine throughout the life course through dentinal tubules connected to the pulp chamber and blood supply. Although research into dental cortisol concentrations requires further investigation, this finding represents a potentially new method for examining chronic stress in modern and potentially past populations. Cortisol may be a more sensitive stress indicator than other skeletal markers and could help to identify hidden heterogeneity in frailty, by providing a quantitative assessment of systemic stress. When coupled with evidence that cortisol can be preserved over hundreds and thousands of years (Webb et al., 2015b, 2015a, 2010), this finding has important implications for the assessment of cortisol in archaeological teeth. Because hair is rarely preserved archaeologically and teeth represent some of the best-preserved tissues of the body, the ability to extract cortisol concentrations from archaeological tooth structures has significant implications for bioarchaeology and studies of stress in the past.

3.4 Summary

Assessment of population stress during Late Antiquity has unique potential to reveal the impact of socio-political and cultural change on health, supporting hypotheses of collapse or continuity. Studies of modern populations and the biocultural approach in bioarchaeology demonstrate the interplay of cultural, socio-political and biological factors, thereby highlighting the significance of health data to the debate. However, 'health', which takes into account mental and social states, cannot truly be assessed from skeletal remains. Instead, 'stress' states as a proxy for health are analysed. Previous analyses of skeletal stress indicators during periods of supposed collapse have yielded subtle or ambiguous results. This suggests that a conceptualisation of how societal collapse

affects health and would be manifested in skeletal stress indicators could be beneficial. The impact of cultural and socio-political influences are most pronounced through structural inequalities (as seen in subdivisions of a population) and in health during childhood, suggesting approaches to address subtleties and complexities in assessing 'health' from skeletal remains are needed. The stress pathway through the HPA axis is one mechanism through which external environments and conditions become biologically internalised, impacting health and well-being and potentially underlying the development of skeletal stress indicators. As such, it is important to explore and understand how stress becomes manifested in the body, and the impacts of socio-political change on health through a bioarchaeological and present-day lens. Through this approach, it has been revealed that it might be possible to evaluate cortisol concentration from archaeological tooth structures, which would be an important contribution to bioarchaeological and modern research.

Chapter 4

Materials

For the present analysis, data were collected from 13¹ archaeological skeletal collections located throughout France. Skeletal collections were under the care of four laboratories, De la Préhistoire à l'Actuel : Culture, Environnement et Anthropologie (PACEA) in Bordeaux, L'Anthropologie bio-culturelle, droit, éthique et santé ADES (UMR 7268) with l'ostéothèque régionale Provence-Alpes-Côte d'Azur (PACA) in Marseille and Aix-en-Provence, the Centre de Conservation et d'Etudes de Lorraine (CCEL) in Metz and the Centre de recherches archéologiques et historiques anciennes et médiévales (CRAHAM) in Caen. The collections were chosen based on the date, context and location of the site, the number and preservation of individuals and permission from the various laboratories. Sites that were in proximity to important locations in Gallo-Roman or Late Antique periods, or displayed typical Gallo-Roman burial rituals (Charon's obol, sarcophagi, feasting vessels) or 'Late Antique' rituals (row graves, weapon burials, jewellery) were particularly sought out. Both large and small excavations were included in this analysis, incorporating individuals and data often excluded from other research. Sites were grouped into larger categories based on their time period and geographic location (Gallo-Roman and Late Antique, North and South) (Fig. 4.1, Table 4.3). Pooling the cemetery sites into northern and southern regions permits a more direct comparison, in addition to addressing potential regional variability in transition. Each of the 13 sites is discussed, including summary information on the location, historical context, excavation, dating methods, archaeological features and the number of individuals recorded for the present research. In several cases, it was not possible to collect data from all individuals present or preserved. In these instances, individuals with 'better' preservation and adult individuals were prioritised to provide as much context and data for analysis as possible. Cremations and cremated skeletal remains were not analysed in this research.

¹ Data were collected from a total of 15 sites, but two sites were removed from the primary analysis, as explained below



Fig. 4.1. Map of sites assessed in this analysis. Black dots indicate Gallo-Roman South, white dots indicate Late Antique South and gray dots indicate Late Antique North.

4.1 Gallo-Roman

One of the primary goals of this research was to investigate potential changes in health status during the transition from Roman authority to that of the early Medieval Kingdoms. To accomplish this aim, it was important to provide comparative data from the Gallo-Roman period. The Gallo-Roman South group includes 156 individuals from two sites, one an urban artisanal community (Saintes, Rue Jacques Brel) and the other an urban context (Cirque Romain, Arles). Due to poor preservation in the acidic soil of northern France and the predominance of cremation during much of the Gallo-Roman period, only one small Gallo-Roman site from northern regions was available for research: Bayeux Rue de Verdun, comprising 17 individuals. As a result of the comparatively small sample size and limited representativeness of the remains, the data collected from this site

were not included in the formal analyses of this research. This, unfortunately, limits some of the interpretations that can be drawn from these analyses.

4.1.1 Gallo-Roman South (GRS)

4.1.1.1 Cirque Romain, Arles, 1st-4th centuries (ADES/PACA)

Arles is located in south-eastern France in the Bouches-du-Rhône department along the Rhone River, approximately 40 km from the Mediterranean coast. When the Romans took control of Arles (Arelate) between 123 and 121 BCE, they constructed a canal to connect the city with the Mediterranean (104 BCE), greatly increasing the importance of the port city (Heijmans, 2013). Arles was further incorporated into Roman lifeways when it became a colony for veterans from the Sixth Roman legion and received additional benefits for its support of Julius Caesar against Pompey sometime before 46 BCE (Bedon, 2001). Driven by its coastal location with important trade routes and strong rural economy, Arelate thrived during the 2nd and 3rd centuries as evidenced by the construction of lavish town houses and mosaics (Heijmans, 2013). However, by the end of the 3rd century, most of these villas were destroyed (Heijmans, 2013). In the 4th century, Arles became the site of the first Christian Council and the Roman emperor Constantine, and his family invested heavily in the city, ushering in a 'golden age' (Heijmans and Sintès, 1994). During this time, Arles was an important economic, religious and military centre for the Roman Empire and was even considered the 'Rome' of Gaul by Ausonius (*Ordo Urbium Nobilium*) (Fischer et al., 2010; Heijmans and Sintès, 1994). In the early 5th century, the seat of the Praetorian Prefecture of Gaul was moved from Trier along the Rhine frontier to Arles (Geary, 1988) and Arelate became the seat of the council of the seven provinces (Bedon, 2001). However, also in the 5th century, Arles was besieged at least seven times from 411 to 508 (Fischer et al., 2010; Heather, 2001). Still Arles maintained strategic importance for the Romans, where a mint was re-established in 418 and Avitus fled to the city in the wake of the 455 sack of Rome (Fischer et al., 2010). Arles has been described as 'the last bastion of Roman civilisation', maintaining its 'Romanitas' in the face of an ever increasing Visigothic influence (Heijmans and Sintès, 1994 p 166). By 480, Arles was in the control of the Visigoths and became a Frankish territory in 536 (Heijmans, 2013).

The site known as 'Cirque Romain, Arles' was excavated over the course of four months in 1989 by the Institut de Recherche sur la Provence Antique (IRPA) (Sintès, 1989). The necropolis was located in and around the former circus and was identified as one of several necropoli in Arles and its environs (Fig. 4.2). The site contained multiple types of burial, including cremations, inhumations

directly in the ground, as well as in wooden coffins and amphorae, and the use and re-use of stone sarcophagi (Sintès, 1989). Graves do not appear to be organized in a recognizable format or pattern, where different types of inhumation were dispersed throughout the necropolis (Sintès, 1989). Interestingly, several adult individuals were buried in large amphorae (Fig. 4.3), a practice more commonly associated with child or infant burials. The graves could only be dated to period of cemetery use; between the end of the 1st century to the 4th century, based on analysis of ceramics, pottery and other artifacts in addition to the stratigraphy (Sintès, 1989). Of the 119 burials that were excavated, 74 individuals were used in the present research (27 non-adults and 47 adults).

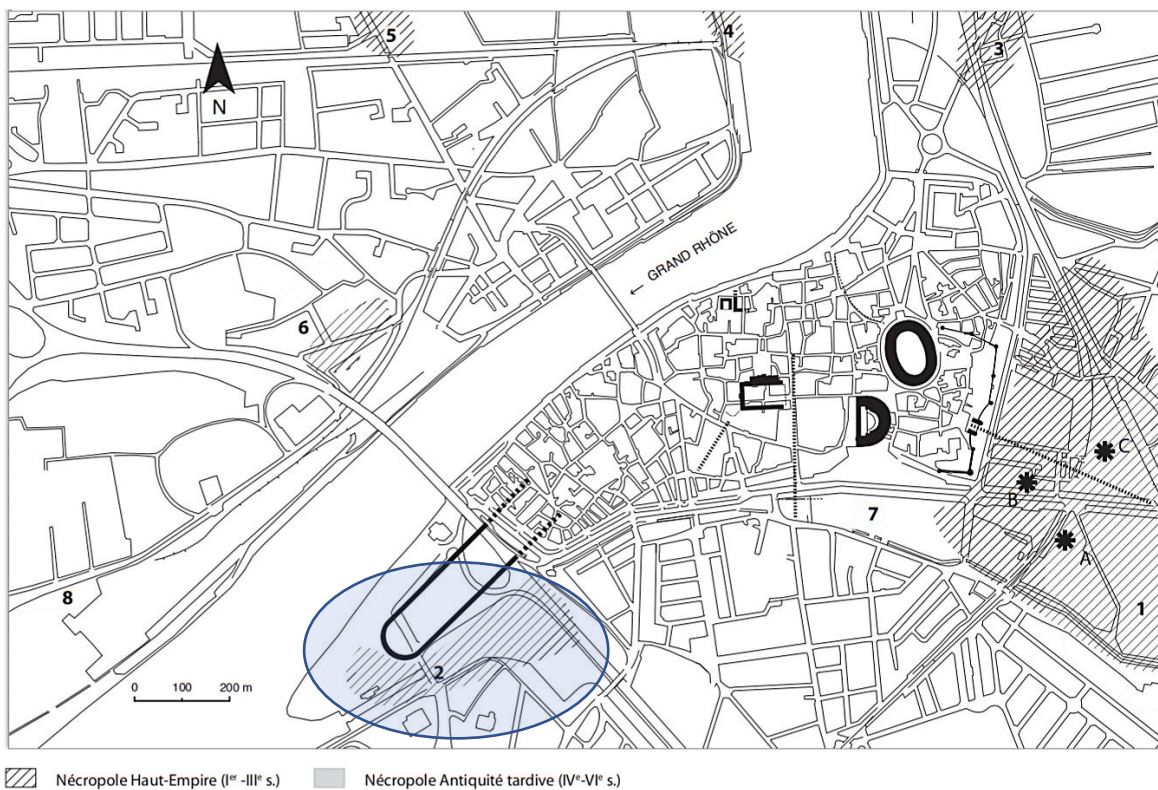


Fig. 4.2 Map of the Roman and Late Antique necropoli of Arles, with Cirque Romain, Arles (2) highlighted (Heijmans et al., 2012, p. 166)

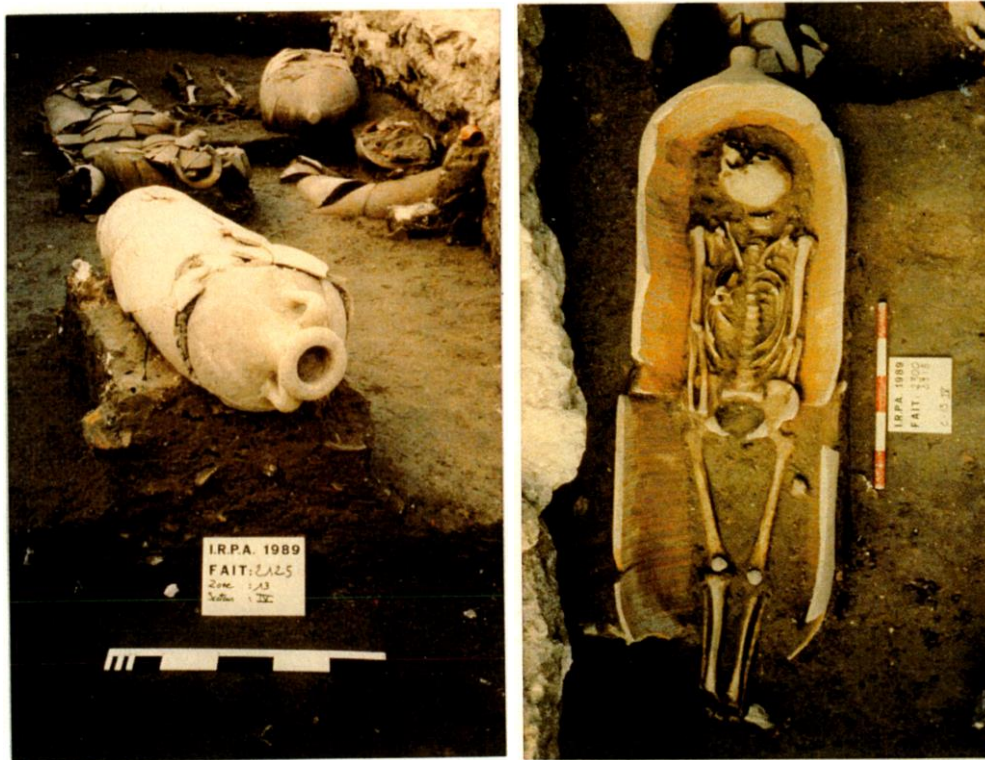


Fig. 4.3 Two adult burials in amphorae (Sintès, 1989 p. 16-17)

4.1.1.2 Saintes, la nécropole de la Rue Jacques Brel, 2nd- 3rd centuries (PACEA)

The necropolis known by the name ‘Saintes, Rue Jacques Brel’ is located in Saintes, southwestern France in the Charente-Maritime department, approximately 120 km north of Bordeaux. Saintes, known as Mediolanum Santonum by the Romans, was founded in the middle of the 1st century BCE and was walled at the end of the 3rd century (Bedon, 2001). Saintes was a large and important Roman town and has been associated with various types of craft works, including bronze work, ceramic manufacture, metallurgy and glass making. The salvage excavation took place over a total of two and a half months from 1995 to 1996. ‘Saintes, Rue Jacques Brel’ was located nearby an ancient Roman road, at the border of a community of artisans (Baigl et al., 1997). The site was excavated in its entirety and was dated to between the second half of the 2nd century CE to the end of the 3rd century based on stratigraphy, architecture and funerary depositions from multiple graves including, ceramics, glass and coins (Baigl et al., 1997). Of the 130 burials identified, 120 were inhumations and 10 were cremations. A little over half of the tombs (59%) had multiple grave goods, largely consisting of glass, ceramics, money, or small objects (all distributed fairly equally amongst males, females, adults and children). Other grave goods included Charon’s obol (in 6 inhumations and one cremation), two fibulae and several rings. Evidence of burial in sandals was found in seven graves (nails) and in 28 other graves, shoes had been placed in the grave by the feet

or shins (Fig. 4.4) (Baigl et al., 1997). The majority of the individuals were buried within wooden coffins, as evidenced by nails, with approximately 20 individuals buried directly in the ground. The inhumations were distributed throughout the excavated area, apart from a central rectangle, containing only five individuals (one cremation, one male, one female and three infants at the border). The remaining graves did not display a particular organization, except that burials 'en pleine terre' tended to be on the edge of the site (Baigl et al., 1997). Men, women and children appeared to be buried throughout the cemetery without any clear pattern (Baigl et al., 1997). Almost all burials were single inhumations, with the exception of a particularly noteworthy double burial (Fig. 4.5). Individuals were mostly buried in a supine position with slight variations of the arms and legs. Again, with the exception of the double burial, in which both individuals were placed on their sides. Within the context of the present research, 82 individuals were assessed (22 non-adults, 60 adults).

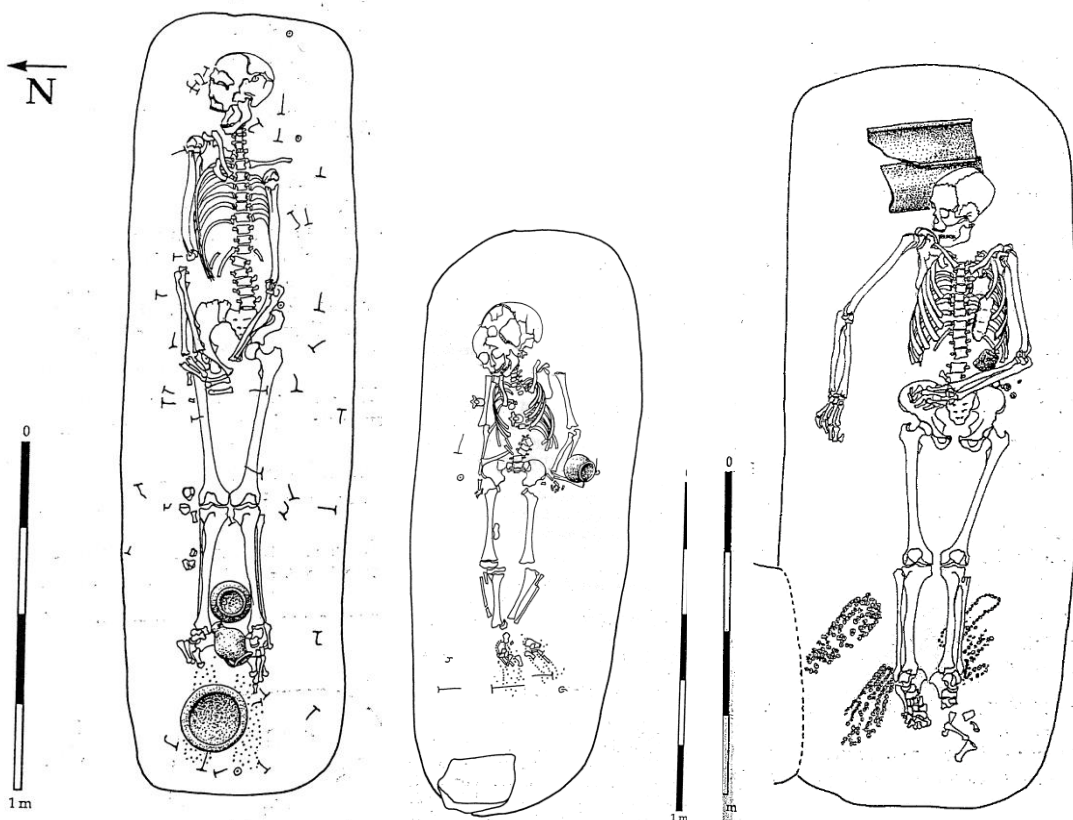


Fig. 4.4 Three separate burials from Saintes, Rue Jacques Brel. Sep 18 displaying multiple nails from a wooden coffin, nails from shoes and three ceramic vessels at the feet (Planche 3); Sep 108 displaying non-adult plain burial with shoes and a small ceramic vessel (Planche 42); Sep 62 displaying adult plain burial with shoes (Planche 24) (Baigl et al., 1997)

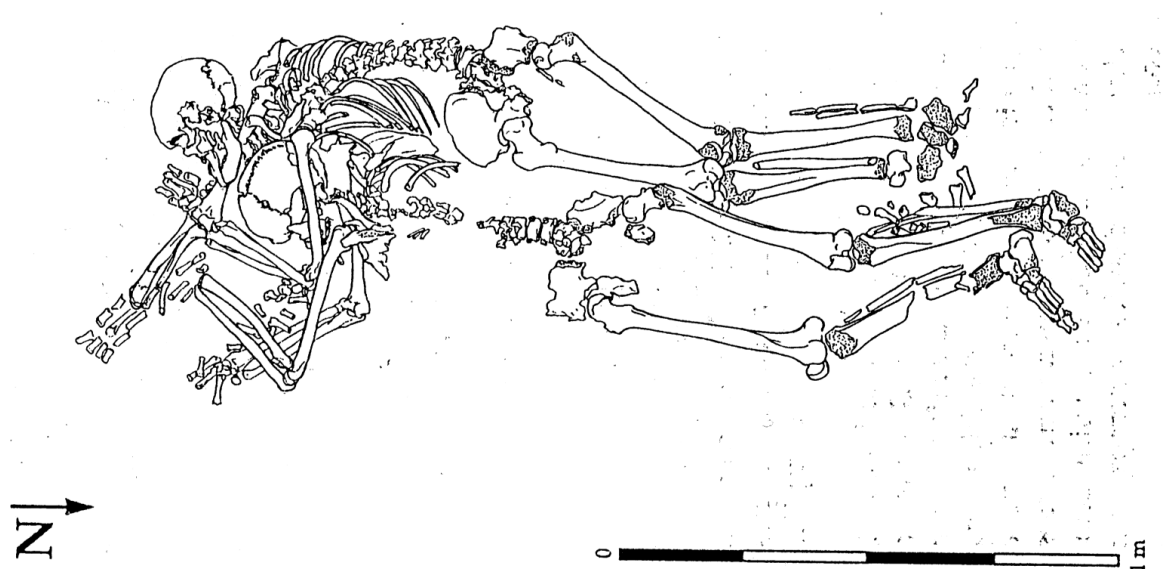


Fig. 4.5 Sep 59 from Saintes, rue Jacques Brel displaying a double burial (Baigl et al., 1997 Planche 23)

4.2 Late Antiquity (4th-7th centuries)

Addressing issues of health during periods of transition, this analysis examines health status of individuals from multiple sites dated to the Late Antique period, broadly understood as between the 4th and 7th centuries. The sites are further grouped based on geographic region (South and North). This permits the observation of regional variability in addition to diachronic change.

4.2.1 Late Antique South (LAS)

Skeletal data for the group known as Late Antique South are derived from six archaeological sites dated from the 4th to the 7th centuries². All sites are located south of the Loire River and as large a geographical coverage as possible was sought. Both 'urban' and rural cemetery sites are included.

²Data from 93 individuals from the site known as Seyssel-Albigny were collected. Original dating of the site was between the 6th and 7th centuries (Bizot and Serralongue, 1988), but subsequent publications have listed the site as dating from the 6th to the 11th centuries (Perez, 2013). Due to these inconsistencies and uncertainties in the dating of the site, these data were omitted from the rest of the analysis to maintain the validity of the study.

4.2.1.1 La nécropole de la Grande Bastide de Cadarache, 4th-7th centuries (ADES/PACA)

The necropolis site of the Grand Bastide de Cadarache is located in the Bouches-du-Rhone department of south-eastern France, approximately 30 km north of Aix-en-Provence. As with many ancient Roman cemeteries, La Grande Bastide de Cadarache was located near to a Roman road; this one connected Aquae Sextiae or Aix-en-Provence to Reii Apollinares or modern day Riez (Pouyé et al., 1994). The necropolis is located in a rural area, away from any known religious centres, but is approximately 1800 metres south of a Roman villa, which was occupied from around the 1st to the 5th centuries (Pouyé et al., 1994). Salvage excavations of the site took place in three phases (A,B,C) from 1964 to 1965 (Pouyé et al., 1994). Zones A and B were excavated concurrently with construction work, complicating and constraining excavation methods. However, Zone C was subject to a more exhaustive and methodological excavation (Figs. 4.6-4.7) (Pouyé et al., 1994).

One-hundred-ninety-eight burials were excavated, nine from zone A, eight from zone B and 181 from zone C. Four types of graves were identified, including coffins formed out of tiles, coffins made of local stone slabs, coffins formed of a mixture of tiles and stones, and burials directly in the ground (Pouyé et al., 1994). Very few grave goods were found, mostly consisting of clothing accessories and jewellery, regional pottery from the 4th and 5th centuries and some bronze buckles dating to the 6th century. Grave 43 was the most elaborately furnished grave, containing a single coin attributed to Childebert (likely minted from 546-548 in Marseille), along with two oval and one rectangular bronze buckles (Pouyé et al., 1994). As a result, the cemetery has been dated from the 4th to the middle of the 7th century (Pouyé et al., 1994). The excavators observed a small temporal trend where the cemetery appears to develop from the northwest to the southwest, with plain earthen burials and the occasional piece of pottery dating to the 4th and 5th century being slowly replaced by burials in tile or stone coffins and 'dressed' burials from the 6th and 7th centuries (Pouyé et al., 1994). The grave goods, although sparse, were distributed amongst a relatively few graves (88 funerary objects across just 39 tombs) (Pouyé et al., 1994). A large iron key was found in tomb 121, which is a practice occasionally found in northern France or in the Alps, especially in female graves (Pouyé et al., 1994). All graves were oriented on the east-west axis and previous analyses of sex found that males, females, children and adults were equally distributed throughout the cemetery (Parmentier and Signoli, 2012). Burials were mostly individual graves with all individuals laid in a supine position, apart from one double burial (Parmentier and Signoli, 2012). Due to time constraints, out of the 198 burials, 106 individuals were utilized in this analysis (27 non-adults and 79 adults).

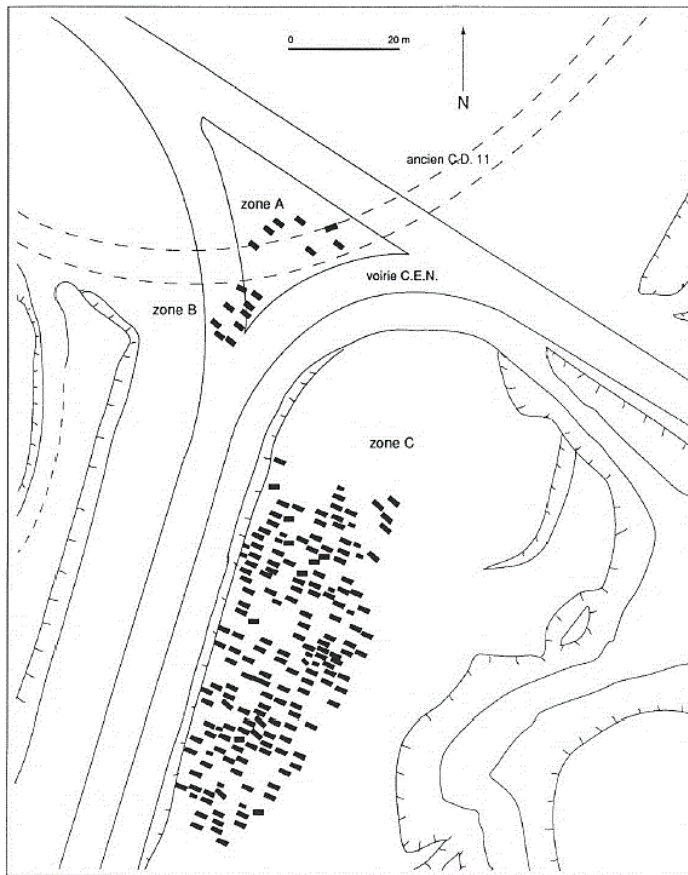


Fig. 4.6 Map of the necropolis de la Grande Bastide de Cadarache (Pouyé et al., 1994 p. 100)



Fig. 4.7 Zone c of the necropolis de la Grande Bastide de Cadarache, view from the south (1965-Cl. C.E.N. Cadarache in Pouyé et al., 1994 p. 99)

4.2.1.2 La Granède, 4th -7th centuries (PACEA)

The site of La Granède is located in Millau, on the top of a rocky plateau in between two rivers in the Aveyron department of south-central France (Saint-Pierre, 2010). Because of its elevated location, La Granède would have been difficult and even impossible to access from the west and southwest, providing a strategic location, but also preserving archaeological remains (Saint-Pierre, 2010). Nearby (2 km from Millau), La Graufesenque was a major pottery/ceramic production centre, producing high quality terra sigillata and exporting it across the Western Roman Empire into the 2nd century (Bourgeois, 1995; Drinkwater, 2014). La Granède was originally identified in 1921 by Albert Carrière but was only subject to systematic excavation in 2007-2009 under Christophe Saint-Pierre (Saint-Pierre, 2010). During excavation, the remains of a Late Antique sanctuary and an early Medieval church were discovered. The church is thought to have been constructed around the 5th century and then greatly expanded from the 8th to the 10th centuries. Remains of sepulchres, or inhumation sites, have been found both inside and outside the church building (Saint-Pierre, 2010). The dominant orientation of the graves is east to west with the head placed to the west, however five graves were placed along a north-south axis, with the head situated toward the north. It appears that this choice was a result of the burials' placement within the walls of the church (Fig. 4.8) (Saint-Pierre, 2010). One hundred-sixty-one individuals were excavated. Radiocarbon dating was applied to a third of the excavated skeletons, finding dates from the 4th to the 13th century (388 CE to 1265 CE) (Saint-Pierre, 2010). Within this broad time period, more specific phases within the site have been identified. However, surrounding archaeological evidence has yet to yield more defined phases within the burials themselves. As a result, only individuals who were radiocarbon dated to the Late Antique period (4th-7th c.) were included in this study (11 individuals-10 adults and 1 non-adult) (Table 4.1).

Table 4.1. Individuals from La Granède included in this analysis (Saint-Pierre, 2010)

Individual	Radiocarbon Dates	Century	Adult/Non-Adult
Sep 37 Suj 18	388-540	4-6	Adult
Sep 10 Suj 8	422-563	5-6	Non-adult
Sep 33 Suj 20	424-573	5-6	Adult
Sep 48 Suj 39	536-638	6-7	Adult
Sep 50 Suj 32	541-644	6-7	Adult
Sep 65 Suj 46	542-645	6-7	Adult
Sep 64 Suj 50	550-654	6-7	Adult
Sep 1 Suj 2	560-652	6-7	Adult
Sep 32 Suj 16	565-653	6-7	Adult

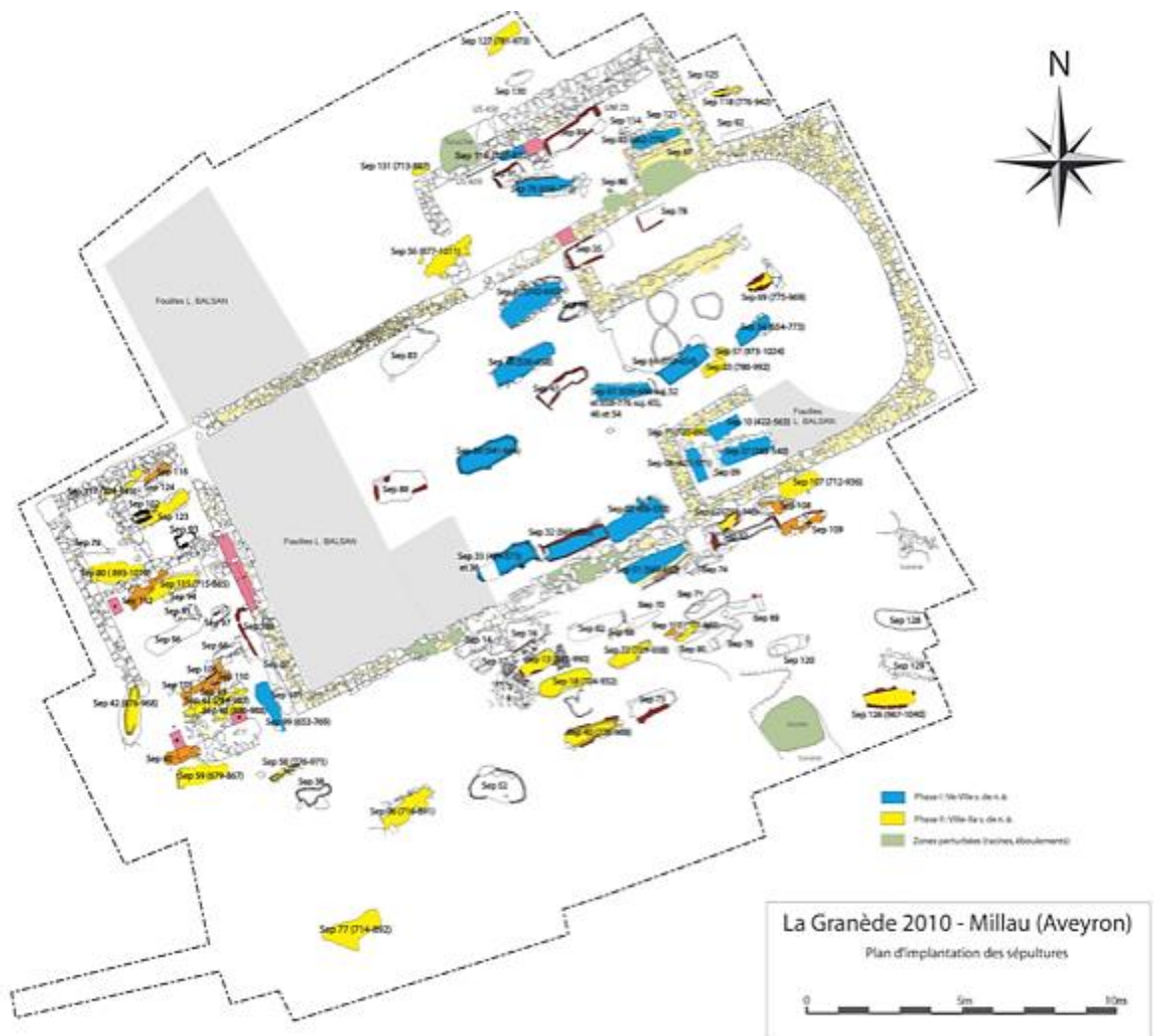


Fig. 4.8 Map of Granède with church walls and sepulture locations (Naji, 2012, p. 87).

4.2.1.3 La nécropole du Colombier, Vaison-la-Romaine, 5th- 6th centuries (ADES/PACA)

La nécropole du Colombier in Vaison-la-Romaine is located in south-eastern France, in the Vaucluse department in the Provence-Alpes-Côte d'Azur region. Conquered by the Romans in the second century (125-118) BCE, Vaison-la-Romaine, known as Vasio Vocontiorum became a thriving and wealthy city in the Roman Empire. However, there is evidence of marked contraction (especially to the north and east of the city) during the 3rd century, without any signs of reconstruction until the middle of the 4th century (Rivet, 1988). From the middle of the 4th century, stone edifices from monumental buildings such as the Northern Baths (thermes du Nord) were re-used as building blocks for new structures (Bedon, 2001). Vasio Vocontiorum was alternatively conquered by the Burgundians and the Goths in the 6th century, eventually becoming part of the Frankish Empire in 545 (Bedon, 2001).

The necropolis of Colombier in Vaison-la-Romaine was located in a peri-urban zone in the north of the city and was excavated from 1987 to 1988 (Carru, 1991). As part of a salvage excavation, the site could not be excavated in its entirety and may be only a small peripheral part (the northern corner) of a much larger cemetery (Carru, 1991). The cemetery appears to surround the Saint-Quenin Chapel, which contains elements of 5th century chancels used in its facade (Carru, 1991). Three major groups of tombs were identified, consisting of 39 simple earthen graves, 57 graves with simple covers and 37 graves in full coffins. Several tomb covers had visible epitaphs. These included a priest named Eripivs dated 519, a deacon, Amicvs who died in 536 and Stephanina who died in 470 (Carru, 1991). Surrounding the chapel, 18 stone sarcophagi were found. These sarcophagi had been constructed out of altars and several had visible inscriptions. Multiple stone sarcophagi were found in the necropolis, including sarcophagi containing children. These sarcophagi displayed evidence of re-use, with as many as four individuals inside. Carru (1991) has argued that the presence of so many stone sarcophagi in Vaison-la-Romaine may reflect special local circumstances (related to the presence of stone within the urban cemetery), as opposed to more general trends in funerary practices or privileged status of the population. No 'Roman' funerary offerings, such as coins or feasting vessels, were discovered at the site. The only grave goods were a small amount of jewellery or decorative items, including several earrings, rings and beads (Carru, 1991). The graves were distributed in an organized fan pattern in curved rows, with a distinct border around each grave and no superimposition of the graves (Fig. 4.9) (Carru, 1991). Based on funerary goods, in addition to stratigraphy and the morphology of the excavated tombs, the necropolis was dated to between the 5th and the 6th centuries (Carru, 1991). All tombs came from a single stratigraphic level. All graves were oriented along the east-west axis, and the majority of individuals were placed in a supine position (Carru, 1991). One hundred-thirty-one individuals were excavated, 53 of whom were under the age of 18 (Carru, 1991). Previous work has identified the earliest evidence of leprosy in France from this site (Blondiaux et al., 1994). Due to time constraints during data collection, 80 individuals (14 non-adults; 66 adults) were included in the present research. Selection of individuals was based on accessibility and availability.

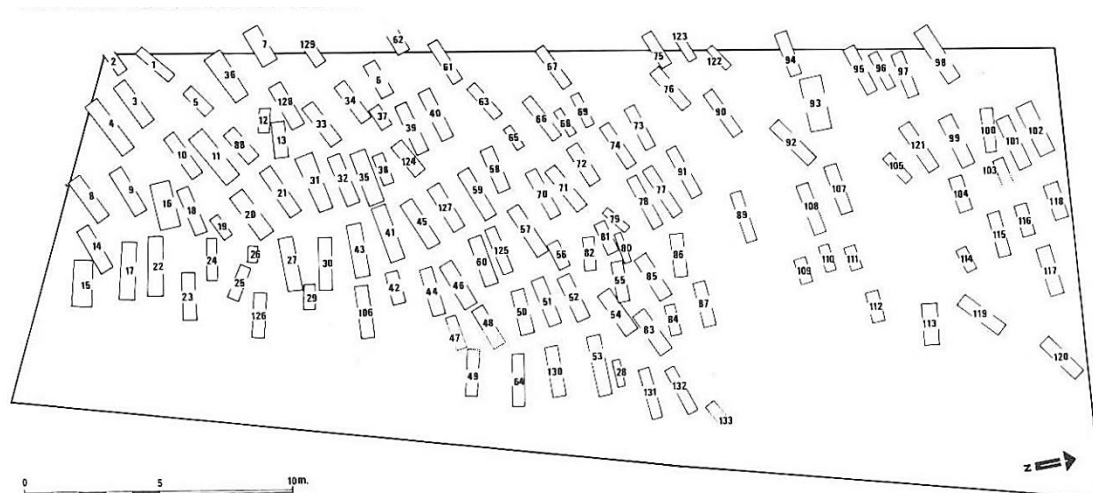


Fig. 4.9 Plan of the Colombier necropolis (Carru, 1991 p. 71)

4.2.1.4 Les Clavelles, 6th -7th centuries (ADES/PACA)

Les Clavelles is a small archaeological site located in the Durance Valley near Lurs in south-eastern France in the Alpes-de-Haute-Provence department. As a rural area with rich agricultural resources and its location along the major communication route of the Via Domitia, the Durance Valley was quite densely populated during Antiquity (Boiron, 1993). The Via Domitia was the first Roman road built in Gaul and connected Italy to Hispania, crossing much of southern Gaul, with a stop at nearby Lurs or Lurium (Drinkwater, 2014). Sources are scant for this area, but there is evidence that the Via Domitia was still in use during the 6th century. A portion of Les Clavelles was the subject of an urgent salvage excavation led by Roger Boiron for the Direction Régionale des Antiquités for the construction of an autoroute in 1988 (Boiron, 1993). Excavations revealed that Les Clavelles had been used as cemetery in Roman and Late Antique periods, with a gap of approximately 300 years, when the site was abandoned (Boiron, 1993). Notably, the earlier cemetery does not appear to have been disturbed (only one cremation is disturbed), as new graves were placed in the spaces left empty by the previous burials (Boiron, 1993). Only four graves had funerary depositions, which consisted of bronze rings, a pair of earrings, and several buckles. These items allowed for an approximate date of the 6th to the 7th centuries for the later cemetery (Boiron, 1993). Thirteen graves contained non-adults, and 19 contained adult burials, but only 20 individuals appear to have been excavated (Boiron, 1993). All graves were simple burials directly in the earth or on a limestone slab, with individuals placed in a supine position in both north-south and east-west orientations (Fig. 4.10) (Boiron, 1993). Twelve individuals comprising 7 adults and 5 non-adults were used in this analysis.

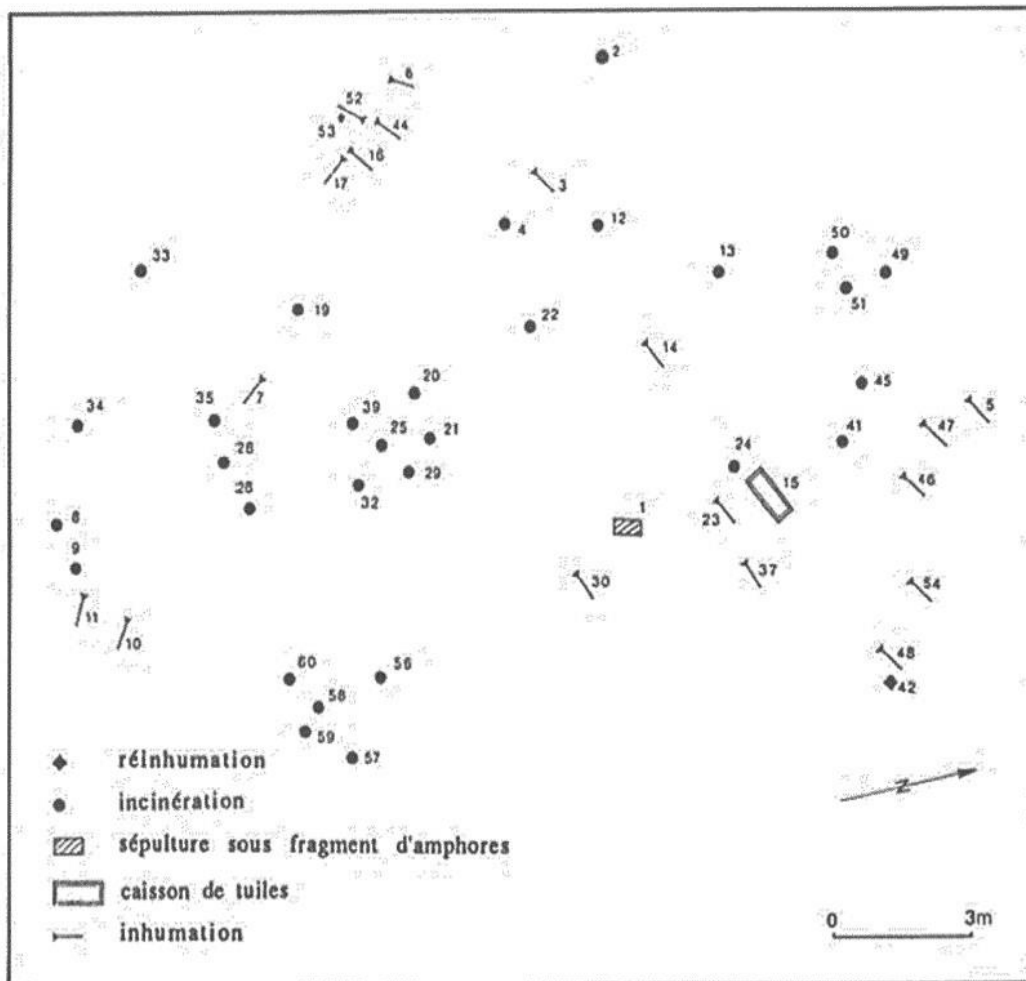


Fig. 4.10 A map of Les Clavelles displaying burials from both the Roman and Late Antique periods (C. Landure in Boiron, 1993 p. 327)

4.2.1.5 Saint-Martin, La Brillanne, 4th-5th centuries (ADES/PACA)

Saint-Martin (La Brillanne) is a small archaeological site located 1.5 km north of the village of La Brillanne (Briniana), also in the Durance Valley of the Alpes-de-Haute-Provence department. As with Les Clavelles, Saint-Martin (La Brillanne) was located in a rural area nearby the via Domitia, meaning that it had a strategic, if rural, position during the Roman Empire and Late Antiquity (Boiron, 1993). In 1988, a portion of the site was the subject of an urgent salvage excavation operated by the Direction Régionale des Antiquités. There was a continued presence at the site through the medieval period, without the interruption seen in Les Clavelles (Boiron, 1993). Funerary evidence indicated that the site was in use between the second quarter of the 4th century and the 5th century (Boiron, 1993). Eight graves seem to have been placed in intentional pairs, mostly consisting of adults (male/female couples). Only one non-adult was excavated (Boiron,

1993). Most graves had grave goods, consisting of ceramics, metal or glass items, placed at either the head or feet (Boiron, 1993). Three graves had decorative items, including bronze bracelets and earrings and several coins were found, placed by or on the head, with one placed near the ribs (Boiron, 1993). The graves were organized into four rows, following both north-south and east-west axes (Fig. 4.11) (Boiron, 1993). Most individuals were lying in a supine position with the exception of one, who was placed on their side (Boiron, 1993). Fifteen individuals were excavated, 10 of whom had adequate preservation to be included in this analysis (9 adults and 1 non-adult).

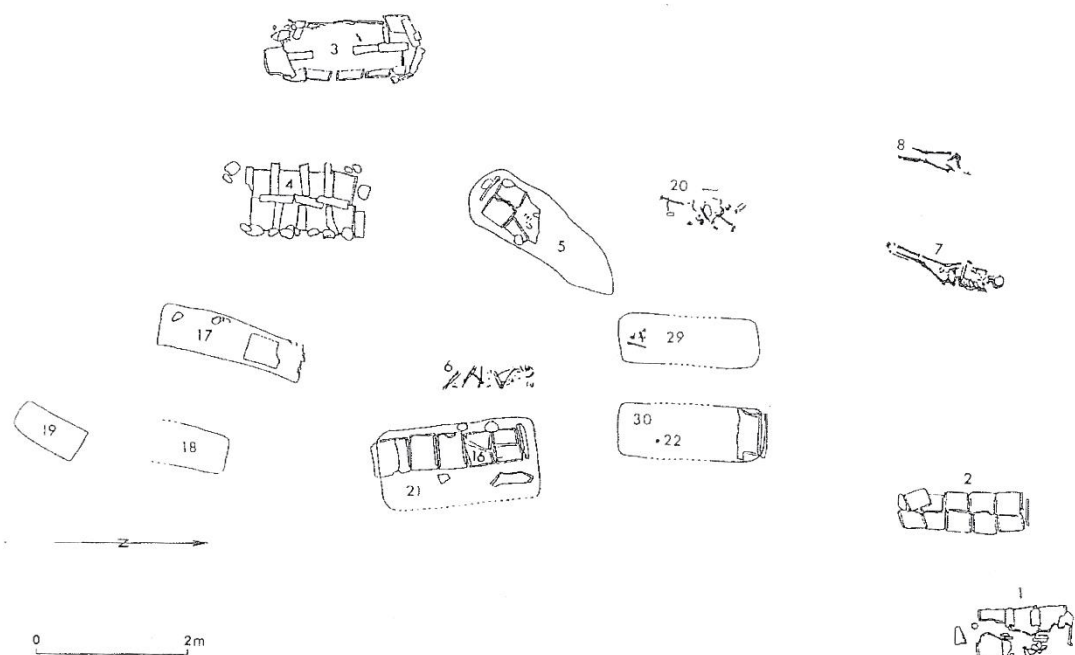


Fig. 4.11 Plan of the Saint-Martin (La Brillanne) cemetery (C. Landure, in Boiron, 1993 p. 329)

4.2.1.6 Rues de Toulon, 4th-7th centuries (ADES/PACA)

Skeletal remains from Toulon used in this research derive from the excavation of several streets within the city, located in the Var department of the Provence-Alpes-Côte d'Azur region on the Mediterranean coast. The Roman colony of Telo Martius was established at Toulon in the 2nd century (123-121 BCE) and quickly became an important harbour city. It was one of two main centres for the manufacture of Roman dyes, including imperial purple (Bedon, 2001). Some have argued that there was considerable continuity in living conditions and practices in Toulon and the greater surrounding areas from the 2nd to 7th centuries (Février, 1978). However, there is evidence of deterioration in finely built houses and mosaics beginning in the mid-4th century (Bedon, 2001). Two urgent salvage excavations took place along several streets within the old centre of Toulon to

install water systems (Fig. 4.12) (Pouget et al., 2002; Salicetti, 1998). The first took place in 1978 on Rue Ch. Poncy, Rue Berthelot and Rue Andrieu under the direction of M. Pasqualini and the Centre Archaeologique du Var (CAV) (Brun, 1978; Salicetti, 1998). The second excavation took place in 1997 on the street Rue Ch. Poncy under P. Salicetti in which four individuals were exhumed (Pouget et al., 2002; Salicetti, 1998). No grave goods were discovered, although seven individuals were buried in African amphorae (dated to 5th and 6th centuries). Based on the grave/tomb typologies and type of African amphora, the sites were dated to between the 4th and the 7th centuries (Pouget et al., 2002). Three individuals were buried in coffins formed from stones, one individual was buried in a coffin made of tiles, stones and pieces of amphorae and one individual was buried directly in the ground (Brun, 1978; Pouget et al., 2002; Salicetti, 1998). These burials were superimposed on mosaics, suggesting that the area had been previously used as a habitation. This has been interpreted as a sign that the living space (and population) in Toulon contracted at some point (Brun, 1978; Pouget et al., 2002; Salicetti, 1998). Most inhumations were oriented on the east-west axis apart from one which was along the north-south axis (Brun, 1978; Salicetti, 1998). There was no evidence of overlapping or disturbed graves, possibly suggesting that there were grave markers visible to the population (Salicetti, 1997). Twenty-seven burials were excavated, yielding 19 individuals that were appropriate for this study (2 non-adults and 17 adults).

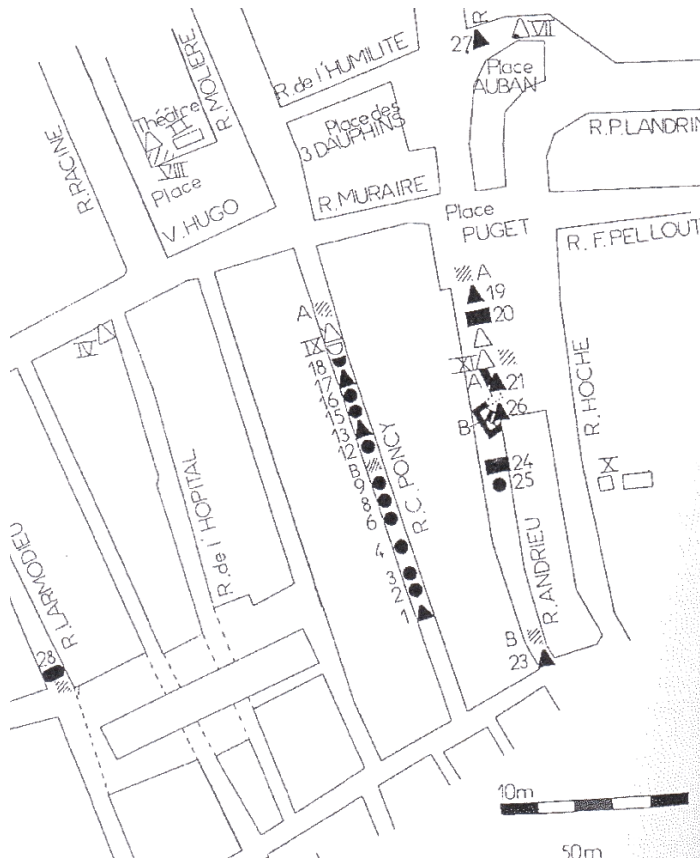


Fig. 4.12 Map of Rues de Toulon excavations (Pouget et al., 2002 p. 296). Triangles indicate burials under stones and tiles; rectangles are stone coffins; circles are tombs in amphorae; ovals are burials en plaine terre.

4.2.2 Late Antique North (LAN)

The Late Antique North group comprises individuals from five archaeological sites dated from the 4th to the 7th centuries. All sites are located north of the Loire River, in eastern or western regions. Sites that showed evidence of 'Late Antique' burial rituals, such as row graves or weapon and jewellery grave goods, were particularly sought out. Both 'urban' and rural cemetery sites are included.

4.2.2.1 Le Clos des Cordeliers, 5th-6th centuries (PACEA)

Le Clos des Cordeliers is an archaeological site in Sens, approximately 120 km south of Paris in the Yonne department. Sens is thought to have been an oppidum for the Senones, a Celtic tribe in Gaul, before it became a Roman city in the first century BC (Bedon, 2001). The city retained its own structure, only adopting a Roman orthogonal structure in the middle of the 1st century; it was walled in the 3rd century. In 356, Sens was attacked and besieged by the Alemanni (Bedon, 2001). Salvage excavations in 1989 led by D. Maranski uncovered four mass graves in addition to living structures (Guignier, 1997, 1996). These were dated roughly to between the 4th and 7th centuries. The excavated individuals had been buried simultaneously, with several bodies entangled and overlapping, but also maintaining their anatomical connections (Fig. 4.13) (Castex, 2008; Guignier, 1997, 1996). Historical sources have suggested that plague (Justinianic Plague) was present in Sens in 571 CE and led archaeologists to speculate as to whether the mass graves at Le Clos des Cordeliers were plague graves (Guignier, 1997). The burials were subsequently radiocarbon dated to between the 4th and the 6th centuries, confirming the proposed dating and aligning the burials with the period when the plague was reportedly in Sens (Castex, 2008). Chemical analyses were then undertaken, discovering the presence of *Yersinia pestis* in 10 teeth from three individuals buried in Le Clos des Cordeliers, confirming the presence of plague (Castex and Drancourt, 2005; Drancourt et al., 2004). However, the validity of these results have been called into question (Eisenberg and Mordechai, 2019; Gilbert et al., 2004) and tests have not been repeated or replicated in subsequent analyses (McCormick, 2016, 2015). Within the four graves, a minimum of 73 individuals were identified, including 45 adults and 28 non-adults (Castex, 2008). Fifty-six individuals were included in this analysis (16 non-adults; 40 adults). Although plague may have been identified in this cemetery site, creating a special set of circumstances surrounding the deaths of these individuals, they remain valid in this analysis. Because this research is examining mostly factors affecting childhood health and development, these individuals still speak to the changes

taking place during the time period. Despite some indications that the plague might have killed indiscriminately, *Yersinia pestis* has been shown to differentially (or selectively) affect mortality based on age and frailty in later Medieval populations (DeWitte, 2010, 2009; DeWitte and Wood, 2008). Factors negatively affecting health in childhood, therefore, could have impacted on adult susceptibility to or the overall morbidity of the individuals who died from plague. As such, the data generated from this site will be interpreted with additional caution and in dialogue with the special context from which they derive.



Fig. 4.13 Burial from Le Clos de Cordeliers (D. Maransky, in Castex, 2008 p. 28)

4.2.2.2 Saint Martin de Fontenay, 4th-7th centuries (CRAHAM)

The necropolis of Saint Martin de Fontenay is located 10 km south of Caen and 7 km from Vieux (Aregenua) in the Calvados department of Normandy, France. Several Gallo-Roman villas have been identified in Normandy and strong Gallo-Roman presence in the region has been noted (Pilet et al., 1994). In the 3rd century, Normandy shows evidence of significant destruction, resulting from raids. After the 3rd century, Aregenua was administratively absorbed into Bayeux as part of the new civitas Viducassium (Buchet, 1993; Vipard, 1987). In 406-7 Germanic raids from the west, coupled with Saxon raids on the coast further troubled the region (Wood, 1997). In 457, the Soissons domain was created by Aegidius, separating the region from Roman authority. This new kingdom remained under his son and heir Syagrius until 486, when it was conquered by the Franks (Heather, 2001). Saint Martin de Fontenay was excavated in its entirety as part of an urgent salvage

excavation from 1985-1986 (Pilet et al., 1994). The site covers a rectangular space of approximately 8000m² and consisted of 944 graves with 880 inhumations and 64 cremations (Fig. 4.14) (Pilet et al., 1994).

Saint Martin de Fontenay was a rural necropolis with evidence of a nearby villa dated to the 50s CE located 700 m to the east. The site was dated to between the 5th or 4th century BCE to the 7th century CE, based on funerary objects and tomb typology (Pilet et al., 1994). Only individuals identified as belonging to the 4th to the 7th centuries were included in the present analysis. There was a wide variety of grave goods present with the inhumations from Saint Martin de Fontenay, including Charon's obol, a pet (?) dog in a child's grave, evidence of grave site feasting (animal jaws and teeth, goblets and ceramics, shells) and jewellery and weaponry (Pilet et al., 1994). Some 745 graves were dated to between the 4th and the 7th centuries (Table 4.2) (Pilet et al., 1994). Several high-status graves from the 5th and 6th centuries were identified based on special weapon or jewellery depositions and 'Danubian' style fibulae (large fibulae made of hammered silver with bronze appliqué and an elongated foot) (Dierkens and Périn, 2003) were also found. Graves were almost entirely single inhumations and were mostly oriented along the east-west axis (exceptions were north-south) (Pilet et al., 1994). Individuals were buried in wood coffins as attested by the presence of nails within the graves, in limestone sarcophagi or were buried directly in the ground (Pilet et al., 1994). From the 5th century onwards, all graves were oriented east-west, and graves were organized in more or less regular rows, with only occasional interruptions, which might suggest some additional familial organisation (Pilet et al., 1994). Almost all individuals were interred in a supine position with variable placement of the arms (Pilet et al., 1994). Previous anthropological work has identified several individuals with artificially deformed crania (Fig. 4.15), as well as several individuals with healed trepanations and at least two individuals with tuberculosis (Alduc-Le Bagousse, 1994; Pilet et al., 1994). Two hundred thirty-two individuals dated from the 4th to the 7th century were assessed for this analysis (Table 4.2).

Table 4.2. Number of individuals excavated and used in the present research organized by century

Century	Individuals Identified (Monograph)	Adults (Monograph)	Non-adults (Monograph)	Individuals used in PhD (total)	Adults used in PhD	Non-adults used in PhD
4 th	34	22	4	8	7	0
5 th	64	56	8	41	35	6
6 th	264	194	54	126	99	28
7 th	550	274	130	61	50	11
Total	912	546	196	236	191	45



Fig. 4.14 Map of the burial plan from Saint Martin de Fontenay (Pilet et al., 1994 p. 63)



Fig. 4.15 Sep 300 from Saint Martin de Fontenay displaying artificial cranial deformation (author) and a pair of silver fibulae found in burial 300 (Pilet et al., 1994 p. 100)

4.2.2.3 Ancienne Chambre des Métiers, Rue de Tombois (Metz), 4th century (CCEL)

The site known as Ancienne Chambre des Métiers, Rue de Tombois is located in the city of Metz, in the Moselle department of Lorraine, France. Metz was a particularly important centre during the Roman, Late Antique and Medieval periods. Previously the site of a Celtic oppidum of the Mediomatrici from 450 BCE, Metz was conquered by the Romans in 52 BCE (Bedon, 2001). Divodurum Mediomatricorum, or Metz in its Roman form, was located at the juncture of several important routes, connecting northern Gaul to the Mediterranean (Lefebvre and Wagner, 1984; Halsall, 1990). In the middle of the 3rd century, Divodurum was walled, perhaps in response to ‘barbarian’ attacks. The Romans lost control over Northern Gaul, with the Gallic Empire established under Postumus in 260 only to be recovered in 274 (Drinkwater, 2014; Wightman, 1985). Around 300 CE, Diocletian’s reforms saw the restructuring of northern Gaul, dividing Belgica into Belgica Prima (Trier, Eastern) and Belgica Secunda (Wightman, 1985). The Moselle valley prospered in the 4th century due to its proximity to Trier, the capital of the Western Roman Empire at the time (Wightman, 1985). However, the invasion of the Vandals, Alans and Suevi over the Rhine in 406/7 resulted in extensive destruction of the Moselle valley, as the barbarians crossed through it (Halsall, 2000). In 451 CE the Huns destroyed Trier and the battle of the Catalaunian fields between the Huns and a combination of Roman and Barbarians (Visigoths and Franks) took place between the Seine and the Moselle rivers, further damaging the region (Collins, 2001). Following the Hunnic raids and their ultimate defeat, the kingdom of Soissons was established in northern Gaul from 457 to 486, further separating the area from Roman authority (Heather, 2001). At the end of the 5th

century, Metz was overtaken by the Franks and it became a residence for the Merovingian kings of Austrasia in the 6th to 8th centuries, cementing its importance (Collins, 2001; Yoon, 2016). Ancienne Chambre des Métiers, Rue de Tombois was part of a larger cemetery, which would have been just outside the walls of the ancient city of Metz. The site was excavated as a salvage excavation for six months in 1995 and 1998 (De Filippo et al., 2000). Based on ceramic, decorative items (fibulae, belt buckles, jewellery) and coin depositions, the graves were dated to the second half of the 4th century (350/60-400 CE) (De Filippo, 2000). Thirty-six burials were excavated; most had been buried directly in the ground with a few individuals buried in wooden coffins with nails (Fig. 4.16) (De Filippo, 2000). Graves were mostly oriented northwest to southeast with individuals placed in a supine position (Figs. 4.17) (De Filippo, 2000). Thirty-five individuals comprising 27 adults and 8 non-adults were used in this analysis.

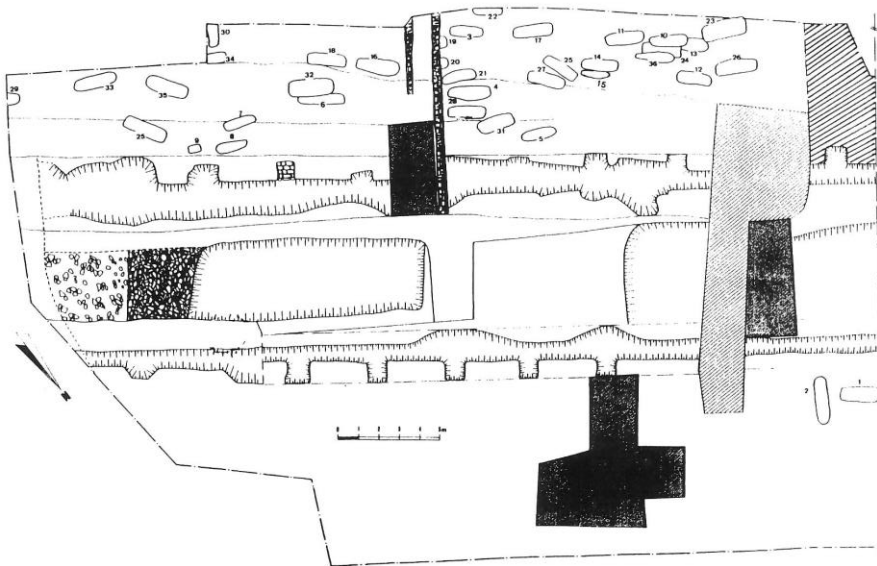


Fig. 4.16 Rue du Tombois plan of Zone 1, the necropolis (De Filippo, 2000 p. 51)

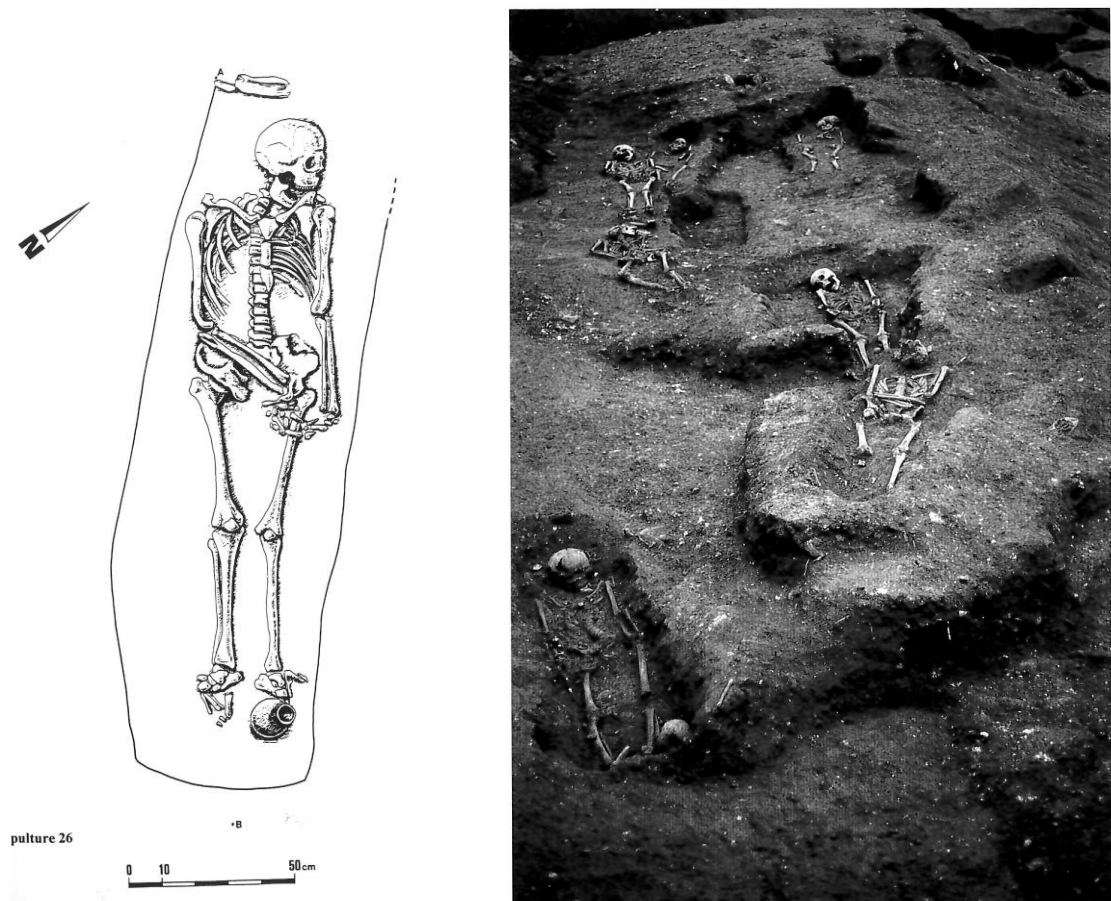


Fig. 4.17 Rue du Tombois Zone 1 tomb 26 and tomb 17 (De Filippo, 2000 p. 52-53)

4.2.2.4 Fontoy, 4th - 7th centuries (CCEL)

The site known as Fontoy Rue de l'église is located 40 km north west of Metz on the Moselle River in the Moselle department, on a small eminence or promontory overlooking the village of Fontoy. Inhabited since the Mesolithic, the Moselle region was conquered by Caesar in 57 BCE (De Planhol and Claval, 1994). As previously mentioned, the region played an important role during the Gallo-Roman period and during Late Antiquity due to its proximity to the Rhine frontier (Wightman, 1985). The necropolis at Fontoy was located near an important Roman road connecting Trier and Metz, in addition to a villa and quarry (Seilly, 1995). Fontoy Rue de l'église was excavated over the course of four months in 1990 as an urgent salvage excavation (Seilly, 1995). The Merovingian cemetery was found to be superseding a Gallo-Roman habitat and cemetery, suggesting continuity in the area, but also a potential contraction of living space (Seilly, 1995). Funerary depositions, including ceramics, buckles, glass and coins, permitted dating the cemetery to between the 4th and 7th centuries (Seilly, 1995). The Merovingian graves were organized in rows, placed next to and in line with Gallo-Roman graves, suggesting these previous graves were either still visible or known,

further suggesting a stable population (Fig. 4.18) (Seilly, 1995). One hundred-seventy-five burials were found and excavated, 29 of which were identified as belonging to the 4th-5th centuries, based on grave orientation and location within the site (Seilly, 1995). These were burials directly in the ground without any evidence of coffins or other structures. Two individuals appear to have been shrouded (Seilly, 1995). Inhumations followed a southeast to northwest axis and bodies were placed in a supine position. Several coins, axes, ceramics and bronze decorative items were found (Seilly, 1995). One-hundred-forty-six burials (99 adults, 32 non-adults) were identified as Merovingian (6th-7th c) and were mostly buried along the northwest to southeast axis. Ten burials contained coins, which were likely Charon's obol. Other grave goods included one axe, two lances and some scram axes, in addition to one sword burial (Fig. 4.19) (Seilly, 1995). One-hundred-twenty individuals, 97 adults and 23 non-adults were used in this analysis.

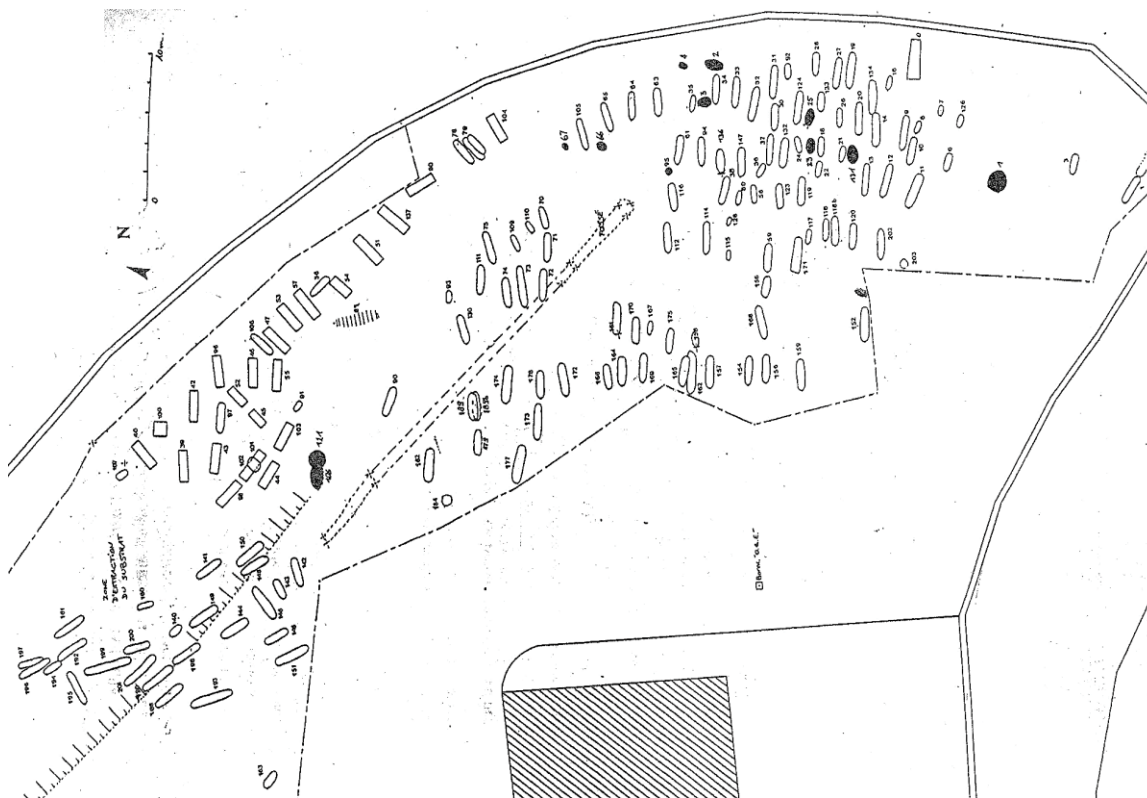


Fig. 4.18 Map of Fontoy necropolis (Seilly, 1995 p. 24)

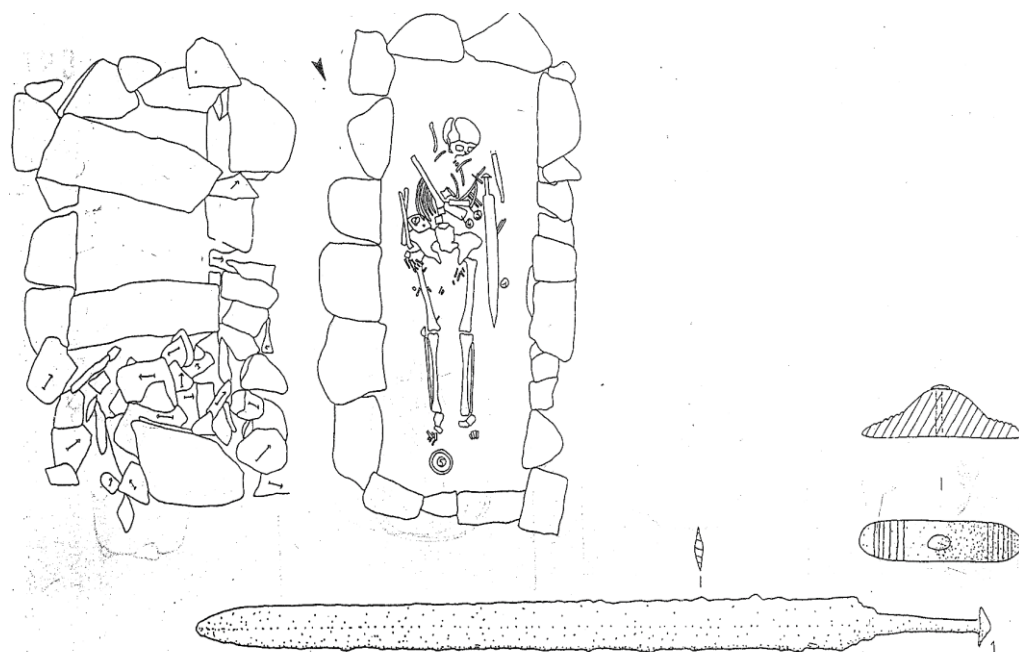


Fig. 4.19 Grave 137 from Fontoy displaying a sword burial from the 7th century (Seilly, 1995 Planche 52)

4.2.2.5 Cutry 4th century (CCEL)

The site of Cutry is located in a small village of the same name on the northern aspect of the Meurthe-et-Moselle department (Liéger and Cussenot, 1997). The periodic discovery of small finds had suggested that the area was a Gallo-Roman site, although full excavations were not conducted until after the 1960s, when the site was purchased by the government. Traces of an antique road from Trier have been found in proximity to the site (Liéger and Cussenot, 1997). The area became a Frankish territory sometime in the late 5th or early 6th century (Liéger and Cussenot, 1997). Excavation of the site took place in 14 successive excavations from 1973 to 1986 under the supervision of Abel Liéger. From 1987 to 1992 excavations continued under Rene Legoux with a focus on the Merovingian cemetery (Fig. 4.20) (Liéger and Cussenot, 1997). A total of 800 individuals were exhumed spanning from the La Tène period to the 8th centuries (Liéger and Cussenot, 1997). Cremations spanning from the La Tène period to the 3rd century CE make up a large portion of the cemetery findings, mostly located in one 600 m² area with multiple graves overlapping one another (Liéger and Cussenot, 1997). Thirteen inhumations, thought to be Gallo-Roman (4th c), were found on the periphery of the cremation zone. All but two of these inhumations were oriented on an east-west axis, and all but one adolescent were laid in a supine position. Fourteen individuals were dated to the 4th and 5th centuries. Some 284 individuals from 271 graves were exhumed from the Merovingian necropolis, which was dated from the end of the 5th century

to the beginning of the 8th century (470-700 CE) (Godot, 2014). The Merovingian section of the site was the subject of a recent thesis on dento-buccal health (Godot, 2014). Eight individuals from the 'Gallo-Roman' section dated to the 4th century were examined in this analysis, composed of one non-adult and seven adults.

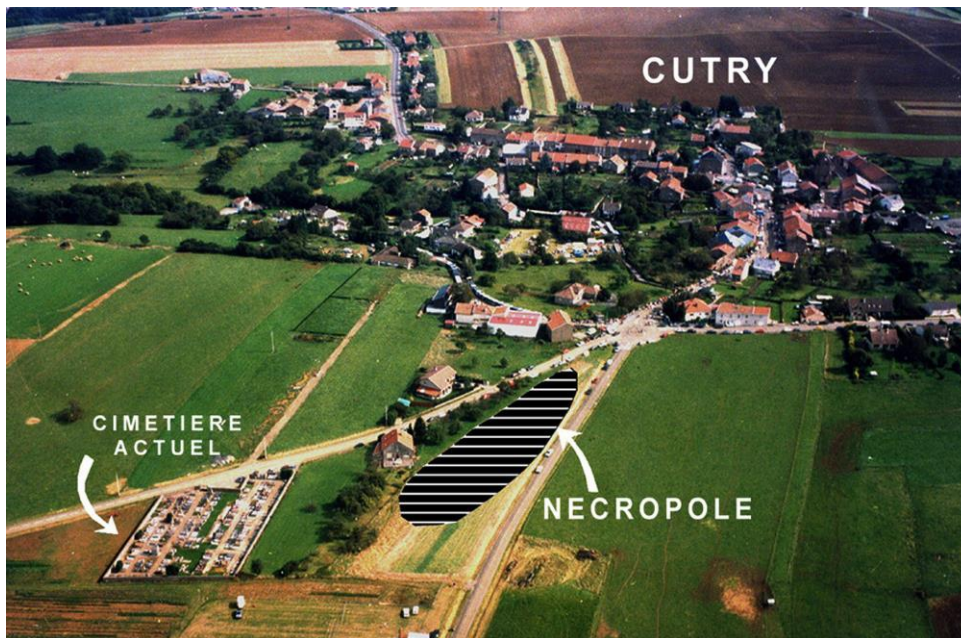


Fig. 4.20 The Cutry necropolis (R. Legoux, 2005 in Godot, 2014 p. 42)

4.3 Summary

To address research questions surrounding transitions taking place in Gaul during Late Antiquity, stress and health data were collected from 13 archaeological sites dated to the Roman and Late Antique periods. The described cemetery sites were selected based on access or permission from the corresponding laboratories, appropriate dating, location and context, and preservation. This included the type of burial ritual and proximity to important locations in Gallo-Roman or Late Antique periods. Due to time constraints in data collection, individuals were further selected based on preservation and accessibility. The lack of cemetery sites from the Gallo-Roman North is unfortunate and limits potential interpretations going forward. The Gallo-Roman South group is composed of individuals from urban contexts, creating an important bias in comparisons with the Late Antique groups, which include individuals from urban and rural contexts. Because both Arles and Saintes were comparatively large and important urban centres during the Roman period, differences between urban and rural conditions may have been particularly pronounced (Pearce and Redfern, 2020; Stark, 2017). The exclusion of cremated individuals may also influence the

results of the present study, as the decision to bury or cremate a deceased individual may be influenced by social and economic status (Blaizot et al., 2009). The chosen cemeteries (and individuals buried within them) derive from a wide variety of contexts and were subject to different excavation techniques and constraints. This undoubtedly introduces bias into the analysis, which cannot be appropriately accounted for or addressed. However, substantial sample sizes were necessary to address the large-scale aims, objectives and questions of this research. Pooling the sites into larger groups focused on time period and region provided larger sample sizes and permitted the inclusion of individuals from small sites, often left unstudied (C. Chapelain de Seréville-Niel, pers. comm., June 2017). Although the selected sites contain different biases, and reflect differing regionalised or localised influences, they provide access to the skeletal remains of people who lived during the period in question. These individuals are an important, precious and direct source of health data and transition experience.

Table 4.3 Sites used in this analysis

Group	N	Site	Dating	Dating based on	No. inds.	Non-adults	Adults	Context	Features	Site Source	Lab
Gallo-Roman South	156	Cirque Romain, Arles	2-4th c	Funerary objects	74	27	47	Urban	Large urban necropolis in an important Roman city; Several adults buried in large amphorae	Sintès, 1989	ADES/PACA
		Saintes, Rue Jacques Brel	1-2 nd c	Funerary objects	82	22	60	Urban	Roman artisan community; Evidence of burial in and with shoes	Baigl et al., 1997	PACEA
Late Antique South	238	La Grande Bastide de Cadarache	4-7 th c	Funerary objects	106	27	79	Rural	Rural cemetery located along a Roman road. No weapons or military evidence in grave goods	Pouyé et al., 1994	ADES/PACA
		La Granède	4-7 th c	C14	11	1	10	Rural	Located near major Roman pottery manufacture site (La Graufesenque). Site of early medieval church	Saint-Pierre, 2010	PACEA
		Colombier Vaison-la-Romain	5-6 th c	Funerary objects	80	15	65	Urban	Urban cemetery with a large proportion of stone sarcophagi	Carru et al., 1991	ADES/PACA
		Les Clavelles	6-7 th c	Funerary objects	12	5	7	Rural	Located along the via Domitia	Boiron, 1993	ADES/PACA
		Saint-Martin (La Brillanne)	4-5 th c	Funerary objects	10	1	9	Rural	Located along the via Domitia	Boiron, 1993	ADES/PACA
		Rues de Toulon	4-7 th c	Funerary objects	19	2	17	-	Possibly urban cemetery, superimposing a previous living space (mosaics)	Pouget et al., 2002 Salicetti, 1998	ADES/PACA
Late Antique North	450	Le Clos des Cordeliers	5-6 th c	C14	56	16	40	Urban?	4 mass graves. Epidemic plague noted in the town in 571. Yersinia pestis bacillus found	Guignier, 1997; Drancourt et al., 2004; Castex, 2008	PACEA
		St Martin de Fontenay	4-7 th c	Funerary objects	231	45	186	Rural	Large cemetery, excavated in its entirety; graves in rows; Sword burials	Pilet et al., 1994	CRAHAM
		Fontoy Rue de l'église	4-7 th c	Funerary objects	120	23	97	Rural	Row graves; Sword burial	Seilly, 1995	Thionville/ CCEL

		Rue du Tombois	4 th c	Funerary objects	35	8	27	Urban	A known urban cemetery in a city important to Roman, Merovingian and Frankish periods	De Filippo, 1995	CCEL
		Cutry	5-7 th c	Funerary objects	8	1	7	Rural/Villa	Large rural Roman and Merovingian necropolis	Liéger and Cussenot, 1997; Godot, 2014	CCEL
Total	844				844	193	651				

Table 4.4 Number of individuals excavated from each site and percentage included in the present analysis

Site	Dating	No. inds. Excavated	No. inds. in the present research	%	Site Source
Cirque Romain, Arles	2-4 th c	119	74	62%	Sintès, 1989
Saintes, Rue Jacques Brel	1-2 nd c	130	82	63%	Baigl et al., 1997
La Grande Bastide de Cadarache	4-7 th c	198	106	54%	Pouyé et al., 1994
La Granède	4-7 th c	161	11	7%	Saint-Pierre, 2010
Colombier Vaison-la-Romain	5-6 th c	131	80	61%	Carru et al., 1991
Les Clavelles	6-7 th c	32	12	38%	Boiron, 1993
Saint-Martin (La Brillanne)	4-5 th c	15	10	67%	Boiron, 1993
Rues de Toulon	4-7 th c	27	19	70%	Pouget et al., 2002; Salicetti, 1998
Le Clos des Cordeliers	5-6 th c	73	56	77%	Guignier, 1997; Drancourt et al., 2004; Castex, 2008
St Martin de Fontenay	4-7 th c	944	231	24%	Pilet et al., 1994
Fontoy Rue de l'église	4-7 th c	175	120	69%	Seilly, 1995
Rue du Tombois	4 th c	146	35	24%	De Filippo, 1995
Cutry	5-7 th c	311	8	3%	Liéger and Cussenot, 1997; Godot, 2014

Chapter 5

Methods

The primary aim of the present research was to assess stress and health status during Gallo-Roman and Late Antique periods, providing new information about Late Antique transitions in Gaul. To address the stated aims and research questions, demographic data (age-at-death, sex), indicators of growth disruption (femur length, HAZ scores, DEH), several pathological lesions (CO, tibial NBF, caries) and patterns of trauma were assessed and statistically compared (Table 5.1). The first analysis of cortisol in archaeological teeth was performed to investigate a new source of data on stress, or dysregulation of the hypothalamic-pituitary-adrenal axis. Several stress indicators were selected because they reflect general health status and well-being during childhood and development, when health is the most sensitive to environmental conditions (Lewis, 2007). The majority of these skeletal stress markers could be examined in individuals who died in childhood, as well as those who survived into adulthood. Non-adult and adult remains were included in this research to present the broadest possible picture of health and disease, including both survivors and non-survivors. The use of multiple indicators helps to mitigate the effects of the osteological paradox (Cohen et al., 1994; Goodman and Martin, 2002; Wood et al., 1992) and provides an opportunity for comparison. The selected methods are described in detail below. Several standard methodologies were applied to broaden the comparability of these results internationally.

5.1 Demographic Profiles

Demographic profiles, including sex and age-at-death estimations, and the degree of skeletal preservation of the studied samples contextualise palaeopathological data. The methods used for assessing sex, age-at-death and bone preservation are detailed below.

5.1.1 Sex

Sex estimations were based on macroscopic analysis of morphological features of the cranium, mandible and pelvis (Brothwell, 1981; Bruzek, 2002; Phenice, 1969). Estimations included definite and probable male or female assessments, as well as 'indeterminate' and 'not observable' categories (Table 5.2). Where sex estimations of the cranial and pelvic remains differed, priority was given to the os coxae. Sex was not estimated for non-adult individuals as current macroscopic methods are considered to be unreliable.

Table 5.1 Summary of macroscopic methods used in the present analysis

	Indicator	Method	Reference
Composition of sample	Age-at-death	Dental development	Moorrees, 1963 a,b; Ubelaker, 1978, AlQahtani et al., 2010
		Epiphyseal closure	Scheuer and Black, 2000
		Auricular surface	Lovejoy <i>et al.</i> , 1985; Schmitt et al., 2002
	Sex	Pubic symphysis	Brooks & Suchey, 1990
		Dental wear	Brothwell, 1981, p. 72
		Morphological features of cranium and mandible	Brothwell 1981, pp. 59-63
Growth Disruption	Dental Enamel Hypoplastic defects (DEH)	Morphological features of os coxae	Phenice, 1969; Bruzek, 2002
		Recorded as: Absent/Present -location -type -number Must be present on a minimum of 3 teeth per individual	Hillson, 1996
		Maximum femur length	Buikstra and Ubelaker, 1994, p. 82; Cardoso et al. 2019
Non-specific stress indicators	Cribra orbitalia (CO)	Recorded as: Absent/Present -Type Non-observable A minimum of type 3 to be recorded as pathological (present)	Stuart-Macadam, 1991
	Periosteal new bone formation (tibiae) (tibia NBF)	Recorded as: Absent/Present - type of bone formation (woven, lamellar, mixed) - active/healing/healed Non-observable Must be present bi-laterally	Weston, 2008; DeWitte, 2014
	Caries	Recorded as: Absent/Present -Tooth element Non-observable	Hillson, 1996; 2001
Trauma	Antemortem Perimortem	Recorded as: Absent/Present -location -type -degree of healing Non-observable	Lovell, 1997

Table 5.2 Sex categories used in the present research

	Sex	Abbreviation
1	Female	F
2	Probable Female	F?
3	Indeterminate Sex	I
4	Probable Male	M?
5	Male	M
0	Not Observable	NO

5.1.2 Age

Adult and non-adult individuals were assessed in this analysis to capture health status across the life course in ‘survivors’ and ‘non-survivors’. This provides a more complete view of health status across the population. Individuals were considered ‘non-adults’ when the estimated age-at-death was below 18 years (Table 5.3). Age estimates for non-adults were calculated from dental developmental stage (AlQahtani et al., 2010; Moorrees et al., 1963a, 1963b; Ubelaker, 1978), degree of epiphyseal closure (Schaefer et al., 2009; Scheuer and Black, 2000) and long bone length (Maresh, 1970). Because dental age is understood to be the least affected by environmental conditions (Cardoso, 2007; Lewis and Garn, 1960; Liversidge et al., 1998), dental mineralization (AlQahtani et al., 2010) was the preferred method of age estimation for non-adult individuals. Patterns of dental eruption (Ubelaker, 1978), degree of epiphyseal closure (Scheuer and Black, 2000) and long bone diaphyseal length were recorded and used to generate age estimations in individuals where teeth were not preserved or not observable macroscopically. For adult individuals (≥ 18 years of age at death), age estimations were based on tooth wear patterns (Brothwell, 1981), degenerative changes of the pubic symphyseal surface (Brooks and Suchey, 1990) and auricular surface of the pelvis (Lovejoy et al., 1985; Schmitt et al., 2002). All individuals were then assigned to standard broad age categories (Table. 5.3) (Brickley and McKinley, 2004; Buikstra and Ubelaker, 1994). These age divisions are understood to reflect skeletal or biological age and do not reflect the social or cultural conceptions of maturity or age during Gallo-Roman or Late Antique periods.

Table 5.3 Age-at-death categories used in the present research

	Age-at-death in years	Age Category
Non-adult	0-4.9	Infant
	5-9.9	Child
	10-14.9	Young Adolescent
	15-17.9	Mature Adolescent
Adult	18-25.9	Young Adult
	26-35.9	Middle Adult
	36-45.9	Mature Adult
	46+	Older Adult
	20+	Adult

5.2 Bone Preservation

The degree of preservation of each skeleton was assessed following McKinley (2004), including analysis of bone surface preservation, degree of fragmentation and completeness. Surface preservation was scored based on seven potential grades (Table 5.4). Degree of fragmentation was categorized as minimal, slight, moderate, severe or extreme, based on how intact bone elements were. Completeness refers to the amount of bone elements present in one individual as a percentage of a complete skeleton. Individuals were included in the analysis if a minimum of three bone elements that could be clearly identified as belonging to that individual were preserved.

Table 5.4 Surface Preservation (Adapted from McKinley, 2004)

Grade	Description
0	Surface morphology clearly visible with fresh appearance to bone and no modifications
1	Slight and patchy surface erosion
2	More extensive surface erosion
3	Most of bone surface affected by some degree of erosion; general morphology maintained but detail of parts of surface masked by erosive action
4	All of bone surface effected by erosive action; general profile maintained and depth of modification not uniform across surface
5	Heavy erosion across whole surface, completely masking normal surface morphology with some modification of profile
6	Extensive modification, completely obscuring the cortical surface of the bone and affecting bone profile

5.3 Growth Disruption

Growth disruption represents a general response to poor living conditions, which prevent an individual from attaining their genetic potential for maximum height or size. Normal growth processes can be interrupted by nutritional deprivation or pathological conditions, forcing the body to retain or divert energy or resources away from growth to address immediate needs for survival (Eveleth and Tanner, 1990a; Humphrey, 2000). Analysis of growth disruption therefore has the potential to identify changes in stressors or environmental conditions during childhood in Late Antiquity, contributing to understandings of transition. In this study, dental enamel hypoplastic defects and femoral growth (as determined by maximum length of the femur) were assessed for signs of potential growth disruptions. Where the necessary bones were not adequately preserved, measurements were not taken. This resulted in the exclusion of some individuals from analyses of growth disruption.

5.3.1 Dental Enamel Hypoplastic Defects

Dental enamel hypoplasia (DEH) are defects formed in the enamel matrix when ameloblast function is inhibited, leaving a permanent mark of a stress episode - for example a childhood disease or dietary deficiency/malnutrition (Goodman and Rose, 1990; Ribot and Roberts, 1996) (Fig. 5.1). These markers can only form during childhood, when amelogenesis, or the process of enamel development; this lasts from birth to approximately nine years of age, when the crown of the second molar is completed (AlQahtani et al., 2010). As a result, the presence of these defects represents periods of physiological stress or malnutrition isolated to the age range of tooth development (King et al., 2005). To be included in the assessment of DEH in this research, individuals had to have a minimum of three teeth preserved; no isolated teeth were included. Dental hypoplastic defects were recorded as both true prevalence rate (TPR), where the percentage of affected teeth were calculated based on all observable teeth; and crude prevalence rate (CPR), where the percentage of individuals displaying enamel defects were considered. For DEH to be counted as 'present' in CPR analysis, an individual needed to have at least three affected teeth, to isolate defects stemming from systemic stress (as opposed to traumatic or hereditary origins) (Goodman and Rose, 1990; Klaus, 2020). In addition to presence/absence, the number of enamel hypoplastic defects per tooth and the form of defect (linear, pit, groove) were also recorded (Hillson, 1996). In cases where multiple hypoplastic defects were present on a single tooth or on only two teeth, DEH was recorded as present in the CPR analysis. All teeth were examined macroscopically using a bright light and magnifying glass as necessary and the defect needed to be discernible tactically (i.e. with a fingernail). The severity or chronology of defects was not assessed.



Fig. 5.1 Multiple enamel hypoplastic defects visible on the permanent canine and 1st premolar of skeleton number 12, Saintes, Rue Jacques Brel

5.3.2 Femur length

Height is influenced by both genetic potential and environmental conditions during growth, where metabolic deficiencies or ill health negatively influences long bone length (Goodman, 1991). Long bone growth was assessed in non-adult individuals through the creation of skeletal growth profiles (SGP) and height-for-age Z scores (HAZ) based on the length of the femur. Skeletal growth profiles compare age estimates based on dental development with age estimates based on femoral length (Cardoso, 2007). Because dental age is thought to be less affected by environmental conditions, notably divergent long bone (femur) age estimates can indicate potential somatic growth disruption. HAZ-scores use data from a reference sample to quantify deviation from expected growth, controlling for the age of the individuals within a sample as well as the increasing variation of long bone length with age (Fig. 5.2) (Cardoso et al., 2019). HAZ scores of less than two standard deviations below the mean of a healthy standard reference population indicate an individual with stunted growth for age as defined by WHO growth standards (de Onis et al., 2006). Growth disruption in childhood can be retained and reflected in adult stature and long bone length. Although regression formulae are commonly used to estimate stature from long bone lengths (Trotter, 1970), these formulae can be problematic due to population variability in body proportions (Vercellotti et al., 2009). Only the maximum length of the femur (without additional regressions equations) was considered in this analysis. To be included in 'adult' comparisons, all

femoral epiphyses had to be fused. Adult male and female femoral lengths were considered separately, as males and females differ in their pattern and rate of long bone growth (Humphrey, 1998). To generate skeletal growth profiles, HAZ scores and adult femoral growth, the maximum length of the femur was measured to the nearest millimeter using a portable osteometric board by Paleotech (Fig. 5.3). In non-adults and adults, left femora were selected wherever possible, following standard osteometric practice.

$$\text{Z-score} = (\text{observed value} - \text{median value of the reference population}) / \text{standard deviation value of reference population}$$

Fig. 5.2 HAZ score formula



Fig. 5.3 Right femur with maximum length measurement displayed (Sep 346, St Martin de Fontenay)

5.4 Non-specific stress indicators

The skeletal remains of all individuals included in this analysis were examined for a suite of pathological lesions related to metabolic and/or environmental stressors (DEH, growth disruption, CO, tibia NBF, caries). Although non-specific in their aetiology, the selected skeletal stress markers are consistently used in palaeopathology as reliable proxies for general health status¹ (Redfern and DeWitte, 2011a; Roberts and Cox, 2003; Steckel and Rose, 2002). In this way, they contribute to

¹ The presence of specific pathological conditions such as scurvy, rickets (active and residual), tuberculosis and leprosy were recorded anecdotally, rather than systematically. This was in large part due to differential preservation in skeletons and sample populations. As such, their presence is noted, but not further analysed in terms of prevalence or in further statistical analyses.

the examination of health status during the Gallo-Roman and Late Antique periods. Although the focus of this research was on relative 'health' and well-being during childhood, several pathological lesions that more often develop during adulthood were also examined. These included crude prevalence rates of periosteal reactions of the tibiae, as well as both crude and true prevalence rates of carious lesions. As with analyses of growth disruption, in cases where the necessary bones were not adequately preserved, they were excluded from analysis.

5.4.1 Cribra orbitalia

Cribra orbitalia (CO) is a skeletal lesion of the eye orbits that develops to expand hematopoietic marrow surface area and produce more red blood cells (Brickley, 2018; Ortner, 2003). It is characterised by hypertrophy of the diploë within the frontal bone and a thinning of the outer table of the orbital roof, appearing as porosity or an outgrowth of the diploë (Fig. 5.4) (Brickley, 2018; Ortner, 2003). Although often studied in conjunction with CO (Brickley, 2018; Oxenham and Cavill, 2010; Stuart-Macadam, 1991), porotic hyperostosis was not analysed in the present analysis. Porotic hyperostosis is rarely found in studies of European populations in comparison with those of North and South America (Lewis and Roberts, 1997). Additionally, recent research has suggested that the aetiologies of CO and porotic hyperostosis are dissociated (Rivera and Lahr, 2017). CO was initially thought to develop in response to iron deficiency anaemia, resulting from blood loss, high pathogen load or nutritional deficiencies (Stuart-Macadam, 1991). However, recent research has suggested that other aetiologies, including acquired megaloblastic anaemia resulting from vitamin B12 deficiency and gastrointestinal infections sustained by unhygienic living environments, are more likely (Walker et al., 2009). Despite controversies surrounding its aetiology (McIlvaine, 2015; Oxenham and Cavill, 2010; Piperata et al., 2014; Walker et al., 2009), CO is frequently assessed in palaeopathological studies as a non-specific indicator of physiological stress. As in previous work (Belcastro et al., 2007; Goodman and Martin, 2002; Klaus, 2020; Redfern and DeWitte, 2011a; Roberts and Cox, 2003; Steckel and Rose, 2002), CO is here understood to reflect a non-specific insult to health, as a result of several possible aetiologies, including metabolic deficiencies or stressors, high pathogen loads, or diarrheal disease. Although similar appearing lesions can develop during adulthood (Smith-Guzmán, 2015; Wapler et al., 2004), CO most often develops during early childhood with healed or healing lesions retained into adulthood (Brickley, 2018). Within this analysis, CO was scored according to Stuart-Macadam (1991) (Table 5.5) but was considered on a presence or absence basis. Stages one and two can sometimes reflect normal variation or be the result of taphonomic processes. To prevent over-recording, only when a lesion

was scored as stage three or above, was the pathology considered present within an individual (Rohnbogner and Lewis, 2017). CO was recorded both as crude and true prevalence rates and individuals needed to have at least one orbit present to be included in this assessment. Although state of healing was not assessed, care was taken to distinguish expansion of the diploë from new bone formation on the outer orbital surface.

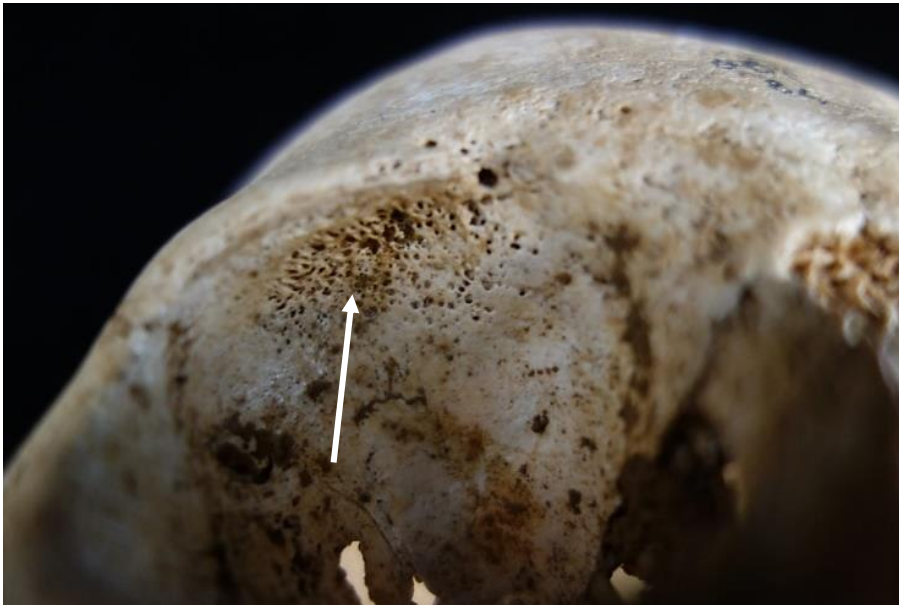


Fig. 5.4 Example of cribra orbitalia, grade 4 in the right orbit of Sepulture 84, Cadarache

Table 5.5 Grades of cribra orbitalia, adapted from Stuart-Macadam, 1991

Score	Description	Pathological?
0	Normal bone surface	No
1	Capillary-like impressions on the bone	No
2	Scattered fine foramina	No
3	Large and small isolated foramina	Yes
4	Foramina have linked into a trabecular structure	Yes
5	Outgrowth in trabecular form from the outer table surface	Yes

5.4.2 Tibia Periosteal New Bone Formation

Periosteal new bone formation (NBF) develops in response to inflammation of the periosteum, which can result from a wide range of different pathological stimuli, including infection, trauma, muscle activity, or vascular diseases (Larsen, 1997; Ortner, 2003; Ribot and Roberts, 1996; Weston, 2009, 2008). Although the multifactorial aetiology complicates interpretation, the lesion can be an informative indicator of overall poor health and frailty (DeWitte, 2014; DeWitte and Wood, 2008; Klaus, 2014). In this way, the relative frequency of the lesion could help to identify changes in the

presence of chronic stressors in Gallo-Roman and Late Antique periods. The tibiae of both adult and non-adult individuals were assessed macroscopically for the presence of new bone formation on periosteal surfaces. Crude prevalence rates of periosteal reaction of the tibia were recorded as present when clear patterns of grey porous or layered woven bone or striated lamellar bone were observed on any shaft surface. This was further specified by the type of new bone formation including if it was woven, lamellar or mixed new bone formation and if it was active, healing or healed (Fig. 5.5). In the analysis of CPR, only individuals presenting new bone formation on both tibiae were considered as presenting with this pathology. This was done to rule out periosteal reactions caused by trauma and in an attempt to isolate more systemic physiological stress and inflammation. Only the tibiae were systematically examined for periosteal new bone formation as the tibia is most commonly affected by these lesions (DeWitte, 2014; Klaus, 2014; Larsen, 1997).



Fig. 5.5 Three examples of periosteal reaction of the tibia. Top: woven bone (Sep 97 Saintes, Rue Jacques Brel). Middle: mixed new bone formation (Sep 40 Saintes, Rue Jacques Brel). Bottom: lamellar new bone formation (Sep 67 Saintes, Rue Jacques Brel)

5.4.3 Caries

Carious lesions develop from the bacterial demineralization of tooth structures, including enamel and dentine. Development of the lesion has been associated with diets high in carbohydrates and sugars and limited dental hygiene (Hillson, 1996; Larsen, 1997). Caries formation may also be affected by malnutrition (Walter et al., 2016) and hormonal fluctuations (Lukacs and Largaespada, 2006). As such, analysis of caries reflects dietary practices (Redfern and DeWitte, 2011a; Roberts and Manchester, 2005), but also represents overall living conditions and greater health trends (DeWitte and Bekvalac, 2011). Changing prevalence or patterns of caries formation could suggest potential shifts in diet and lifestyle in Gallo-Roman and Late Antique samples. Both deciduous and permanent teeth were examined for crude and true prevalence rates of carious lesions through macroscopic observation of teeth using a bright light, magnifying glass and dental probe (Hillson, 2001, 1996). Only clear areas of demineralisation were scored as carious lesions; potentially precarious white or brown discolorations of the enamel were not considered in this study, as these can sometimes be confused with taphonomic alterations to the tooth surface (Hillson, 2001). Given that untreated caries can lead to loss of teeth prior to death, ante-mortem tooth loss was also recorded, where alveolar bone around or within a tooth socket demonstrated significant healing or was fully healed (Fig. 5.6).

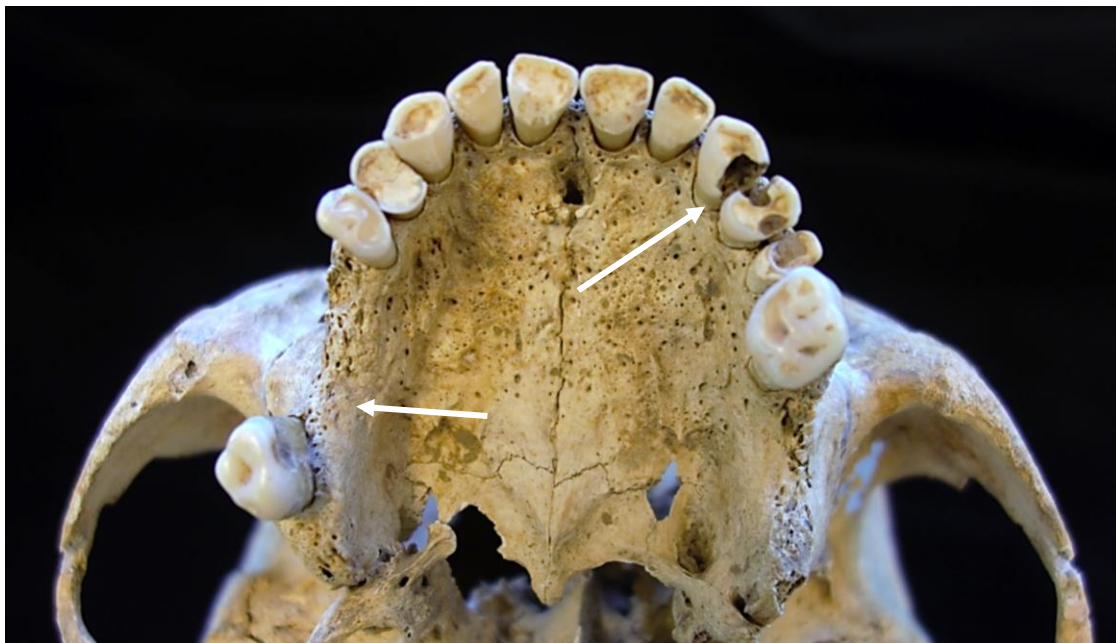


Fig. 5.6 Example of carious lesions in the left canine and 1st premolar and antemortem tooth loss in the right 1st and 2nd molars (Sk 18, Bayeux Rue de Verdun)

5.5 Trauma

Analysis of injury or trauma prevalence provides information about the degree of accidents or hazards and potential interpersonal violence within a society. Changes in the frequency or type of injury could therefore help to identify potential shifts taking place during Late Antiquity. Patterns of ante- and peri-mortem injury were assessed in this study as true and crude prevalence rates. All long bones (humerus, ulna, radius, femur, tibia, fibula) with 30% or more of the bone element preserved were macroscopically examined for any signs of trauma. Injuries were considered to have occurred before death (ante-mortem) if there was clear evidence of healing (Fig 5.7) (Lovell, 1997). Injuries occurring peri-mortem (around the time of death) were identified through the lack of visible healing and observation of fracture patterns, patination and texture of fractured edges (Fig. 5.8) (Knüsel, 2005; Ubelaker and Adams, 1995). Because bone remains 'wet' or fresh for a period of time after death, peri-mortem injuries could have occurred slightly before, after or at the time of death. The type of injury and degree of healing was noted wherever possible. Careful efforts were made to distinguish traumatic injury from taphonomic or post-mortem damage to the bones (Ubelaker and Adams, 1995). Where possible, trauma was identified as blunt force, sharp force or projectile (Knüsel, 2005; Lovell, 1997).



Fig. 5.7 Left and right 5th metacarpals from Sep 2, Seyssel. The right metacarpal (left side of image) is an example of an ante-mortem fracture



Fig. 5.8 Example of a peri-mortem sharp force injury to the frontal bone (and maxilla) (Sep 53rb, Seyssel)

5.6 Statistical Analyses

Statistical comparisons of the collected data were made to identify potential patterns in health and well-being within and between samples across time and/or geographic location. Significance was set at 0.05 and all statistical analyses were performed with Excel or SPSS.

Crude and true prevalence rates of pathological conditions that were considered on a presence/absence basis (DEH, CO, carious lesions, tibial periosteal reaction) were assessed using chi-squared tests, with Pearson's correction factors (for expected counts of less than 5), applied as appropriate. To decrease the false discovery rate created by multiple statistical tests, Benjamini-Hochberg post-hoc analysis was applied to these data, reducing the probability of Type 1 errors

(Benjamini and Hochberg, 1995) (results in appendix). In this procedure, ranks are determined for all existing p-values as a function of the total number of statistical tests performed. A Benjamini-Hochberg critical value is generated $[(i/m)Q]$. In this equation, i is the rank, m is the total number of tests, and Q is the false discovery rate (10%) (Benjamini and Hochberg, 1995). The Benjamini-Hochberg critical value is then compared to the original p-value and rank to determine significance.

Mann-Whitney U and Kruskal-Wallis tests were used to compare differences between groups in ordinal or continuous sets of data (e.g. femur length, HAZ scores, cortisol concentration). The tests are non-parametric, meaning that they are designed for data sets that are not normally distributed. Mann-Whitney U tests were used to examine differences in comparisons of two groups, while Kruskal-Wallis tests were used in comparisons of three or more groups. When significant differences were found using Kruskal-Wallis tests, post-hoc analyses were used to identify which groups significantly differed from each other.

Kruskal-Wallis and Kolmogorov-Smirnov tests were used to compare age-at-death distributions within and between samples, as appropriate. Kaplan-Meier survival analysis with a log-rank test using pooled data on age were used to assess potential differences in survival (age-at-death) between Gallo-Roman and Late Antique groups and between adult males and females (both within and between groups). Kaplan-Meier survival analysis is used to examine differences between groups in the 'time' it takes an event to occur (Stel et al., 2011). Within this analysis, the event was death and the 'time' was age.

5.6.1 Intra-observer Error

All of the data in this analysis was collected personally by the author. To assess the reliability of the measurements and the precision of the author's ability to replicate the data, intra-observer error tests were conducted. Sixty individuals were re-analysed using all of the aforementioned methods and statistically tested using Cohen's Kappa value (Cicchetti and Sparrow, 1981; Landis and Koch, 1977) and the technical error of measurement (TEM) with coefficient of reliability (R) (Goto and Mascie-Taylor, 2007), as appropriate (Fig. 5.9). Cohen's Kappa is a chance corrected standardised measure of agreement between categorical scores and was used to assess intra-observer reliability in data collected on presence/absence basis (CO, DEH, Tibia PR, Trauma presence, Caries) (Cicchetti and Sparrow, 1981; Landis and Koch, 1977). The technical error of measurement was applied to

continuous data (femur length). In both analyses, when values approach '1', the data have been consistently and reliably measured. Results of this analysis are available in the appendix.

$$TEM = \sqrt{\sum D^2 / 2N}$$

(D= the difference between the measurements, and N= the number of bones measured).

$$R = 1 - (TEM^2 / SD^2)$$

(SD= the standard deviation of all the measurements taken).

Fig. 5.9 Technical error of measurement formula (Goto and Mascie-Taylor, 2007)

5.7 Cortisol Analysis

Within this research, the first analysis of cortisol in archaeological human dental remains was conducted. The methodology was modified from Nejad and colleagues (2016), who found cortisol in modern human teeth, and was supplemented with clinical literature and similar analyses of different archaeological materials. All analyses were performed by the author. Tooth sample preparation was completed in the Stable Isotope Biogeochemistry Laboratory (SIBL) in the Archaeology Department and Analytical Research Laboratory in the Geography Department of Durham University. The ELISA (enzyme-linked immunosorbent assay) was performed in the Biosciences Department.

5.7.1 Tooth Selection and Preparation

Sixty-nine teeth from 65 individuals were analysed for cortisol concentrations in tooth dentine and enamel (Table 5.6). Of the 69 teeth, 29 were sampled twice, for a total of 96 samples. Teeth were selected from males, females and individuals of indeterminate sex. To exclude teeth that might have been affected by the period when the HPA axis is still developing and has yet to reach adult rhythms and values, only permanent teeth, which began development after four months of age were selected, with a preference for permanent 2nd molars. Only teeth free from pathological lesions or wear that might expose the dentine to the oral environment during life, or the burial environment after death were selected. This reduces the risk of analysing exogenous sources of glucocorticoid hormones or other potential contaminants.

Table 5.6. Description of sites where teeth were analysed

Site	Dating	Individuals (n=)	Teeth (n=)	Dentine Samples (n=)	Enamel samples (n=)	Total samples (n=)	Site Source
Saintes, Rue Jacques Brel	1-2 nd c	10	11	11	10	21	(Baigl et al., 1997)
La Granède	4-7 th c	4	4	2	4	6	(Saint-Pierre, 2010)
Fontoy	4-7 th c	18	18	15	15	30	(Seilly, 1995)
Rue du Tombois	4 th c	9	9	5	9	14	(De Filippo et al., 2000)
Saint Martin de Fontenay	4-7 th c	24	27	27	0	27	(Pilet et al., 1994)
Total		65	69	60	38	98	

Tooth preparation for subsequent ELISA analysis of cortisol was modified from Nejad and colleagues (2016). Before destructive sampling, each tooth was recorded and photographed in accordance with ethical guidelines for archaeological human skeletal remains (BABAO, 2019). Each tooth was washed in isopropanol to remove any contaminants present on the tooth surface and left to dry. Once dry, the tooth was bisected from crown to root using a diamond tipped saw to expose the dentin. Using a rosehead dental burr, 150 mg of dentine were drilled out of the tooth in a fine powder. Enamel samples were abraded with a dental burr to produce a chip of core enamel of 300 mg. The enamel was then ground into a powder. The samples were stored in polypropylene microcentrifuge tubes. To prevent contamination between teeth, all tools were washed in ultrapure water, placed in an ultrasonic bath for five minutes and then dried with acetone after each tooth was sampled. One hundred-fifty (dentine) or 300 (enamel) mg of each sample were weighed into microcentrifuge tubes and 1 ml of methanol was added to the samples. The tubes were then left to incubate for 24 hours, with slow rotation at room temperature to elute the cortisol. All tooth samples were then centrifuged at 1000rpm for five minutes in preparation for separation and dehydration. To dehydrate the samples, a stream of nitrogen was placed over the remaining aliquot for approximately one hour, until all of the liquid evaporated. All samples were frozen until the day the ELISA was performed.

5.7.2 ELISA

Competitive ELISA salivary cortisol kits by Salimetrics were used to analyse the cortisol concentrations present in the tooth dentine and enamel. On the day of analysis, samples were re-constituted with 30 µl of phosphate buffer. The ELISA kits were run according to all specifications

made by the manufacturer and wells were read in a Thermo Scientific Multiskan FC ELISA plate reader at 405 or 450 nm (Table 5.7). A standard curve was generated for each kit based on standards and controls, and fourth order polynomial curve fit regressions were produced to define the cortisol concentrations within each sample. Student t-tests and Mann-Whitney U-tests were used to analyse differences between the sexes and tooth structures as appropriate. All samples were kept frozen unless otherwise stated.

Table 5.7 Steps in ELISA cortisol analysis (Modified from Salimetrics Instructions)

	Steps	Brief Description
1.	Reconstitute samples	Reconstitute prepared samples with phosphate buffer
2.	Add standards, controls, zeros, and samples to plate	Pipette 25 μ L of standards, controls, and saliva samples into appropriate wells and 25 μ L of Assay Diluent into 2 wells to serve as the zero
3.	Add conjugate	Using a multichannel pipette, add 200 μ L of diluted conjugate solution to each well
4.	Mix and incubate plate	Rotate plate on a plate rotator at 500 rpm for five minutes and incubate at room temperature for 1 hour (includes 5 minutes of rotation)
5.	Wash plate	Wash the plate with 300 μ L of wash buffer four times
6.	Add substrate	Pipette 200 μ L of TMB Substrate Solution into each well
7.	Mix and incubate	Rotate plate on plate rotator at 500 rpm and incubate covered at room temperature for 25 minutes
8.	Stop chemical reaction	Pipette 50 μ L of Stop Solution into each well with a multichannel pipette
9.	Mix and check colour	Mix on a plate rotator for 3 minutes at 500 rpm until all wells display a yellow colour
10.	Read in plate reader	Read the plate in a plate reader

5.8 Summary

This research examines stress and health status from human skeletal remains of individuals dated to Gallo-Roman and Late Antique periods to better understand transitions taking place in Late Antiquity. Methods that focused on childhood health and stress were selected, including growth disruption as indexed by DEH, skeletal growth profiles, HAZ scores and adult femur lengths. Non-specific stress indicators included CO, periosteal reaction of the tibiae and carious lesions. Trauma was also examined to identify potential changes in patterns of accidents, violence or injury. These skeletal stress markers were analysed with respect to age-at-death and sex, providing important contextual information. By examining childhood health indicators in adults, differences between survivors and non-survivors and between males and females could be assessed. The selected methods yield data on general health status, which is responsive to environmental conditions and stressors and are, therefore, appropriate for this research. Additionally, a new method for assessing stress (Nejad et al., 2016) was adapted and tested in archaeological teeth. Despite the

novelty of this method, it represents an attempt to examine biochemical signatures of stress, which has the potential to be more sensitive to stressors than other forms of skeletal stress lesions. The following chapter is composed of five manuscripts that include the materials and methods previously discussed. Due to requirements for publication, the data and methods are divided between the five manuscripts. In Chapter 7 (Discussion), the five manuscripts, as well as additional data that could not be included in the manuscripts are discussed, addressing this study's research questions.

Title: Modelling Health during Societal Collapse: Can Recent History help our understanding of Post-Roman Gaul?

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Keywords: Growth stunting, Stress, Late Antiquity

Abstract:

Societal collapse results in structural breakdowns and instability, which can impact life expectancy and population health. Previous bioarchaeological studies have, however, sometimes struggled to identify correlations between socio-political changes and skeletal indicators of morbidity and mortality. Late Antiquity (c. 300-700 CE) has often been conceptualized as a period of socio-political rupture marked by the collapse of the Western Roman Empire and the transition to the Medieval period. The nature of this transition and whether it was marked by either catastrophic or more gradual change has been much debated. To date, bioarchaeological analysis has contributed little to these discussions. A model of the effects of societal collapse on health is generated from a modern example (The Soviet Union) and used to assess the bioarchaeological evidence. While contextually far removed from the Roman Empire, the Soviet Union is the only example of a large-scale union of multiple countries with a predominantly centralized economy and government for which clinical data relating to its collapse is available. Femoral lengths and height-for-age (HAZ) Z-scores from non-adult and adult skeletal remains (269 individuals) from northern and southern Gaul are analyzed as a proxy for health. Contrary to the Soviet model, results indicate a period of greater physiological stress during the Gallo-Roman period than the later transition. Differences in growth patterns suggest social and cultural factors rooted in Roman lifeways were manufacturing a non-traditional distribution of biological vulnerability, which was more deleterious to health than the process of transformation.

Late Antiquity (here defined as 300-700 CE) refers to the transition from the Roman to Medieval period, often colloquially referred to as the 'Dark Ages'. The nature of this transition, whether it was gradual or catastrophic, and the effects on those living at the time, is heavily debated. Numerous studies have examined proxies for health and well-being in the Roman period (Jongman et al. 2019; Koepke and Baten 2008; Koepke 2014; Scheidel 2015; Redfern 2008; Redfern et al. 2018; Redfern and DeWitte 2011), but few have specifically sought to examine health during Late Antiquity, a period of putative societal collapse. Gaul (modern-day France) exemplifies the contradictory narrative that characterizes the Late Antique period: academically it straddles both continuity and catastrophe. Gaul captures a diverse area in the Roman Empire, with territories deeply entrenched within Roman lifeways surrounding the Mediterranean and important (though nebulous) boundary frontiers along the Rhine. Evidence of decline or catastrophe has been identified through the drastic reduction and abandonment of urban areas and rural villa systems (Galinié 1997; Halsall 2006, 2007; Wickham 2005), dramatic increases in security needs as seen through the construction of city walls (Clout 2013; Sarti 2013), decline in the quantity and quality of various industries including pottery-making, metalworking, tile-making and stone quarrying (Ward-Perkins 1996), and a reduction in trade networks (Wickham 2005). This evidence is not uniform across Gaul and in some regions the archaeological evidence suggests a large degree of continuity in living systems and structures, with only superficial changes. Some towns retained their prominence and connectivity with Roman authority throughout much of Late Antiquity and systems of trade continued to function, even if these did not match the vigor and complexity of previous centuries (Drinkwater and Elton 2002; Halsall 2007; Härke 2007; Wickham 2005). Where trade stopped or was reduced, local products emerged, although the quality of these items was markedly inferior compared to the preceding period (Wickham 2005). Much of this evidence falls along geographic divisions, with northern regions showing more pronounced evidence of rupture and societal collapse, while southern regions appear to have experienced this transition more gradually (Galinié 1997; Wickham 2005).

Late Antiquity and the nature of this transition has been challenging to characterize from the archaeological record. To date, large-scale analysis of human skeletal remains and evidence for mortality and disease during this period of transition have contributed little to current debates. (Although see the following for other geographic regions-(Al-Shorman and El-Khoury 2011; Belcastro et al. 2007; Giannecchini and Moggi-Cecchi 2008; Harper 2017; Manzi et al. 1999; Pálfi 1997; Salvadei et al. 2001; Šlaus 2008; Šlaus et al. 2011; Vodanović et al. 2012). Skeletal analysis provides critical

evidence for understanding how Late Antiquity was experienced and if larger patterns of continuity or catastrophe emerge.

This research has two primary aims:

- (1) To develop a model for understanding the type of changes occurring during societal collapse, based on a modern example.
- (2) To test the model against the skeletal evidence from northern and southern Gaul dated to Late Antiquity to see if it supports either continuous or catastrophic change.

Examining health in relation to large-scale cultural transitions is a cornerstone of bioarchaeological research (Agarwal and Glencross 2011; Armelagos 2003; Armelagos and Cohen 1984; Larsen et al. 2015; Reitsema et al. 2017). Previous studies have, however, occasionally struggled to identify correlations between socio-political changes and skeletal indicators of morbidity and mortality during periods of supposed societal collapse (Kurin 2012, 2016; Jennings 2010; Schrader and Buzon 2017; Wright 1997a, 1997b, 2006; Wright and White 1996). Collapse, as the most extreme form of societal transformation (Storey and Storey 2017), would be expected to exert a notable impact on the 'stress' state of populations. Several features of societal collapse would likely affect health and stress, including rapid loss of established socio-political structures, changes in social stratification or differentiation, settlement patterns, technologies and rituals, declines or decreases in spheres of trade and information (access to resources), and population declines (through migration or death) (Härke 2007; Scheidel 2017; Tainter 1995). It has therefore been hypothesized that catastrophic collapse would be reflected in marked differences in the frequency of skeletal manifestations of stress; however, a number of bioarchaeological studies of such populations have revealed only limited changes (Kurin 2016; Wright 1997a, 1997b). Associating patterns of skeletal stress with societal collapse may be problematic due to a dearth of relevant clinical parallels against which to assess the bioarchaeological evidence. Health data from populations that have experienced systems collapse may provide a framework to better understand the skeletal data. Such models can be helpful for understanding patterns of morbidity and mortality and for constructing boundaries and thresholds of collapse. Therefore, a critical aspect of this research is to better understand the ways that societal collapse, as the most extreme form of societal transformation, can affect health.

Models of recent episodes of societal collapse have previously been applied to Late Antiquity (Esmonde Cleary 2011; Härke 2004, 2007; Gaidar 2010; Pilkington 2013). Härke (2007) provided an in-depth theoretical comparison of the Post-Roman (Late Antique) period in Britain with the collapse of the Soviet Union and demonstrated the utility of this approach. Although contextually disparate, there are some loose commonalities between the Roman Empire and the USSR - both were vast geographical unions involving multiple countries with a largely centralized economy and government. Härke examined the impact of societal collapse on material culture in the Soviet Union and identified patterns in settlement structure and material manufacture that he argued were applicable to observations of Late Antiquity (2007). Whilst the limitations inherent in comparing modern and ancient societies are acknowledged, *process* might still be understood from the data. Following Härke's example of focusing on process, rather than absolute comparability, this research attempts to create a loose model for skeletal indicators of health stress resulting from one example of societal collapse, generated from the Soviet Union, to apply to skeletal remains from Late Antiquity. While not suggesting that the collapse of the Soviet Union in the 20th century and the Roman Empire are directly comparable, this case study provides the only modern collapse for which clinical data is currently available. Given the complicated nature of working with archaeological remains that have differing levels of preservation, completeness, biased and small sample sizes, it is imperative that hypothesis-driven targets are clearly defined. There needs to be a conceptualization of how societal transformations impact health in ways that are visible on the skeleton, so that specific patterns in health are clearly linked with societal collapse.

2. Health and Collapse: The Fall of Soviet Union (a case study)

The consequences of the Soviet collapse on health have received considerable attention. The Soviet Union displayed an overall trend for improving health during the 20th century, as indexed through infant and child height, weight and mortality (Brainerd 2010). This trend quickly reversed during Perestroika and the ultimate collapse of the Soviet Union in the early 1990s. The average weight and lengths of new-born babies decreased from 3476 g and 51.4 cm in Soviet times to 3379 g and 50.8 cm in the Perestroika and transition period (Mironov 2007)(Table 1). In children under the age of two, rates of stunted growth (heights more than two standard deviations smaller than expected height-for-age) doubled from 6.9% to 12.8% between 1992 and 1993 (WHO 1998). Older children (25 months to

six years) showed only a slight increase in stunting from 9% to 10.4%. In native Siberian populations, this trend was amplified, and the percentage of 'stunted' children increased from 34% to 61% between 1991 and 1995, and 'wasted' (significantly underweight) children increased from 2% to 17% (Sorensen et al. 2005). Siberian natives, who had been supported by the Soviet government through food and medical supply shipments, all of which ceased after the government's collapse, were forced to return to traditional subsistence strategies (Leonard et al. 2002; Sorensen et al. 2005; Stillman 2006). This increased isolation contributed to the higher prevalence of stunting in these native children (Leonard et al. 2008). Data gathered from the Russian Longitudinal Monitoring Survey (RLMS), involving thousands of Russian households from 1994-2014, provides information on economic, social, demographic and health information during much of this period (Kozyreva et al. 2016; Stillman 2006). These data revealed that children born during or one year after the transition year were on average 1.5 cm shorter at adulthood than expected (Adserà et al. 2020). Height differences between siblings (one born during transition and others not) suggested that the impact of being born during transition could result in siblings with 3-4 cm in height difference (Adserà et al. 2020).

Primary factors affecting health during the Soviet collapse were increased alcohol consumption (Leon et al. 1997; Leonard et al. 2002), increased rates of impoverishment and material deprivation (Bobak et al. 1998; Tragakes and Lessof 2003), the reduction and dilapidation of the healthcare system (Field 1995; Karanikolos et al. 2013; Stillman 2006) and changes in lifestyle and increased psychosocial stress (Field 1995; Leonard et al. 2008, 2002; Carlson 2000). One of the most dramatic features of the Soviet collapse was the change in life expectancy (mortality) (Leonard et al. 2002; Notzon et al. 1998; Shkolnikov et al. 1998). From 1990 to 1994 male life expectancy dropped from 64 to 57 years (7 years), an unprecedented decline in a twentieth century industrial nation (Brainerd and Cutler 2005; Leon et al. 1997; WHO 1998). Deaths resulting from alcohol poisoning, accidents, homicide and suicide made up a large proportion of the working-age male mortality rate (King et al. 2009; Stillman 2006). Female mortality rates were less dramatically affected, falling by only 3.3 years from 74.4 to 71.0 years (Brainerd and Cutler 2005; Leon et al. 1997). Mortality from infectious and parasitic diseases nearly doubled, with rates of diphtheria (increased 54-fold in the early 1990s), tuberculosis (especially in prison contexts) and whooping cough rising considerably (Tragakes and Lessof 2003; WHO 1998). Some of the upsurge in infectious disease prevalence resulted from a rising fear of AIDS and transmission via needles, meaning that many citizens chose not to get the limited vaccines and immunizations that were available (especially in the case of diphtheria) (Tragakes and Lessof 2003). Diseases that had been

previously under control, including cholera, typhus, typhoid, measles, hepatitis and even malaria made a comeback during the Soviet transition and post-transition period (Tragakes and Lessof 2003). The health crisis was still on-going in 2006, with 11 of the 25 post-Soviet countries yet to have achieved pre-transition mortality levels, and drug-resistant strains of tuberculosis and multi-drug resistant HIV/AIDS posing a threat to the control of these diseases in the rest of the world (King et al. 2009). The overall 'additional' loss of life resulting from the Soviet collapse has been calculated to between 1 million (WHO 1998) and over 3.2 million (King et al. 2009). The primary causes of death were cardiovascular disease, neoplastic disease, trauma, and respiratory disease (WHO 1998). Based on these data, it is evident that the collapse of the Soviet Union had an appreciable and detrimental effect on the health of the population.

Table 1. Health trends before and during the collapse of the Soviet Union

Health Indicator	Trend During Collapse	Pre-Collapse <1991	During Collapse (1991-1994)	Source
Infant Mortality	↑	17.8 per 1000 live births	20 deaths p/1000 deliveries	Field 1995; WHO 1998
Birth Weight	↓	3476 g	3379 g	Mironov 2007
Birth Length (height)	↓	51.4 cm	50.8 cm	Mironov 2007
Growth Stunting (children <2 years old)	↑	6.9%	12.8%	WHO 1998
Growth Stunting (children 25 months to six years)	↑	9%	10.4%	WHO 1998
Growth Stunting (Native Siberian Children)	↑	34%	61%	Leonard et al. 2002, 2008; Sorensen et al. 2005
Wasting (Native Siberian Children)	↑	2%	17%	Leonard et al. 2002, 2008; Sorensen et al. 2005
Adult Height	↓		1.5 cm shorter	Adsera et al. 2016
Male Life Expectancy at birth	↓	65.0 years	57.0 years	WHO 1998
Female Life Expectancy at birth	↓	74.4 years	71.0 years	Leon et al. 1997
Mortality from infectious and Parasitic Disease	↑		Doubled	Tragakes and Lessof 2003
Mortality from Accidents & Violence (Mortality per 10 ⁶)	↑	Males-2519 Females- 597	Males- 3768 Females- 873	Leon et al. 1997
Alcohol-related Disease (Mortality per 10 ⁶)	↑	Males-455 Females- 123	Males- 863 Females- 230	Leon et al. 1997

2.1 Differential impact on the population

An important observation regarding the health data from the Soviet collapse is that not everyone was affected equally (Cockerham 1997; King et al. 2009; Leonard et al. 2002, 2008; Costa-Font and Kossarova 2019). For example, adult native Siberians showed increased rates of obesity, while children displayed an increase in undernutrition and stunted growth (Leonard et al. 2008, 2002). Increased mortality was also differentially distributed amongst the population, with young to middle aged males suffering the most, rather than the very young and the elderly who are more biologically vulnerable (King et al. 2009). This led to the assertion that the observed health changes stemmed predominantly from cultural or societal issues, rather than biomedical causes (Cockerham 1997; Field 1995; King et al. 2009; Stillman 2006). Leonard et al. (2002) also found a differentiation between the sexes. Male and female roles were restructured during the transition, resulting in differential energy expenditure and activity levels, which the authors suggest led directly to the different rates of cardiovascular disease and obesity between males and females in Native Siberian populations. Even childhood stunting differed by sex, with girls more negatively affected than boys: the rate of growth stunting in girls rose from 29% in 1991 to 64% in 1995 (difference of 35%) and in boys from 39% in 1991 to 57% in 1995 (18%). This demonstrates that societal collapse has differential impacts on health that are dependent on individual biocultural characteristics. While different patterns in Late Antiquity would be expected, the data from the collapse of the Soviet Union provides a concrete example of the impact of changes in culture, power, and authority on health.

2.2 A 'model'?

Clinical evidence from the collapse of the Soviet Union has highlighted the following key features relating to health.

- (1) Health is substantially and negatively impacted by societal collapse;
- (2) child health and in particular early childhood health (conception to 1000 days) is a sensitive barometer for these changes;
- (3) subgroups within the populations are affected differentially;
- (4) these subgroups do not necessarily conform to traditional expectations of who the most vulnerable within a society are (e.g. young to middle aged adult males, rather than the elderly).

These observations can be operationalized and applied to the archaeological record to identify the more subtle effects of collapse on health in the past. Growth and adult stature were markedly affected during the Soviet collapse. These are measurable skeletal parameters. Adult stature reflects overall well-being during development and is positively correlated with life expectancy. Growth disruption occurs when factors such as inadequate nutrition, illness, and poor living conditions force the body to divert energy or resources away from growth to address more immediate needs for survival. Emotional stress, a natural sequela of societal collapse, is also a known contributor of growth disruption (Bogin 1999; Scheidel 2012). If the stress event persists for an extended period of time, the growth process is slowed and even halted, resulting in individuals with reduced adult height (genetic potential for maximum height or size not attained) (Gowland and Walther 2019; Humphrey 2000). In modern clinical research, children are defined as having stunted growth when height-for-age Z-scores (HAZ) are less than two standard deviations below the mean or median of a healthy standard reference population (De Onis and Blössner 2003). HAZ scores can be generated and examined from archaeological remains of non-adult individuals.

For the purposes of this study, femoral lengths, generated statures and HAZ scores from non-adults (non-survivors) and adult femoral lengths (survivors) from sites in northern and southern Gaul dating to the Gallo-Roman period and Late Antiquity are recorded. These data are analyzed in relation to the Soviet model to see if they support either the continuous or catastrophic hypotheses of the Late Antique transition. If the data are comparable to the Soviet model, it could suggest that the decline of the Roman Empire in Gaul was more catastrophic in scale. If not, a more gradual transition from Roman to Medieval periods might be proposed. Geographic divisions are explored and a 'control' group of individuals from the Gallo-Roman period are incorporated.

3. Materials and Methods

Demographic (age, sex) data, measurements of growth and maximum femur lengths were collected from 12 skeletal collections throughout France. Collections were grouped by time period: Gallo-Roman (1st-4th centuries CE) and Late Antique (4th -7th centuries CE). Sites were also divided by their location in the North or South, demarcated by the Loire River (Table 2; Fig. 1). Data were collected from both non-adult (<18yrs) and adult (18yrs+) human skeletal remains.

Skeletal collections were chosen based on the date, context and location of the site, the number and preservation of individuals and permission for analysis. Sites that displayed typical Gallo-Roman monumental/building features and burial rituals (Charon's obol, sarcophagi, feasting vessels) or 'Late Antique' rituals (row graves, weapon burials, jewelry) were prioritized. Both large and small excavations were included in this analysis, incorporating individuals and data often excluded from systematic research. The Gallo-Roman South group includes individuals from two sites, one an artisanal community (Rue de Jacques Brel) and the other an urban context (Cirque Romain, Arles). Skeletal data for the Late Antique South group derived from six archaeological sites located south of the Loire River. The Late Antique North group is composed of individuals from five sites north of the Loire River. Both 'urban' and rural cemetery sites were included in both Late Antique groups.



Fig. 1 Map of sites assessed in this analysis. Black dots indicate Gallo-Roman South, white dots indicate Late Antique South and gray dots indicate Late Antique North.

Table 2. Sites included in the present research

Group	N	Site	Dating	Context	No inds.	Non-adults	Adults	Site Reference
Gallo-Roman South (GRS)	47	Cirque Romain, Arles	2-4 th c	Urban	39	10	29	Sintès 1989
		Saintes, Rue Jacques Brel	1-2 nd c	Sub-urban	8	8	0	Baigl et al. 1997
Late Antique South (LAS)	139	La Grande Bastide de Cadarache	4-7 th c	Rural	50	7	43	Pouyé et al. 1994
		Colombier Vaison-la-Romain	5-6 th c	Urban	65	7	58	Carru 1991
		Les Clavelles	6-7 th c	Rural	6	3	3	Boiron 1993
		Rues de Toulon	4-7 th c	-	11	1	10	Pouget et al. 2002; Salicetti 1998
		Saint-Martin (La Brillane)	4-5 th c	Rural	7	0	7	Boiron 1993
Late Antique North (LAN)	83	Le Clos des Cordeliers	5-6 th c	Urban?	1	1	0	Castex 2008; Guignier 1997
		St Martin de Fontenay	4-7 th c	Rural	4	4	0	Pilet et al. 1994
		Fontoy	4-7 th c	Rural	53	6	47	Seilly 1995
		Rue du Tombois	4 th c	Urban	23	4	19	De Filippo et al. 2000
		Cutry	5-7 th c	Rural	2	0	2	Liéger and Cussenot 1997
Total	269				269	51	218	

3.1 Non-adults

For non-adults, age was estimated from dental development (AlQahtani et al. 2010) and maximum length of the femur (Maresh 1970; Schaefer et al. 2009). Because dental development is under the strongest genetic control and the least impacted by the environment (Cardoso 2007; Lewis and Garn 1960; Liversidge et al. 1998), dental age estimates were used as a baseline against which to assess long bone growth. The mean of the dental age range was ultimately used in this analysis in common with other growth studies (Mays et al. 2008; Newman and Gowland 2015). Individuals were therefore required to have dental remains preserved to generate age estimations as well as at least one femur with adequate preservation to be included in this analysis. Left femora were selected wherever possible following usual osteometric practice. HAZ (height-for-age Z) scores were generated based on

estimated stature to identify individuals with stunted growth for age (<-2) as defined by WHO growth standards. Z-scores quantify deviation from expected growth, controlling for the age of the individuals within a sample as well as the increasing variation of long bone length with age (Cardoso et al. 2019). HAZ scores are based on a reference sample. The WHO worldwide reference sample was selected because the WHO data present a growth standard, depicting normal human growth regardless of ethnicity and status (De Onis et al. 2003). To produce HAZ scores, non-adult stature was generated based on regression equations developed by Ruff (2005). It is acknowledged that the application of Ruff's formula introduces error that would preferentially be avoided (Schillaci et al. 2012). However, the data remain comparable against each other. Kruskal-Wallis non-parametric tests were used to compare the distributions and medians of Z-scores between groups (Gallo-Roman South-GRS; Late Antique South-LAS; Late Antique North-LAN), where statistical significance was set at 0.05. Chi-squared with Pearson's correction factors were applied as appropriate. Sex was not estimated for non-adult individuals as current macroscopic methods are considered to be unreliable.

3.2 Adults

Sex was determined for adult individuals through the analysis of morphological features of the skull and pelvis (Brothwell 1981; Bruzek 2002; Phenice 1969). Wherever possible, sex estimates based on pelvic morphology were used preferentially over estimates based on cranial remains. Individuals determined to be female or probable female were considered in the analysis as 'female' and likewise male and probable male individuals were pooled as male. Age-at-death was estimated based on observation of degenerative changes in the pelvis (Brooks and Suchey 1990; Lovejoy et al. 1985; Schmitt et al. 2002) and patterns of dental wear (Brothwell 1981). Regression formulae for stature remain problematic due to population variability in body proportions (Vercellotti et al. 2009), so only the maximum length of the femur was considered. Femora were measured to the nearest millimeter using an osteometric board by Paleotech. Left femora were preferentially selected in all adult and non-adult analyses of femoral length. Adult male and female femoral lengths were considered separately. Kruskal-Wallis non-parametric tests were used to compare male and female femoral lengths between groups, where statistical significance was set at 0.05.

4. Results

4.1 Age and sex distribution

Age and sex distributions followed standard patterns of attritional cemetery populations, whereby mortality is high in early childhood, decreasing until more advanced adult age (Table 3, Fig. 2). It is noteworthy that the Gallo-Roman South (GRS) group has slightly higher percentages of very young individuals (12.2% 0-4; 8.2% 5-9; 10.2% 10-14; 8.2% 15-17-year-olds), whereas all of these age groups are between 0 and 7.2% in both Late Antique groups. The large percentage (19.4%) of 18-25-year-olds in the LAS group is also noteworthy. It is important to bear in mind that these data are reflecting only the individuals with skeletal preservation that allowed them to be included in this analysis, placing additional limitations on the degree to which they are representative of the living population.

Table 3. Individuals included in this analysis

Group	N	Non-Adults	Adults		
			Females	Males	Total
Gallo-Roman South	47	18 (38.3%)	13 (44.8%)	14 (48.2%)	29 (61.7%)
Late Antique South	139	18 (12.9%)	59 (48.7%)	48 (39.6%)	121 (87.1%)
Late Antique North	83	15 (18.1%)	28 (41.2%)	31 (45.6%)	68 (81.9%)
Total	269	51 (19.0%)	100 (45.9%)	93 (42.7%)	218 (81.0%)

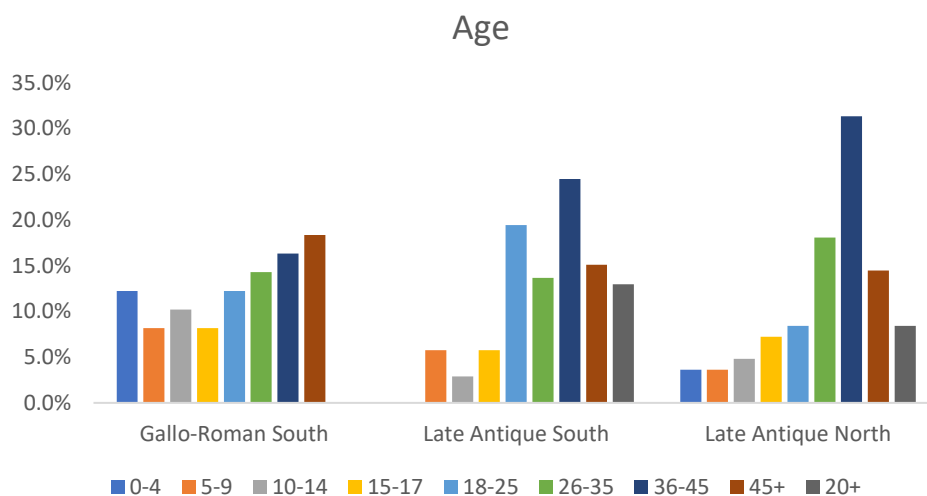


Fig. 2 Age distribution of individuals assessed in this analysis

4.2 Non-adults

4.2.1 Height-for-age. Only four individuals aged 2 years or younger had teeth and femora adequately preserved for measurement, all of which derived from the Gallo-Roman context, preventing comparison with the other groups. Three of these four individuals displayed small height-for-age, indicating delayed growth (Table 1 supplementary materials). To facilitate an understanding of changes in height-for-age in relation to WHO standards, height-for-age was generated from femoral lengths for children with dental ages between three and 18 years (Ruff et al. 2005). These estimated statures are plotted against modern worldwide data from WHO (De Onis and Blössner 2003) (Fig. 3). The data from all groups suggest a challenging growth period, where height-for-age was diminished in comparison with modern data, except for two individuals. Differences between groups were not significant ($P= 0.791$).

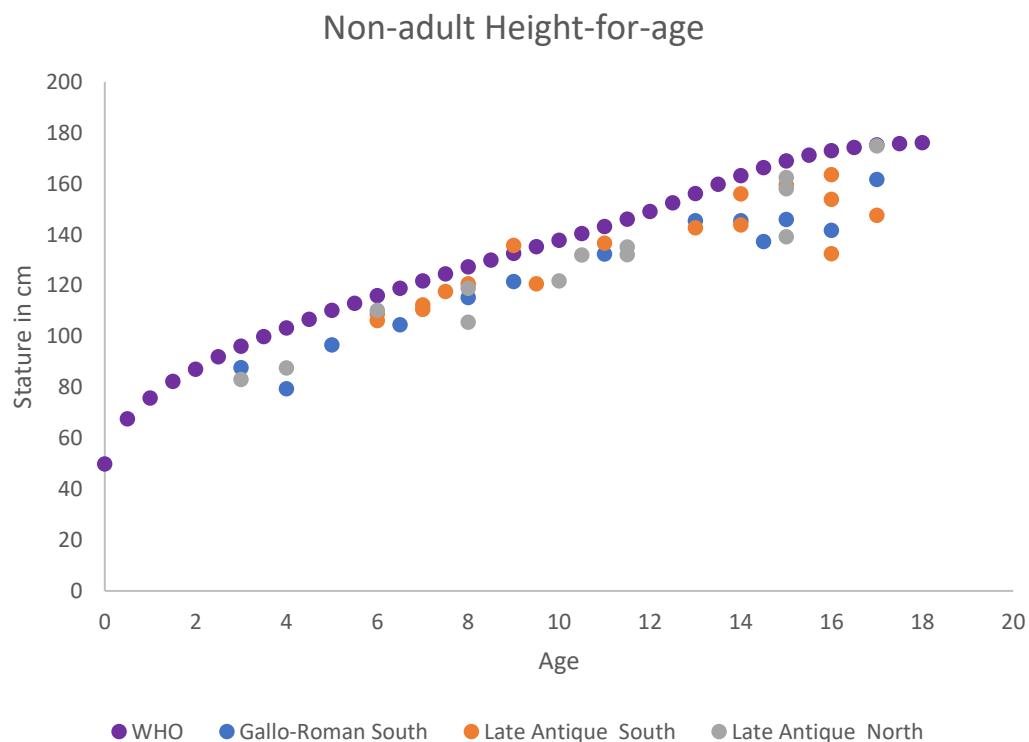


Fig. 3 Skeletal Growth Profile displaying the generated statures from individuals 3-18 years of age against WHO modern reference populations

HAZ scores generated based on the WHO data allow for a standardized and comparable method for assessing growth ‘stunting’ across different ages (De Onis and Blössner 2003). The HAZ scores demonstrate that in all groups there are multiple individuals with stunted growth for age (Fig. 4). Over half of non-adult individuals (51.2%) meet the technical criteria for stunted growth, falling more than two standard deviations below the reference populations’ median (Z-score of zero). The distribution of HAZ scores was just above being statistically significantly different between groups ($P=0.053$). Gallo-Roman children and adolescents have the lowest mean, median and overall HAZ scores (Table 4, Fig. 4). Median HAZ scores from both the Late Antique contexts are above the threshold for stunted growth. In the LAS, HAZ scores are highly variable, with notably high and low scores. Despite the large differences in the proportion of individuals with stunted growth in each group (Table 4), this was not statistically significant ($P=0.07$).

Table 4. HAZ Scores summary statistics based on WHO data, 3-18 years (CPR=Crude prevalence rate)

Group	N Non-adults 3-18 years	n Individuals with stunted growth	% Stunted n/CPR	% Stunted n/N
Gallo-Roman South	13	10	21.3%	76.9%
Late Antique South	17	6	4.4%	35.3%
Late Antique North	13	6	7.4%	46.2%
Total	43	22	8.2%	51.2%

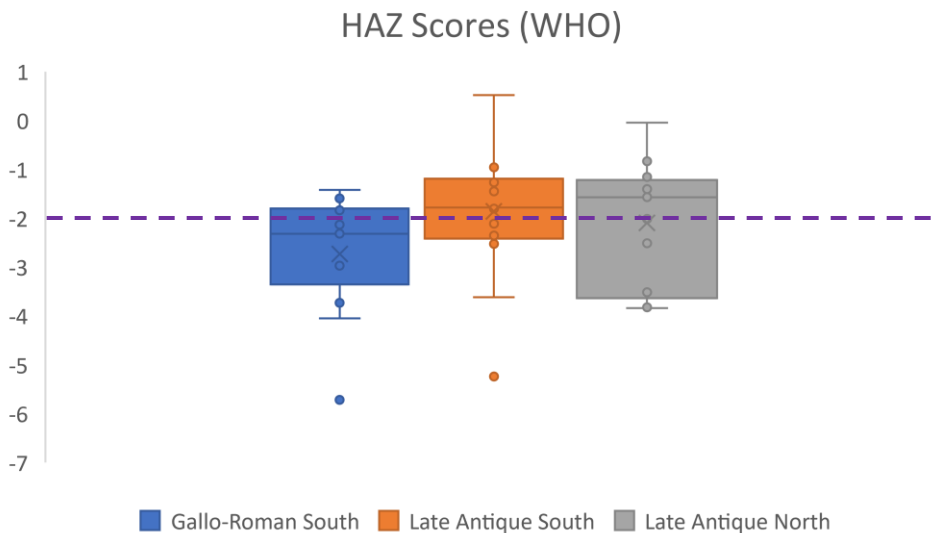


Fig. 4 HAZ scores derived from the WHO modern reference sample femoral lengths, including individuals from 3 to 18 years of age. The line equals the median, the X is the mean, the box is quartiles 2 and 3 and whiskers are the maximum and minimum values, not including outliers. Additional dots are outliers. The purple line represents the threshold for stunting.

4.2.2 *Growth and stunted growth by age category.* Examining the data by age category permits the identification of vulnerable subgroups within the sample populations to test some of the key assumptions of the proposed model. When organized and pooled by age category, children and adolescents from the GRS context show severe, but relatively equal degrees of average growth stunting across age groups (Fig. 5). In both the GRS and LAS contexts, the 15-17-year-old age group displays the lowest mean HAZ score. The LAN context shows the opposite pattern, where mean HAZ score is lowest in three-to-four-year-olds and improves with increasing age category.

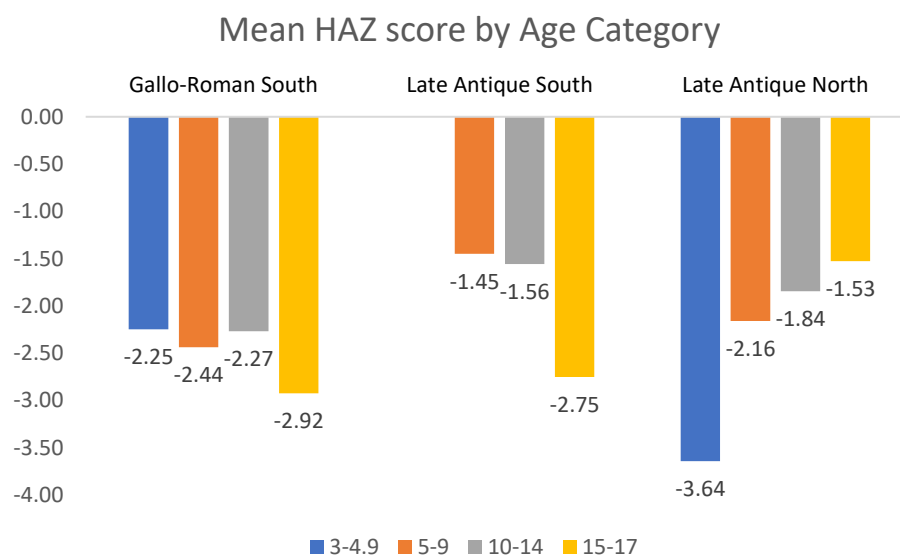


Fig. 5 Average HAZ scores derived from the WHO modern reference sample femoral lengths, including individuals from 3 to 18 years of age, by larger age category.

Investigating the proportion of individuals with stunted growth in each group across age categories reveals patterns of health during the developmental period (Fig. 6). As before, the GRS individuals show the highest rates of growth faltering across age groups. Examining the mean HAZ score values in combination with the proportion of individuals with stunted growth reveals that the Gallo-Roman 15-17-year-olds had a small percentage of ‘stunted’ individuals (2.1%), but that their growth was severely stunted (mean HAZ score= -2.92). In contrast, 15-17-year-olds in the LAS group had the highest proportion of stunted individuals and the most severe average degree of stunting. The LAN sample shows a peak in the proportion of individuals suffering from growth stunting in the 3-4 and 10-14-year

age categories, although HAZ scores indicate a trend of decreasing growth faltering with increasing age. Sample sizes become very small when divided to this degree, so the results should be interpreted cautiously.

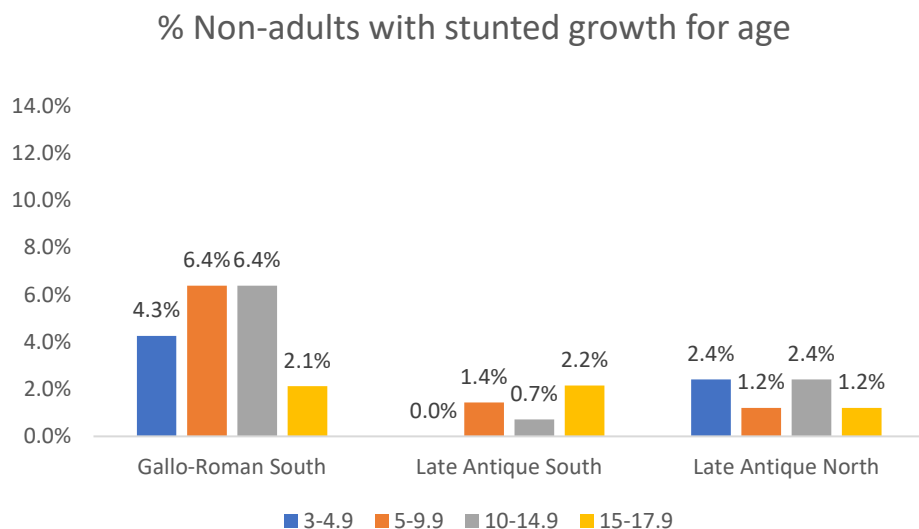


Fig. 6 Percent of individuals with stunted growth (CPR) (based on WHO reference sample)

4.3 Adults

4.3.1 Femur length. Adult femoral lengths represent a cumulative measure of environmental conditions throughout the period of growth and development. Average femur length shifted slightly in females from the Gallo-Roman to the Late Antique period, with increases of 0.1 cm in the LAS sample and 0.8 cm in the LAN group (this does include the presence of one notable female outlier) (Fig. 7). These differences were not statistically significant ($P=0.352$). Male average femoral lengths were identical in GRS and LAS groups, with a statistically significant increase in femoral length (1.8 cm) in the LAN group ($P=0.004$). Examining the distribution of maximum femoral lengths provides an opportunity for a more in-depth interpretation of the data. Gallo-Roman females and males display the lowest means and medians, with the latter falling well below the other groups (Fig. 7). Examining both the mean and median highlights how outliers (some particularly long and short femora) are influencing average femoral lengths. Females and males from both Late Antique samples have a wider distribution of femoral lengths in comparison with the Gallo-Roman sample. In females, Gallo-Roman

femoral lengths are relatively small with a narrow distribution (with the exception of one outlier). Male femoral lengths appear to be more normally distributed with mean and medians more closely aligned than in female comparisons. Gallo-Roman male femur lengths (median=44.3 cm) are smaller than the Late Antique groups (medians =45.0 and 46.9 cm respectively), although the distribution covers a wide area within the 2nd and 3rd quartiles of the data. The LAS group has a variable distribution of femoral lengths, ranging from 40.8 to 49.0 cm. Figure seven reveals that in both females and males, the first quartile (lowest femoral lengths) all have quite similar values between the groups. Most of the differences between groups exist in the upper third and fourth quartiles (highest femoral lengths), suggesting that although all populations had individuals with short femoral lengths or possibly filtered growth, a larger number of 'tall' individuals are present in Late Antique samples.

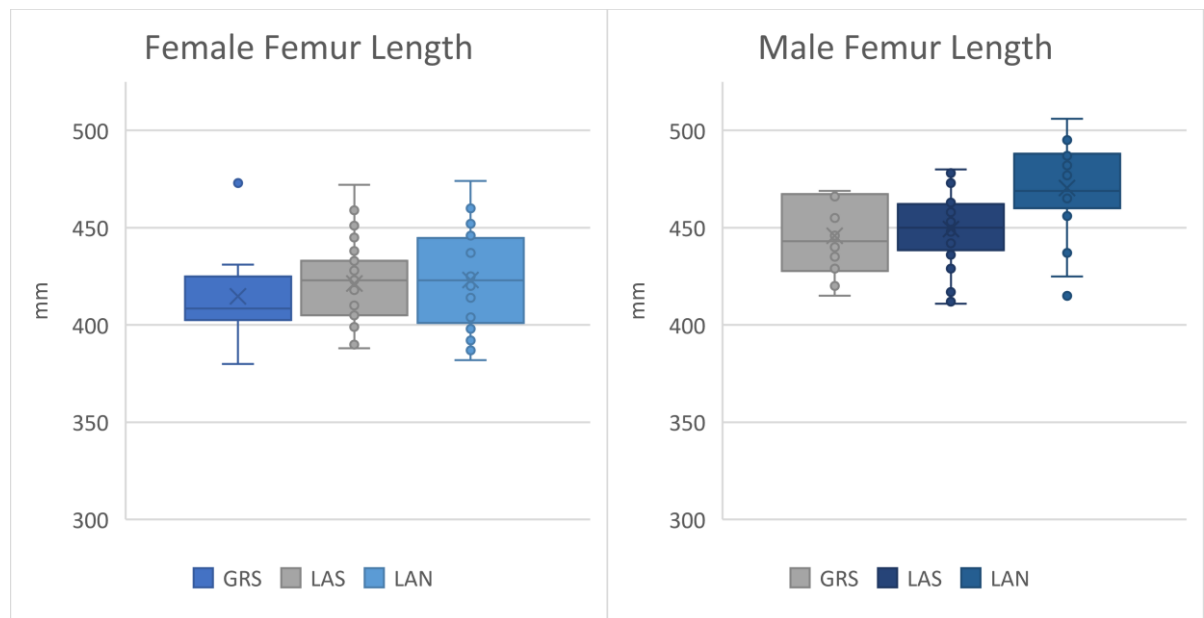


Fig. 7 Box and whisker plot of maximum femoral lengths. The line equals the median, the X is the mean, the box is quartiles 2 and 3 and whiskers are the maximum and minimum values, not including outliers. Additional dots are outliers. The outlier in the GRS sample was assessed as probable female.

5. Discussion

This section investigates how the data from Late Antique periods in Gaul correspond to the set of assumptions generated from health patterns observed during the collapse of the Soviet Union. The efficacy of the 'model' derived from the collapse of the Soviet Union is evaluated, identifying strengths and limitations. The implications of the findings are discussed in relation to the historical context.

5.1 Application of the 'model'

1. Health is substantially and negatively impacted by societal collapse. As demonstrated by patterns of growth and femoral lengths in non-adults and adults, environmental factors affecting health changed from the Gallo-Roman to the Late Antique period. In contrast to our hypothesis, adult femoral lengths increased, and degrees of growth stunting decreased during Late Antiquity as compared to the Roman period in Gaul. Children from Gallo-Roman contexts displayed a pattern of more severe growth stunting and in higher proportions than the Late Antique samples ($p=0.05$ and $P=0.07$). Adult average femur length increased in Late Antiquity, with significant increases (1.8 cm) in males from northern Gaul. Although not all statistical tests found significant differences between groups, some noteworthy patterns in growth and femoral lengths were observed, partially supporting tenet one in this analysis. A more nuanced interpretation of these patterns is discussed in a later section.

2. Child health and in particular, early childhood health (conception to 1000 days) demonstrates severe examples of health changes. Individuals who died in childhood and adolescence displayed signs of physiological stress as evidenced through growth faltering and stunting, regardless of time period or geographic region. Almost all non-adult individuals had reduced height-for-age in comparison with modern WHO growth standards. This finding is not surprising considering the sample is comprised of 'non-survivors' or children who died before reaching maturity, in comparison with healthy children from a post-Jennerian society. In this way, the data are most strongly reflecting the

challenges of growing up in the past in general, rather than furthering discussion about supposed periods of collapse.

Gallo-Roman non-adults, however, show a pattern of more individuals with more severely stunted growth in most age categories. Although this finding is congruent with tenet two of the model, it is in contrast with the hypothesized results and suggests that factors during the Gallo-Roman period were more negatively affecting growth than transitional circumstances occurring during Late Antiquity. Growth during infancy and early childhood proved elusive due to poor preservation. All four of the infants (<three years old) examined in this analysis derived from the Gallo-Roman context, preventing comparison with Late Antiquity. Tenet two can only therefore be examined in individuals who survived this precarious period of life. All individuals who survive infancy retain a 'record' of early life experience, as femoral lengths are a cumulative measure of growth throughout the developmental period and early childhood in particular. Clinical research has identified that delays in growth most often begin in utero or during the weaning period (Hoffman and Klein 2012; Kuzawa and Quinn 2009), suggesting the importance of early life nutrition and environment. As such, any individual in this study may have had the most severe effects to their growth during this early developmental phase. The next youngest age category of three-to-five-year-olds, who would have had the least opportunity to recover from early life growth impediments, reveals a high level of stunted growth with a particularly severe average degree of stunting in the LAN group. This finding provides support for tenet two, as the youngest available section of the LAN burial sample is demonstrating a marked response to environmental factors.

3. *Subgroups within the sample populations were differentially affected.* Subgroups within both adult and non-adult samples were differentially affected by environmental factors in the Roman and Late Antique periods, supporting tenet three of the model. Female femoral lengths did not undergo any significant changes from Gallo-Roman to Late Antique periods, although the distribution of femoral lengths was broader in Late Antiquity in both the north and the south. In contrast, male femoral lengths dramatically increased in the LAN group. This would suggest that males and females were not exposed to or experiencing the same environmental factors affecting growth during development.

Previous studies (Barker et al. 2002; Pezo-Lanfranco et al. 2020; Watts 2011) have found relationships between short stature and early mortality, indicating increased frailty with growth stunting. In this analysis, all adult age categories had similar distributions of femoral lengths, regardless of sex, indicating that there was no discernible correlation between age-at-death and femoral length. In non-adults, subgroups divided by age-at-death categories demonstrate a differing severity of growth stunting (HAZ scores). Isolating data on growth by age category is complicated because although the earliest life periods are thought to be the most sensitive to environmental conditions, growth disruption could have occurred at any stage of bone development, regardless of when an individual died. However, HAZ score patterns based on age-at-death were different between groups, indicating again that environmental conditions affecting growth were not uniform across subgroups or between time periods or geographic regions. This suggests that cultural or societal values in resource distribution or care differed between the groups. It would be interesting to look at non-adult subgroups by sex, especially given sex-specific differences in growth patterns and disease susceptibility (Stinson 1985). However, unreliability in current macroscopic methods of sex determinations of non-adults prevent this type of analysis.

4. *Subgroups do not conform to typical distributions of vulnerability.* This analysis identified patterns of stunted growth and changes in femoral length in subgroups of the sample populations that do not conform to standard distributions of vulnerability, supporting tenet four of the model. In a typical population, the youngest and eldest members are most vulnerable to disease and negative environmental conditions. This research found that older children and adolescents in the GRS and LAS contexts displayed some of the highest degrees of growth stunting. This suggests a divergence from traditional growth and disease patterns, where infancy and early childhood are the most vulnerable developmental periods. Children and adolescents from the GRS context show severe, but relatively equal degrees of growth stunting across age categories, becoming the most severe in adolescents (15-17). This could indicate that intense pressures normally associated with early childhood development and weaning did not subside with increasing age and certainly represents a departure from the pattern seen in the other groups. That adult femoral lengths from the GRS context tend to be smaller also might suggest that this was a population struggling to attain maximum height potential. Also displaying this atypical pattern within the LAS context, the 15-17-year-old age group had a markedly low mean

HAZ score in comparison with younger age categories, suggesting negative health conditions persisting later in the life course than might be explained by traditional patterns of disease susceptibility.

Adult male and female subgroups demonstrated differences in how femoral length was affected during Late Antiquity, where female femoral lengths underwent minimal change and male femoral lengths increased in northern regions. Although sex-based differences in absolute femoral length are expected (Humphrey 1998; Stinson 1985), differences in growth patterns within female and male comparisons suggests cultural practices are manufacturing a non-traditional distribution of biological vulnerability. Many diseases and pathological conditions can be sex-influenced or -dependent, but sex-dependent growth responsivity to environmental stress is less clear. It has been hypothesized that females are more 'buffered' from environmental conditions during growth than males, resulting in higher levels of male growth retardation and morbidity and mortality in the presence of stress (Cabeza de Baca et al. 2016; Stinson 1985). Although this hypothesis has found support during the prenatal period, postnatal growth studies do not consistently show that males are more sensitive to environmental conditions, possibly as a result of preferential treatment and resource access given to males over females in many societies (Stinson 1985). However, even if males are more vulnerable to environmental stress during growth, this does not explain the observed 'stability' in female femoral lengths and the increase in male femoral lengths in Late Antiquity. This sex-based difference in growth pattern is worthy of further exploration and represents a change that is likely based on cultural practices or restrictions rather than biological factors alone.

5.2 Assessment of the model

The four assumptions for health changes during societal collapse established here from the Soviet model were not entirely met for the sample populations from Late Antique Gaul. Although there was an appreciable difference in femoral lengths between the Gallo-Roman period and Late Antiquity, the change was not negative during the period of supposed societal collapse, only partially satisfying tenet one. This finding suggests that the transition from the Roman period to Late Antiquity did bring about change, just not one associated with catastrophic consequences for human health, and in fact quite the opposite. Although it is tempting to suggest that because this research does not support

‘catastrophe’, that it must support gradual transition, this is not what the data are manifesting. Tenets two (children show extreme change), three (subgroups are affected differentially) and four (subgroups outside the traditionally biologically vulnerable), which in some ways deal with the more culturally constructed elements of how health is impacted by societal changes, were met. What this means is that cultural factors are influencing growth and health in the burial samples, but it does not appear to be collapse. In this way, rather than speaking to how change took place during Late Antiquity, this study has inadvertently revealed how culturally mediated environments impacted the lives of Gallo-Romans. What does seem evident is that whether fast, slow, catastrophic or gradual, the transition from Roman to Medieval periods had a positive impact on the health of the studied samples. The results of the present analysis suggest that the four tenets developed from health data during the collapse of the Soviet Union as a loose ‘model’ are successful in identifying changes in health associated with shifts in cultural priorities or conditions and also exposes the heterogeneity of experiences dependent upon gender, age, etc. However, it simultaneously highlights that these changes are not specifically linked to a uniform experience of societal collapse, necessitating greater specificity in the model. It is problematic to apply very specific ideas from modern to past societies, hence the broad and generalized nature of the tenets in the first place. Focusing on what the model does accomplish, the tenets help to identify and isolate trends in health that likely have a culturally mediated basis.

Although unsuccessful in achieving its intended aim of identifying the effects of societal collapse in human skeletal remains, the model provides a novel framework for researching health in relation to historic trends. Previous attempts to isolate the effects of societal collapse on health were unable to satisfactorily relate observed patterns in skeletal stress markers with features of collapse (Kurin 2016; Wright 1997a, 1997b). Although not specific enough to link directly to collapse, the model presented here does highlight patterns in disease prevalence or distribution beyond typical biological mechanisms, suggestive of cultural or social causative factors. The model provides specific criteria and serves to link bioarchaeological and modern analyses of health, well-being, cultural and social influences. This analysis also highlights the challenges in using modern sources and data as a framework for understanding health in past populations. Not all societal collapse may exert the same types of health effects, necessitating room for heterogeneity of experience. The collapse of the Soviet Union thereby acts as (only) one possible example. Further modern examples of health outcomes in relation to social and cultural influences should continue to be consulted in the interpretation of past

populations. Critical examinations of how different environments or social actions affect health and how these effects might manifest in the skeleton could be beneficial to future analyses.

5.3 Continuity or Catastrophe in Late Antique Gaul?

Although the model did not identify societal collapse during Late Antiquity and conversely health improved as Roman control retreated, differences between LAN and LAS groups attest to geographic variation in the impact of the Late Antique transition. Again, in contrast with hypothesized results, overall patterns of growth and adult femoral lengths suggest that living conditions during transition were more advantageous in the north of Gaul. Male femoral lengths were significantly longer in northern Gaul, likely suggesting that environmental conditions were more favorable than in the south, where both male and female femoral lengths remained similar to Gallo-Roman values. This observation is supported by the non-adult results, where LAN non-adults demonstrated high levels of stunted growth (low HAZ scores) in early childhood and decreasing degrees of stunting as age increased. This pattern could be reflecting the perils of infancy and early childhood, where children with the most severely stunted growth did not survive. However, children who were able to overcome this sensitive period in life, appear to have experienced conditions healthy enough for them to survive, thrive, and possibly even overcome negative early life experiences. If physiological stressors impacting growth retreat, catch-up growth can occur, where the rate of growth increases to compensate for periods of delayed growth (Cameron and Demerath 2002; Tanner 1981). Depending on the timing of the stress event and provided it was minimal in severity or duration, maximum growth can be achieved. Coupled with the longer adult femoral lengths also observed in this analysis, that the LAN group potentially experienced catch-up growth is a promising hypothesis. Interestingly, the distribution of female femoral lengths was broadly similar in the LAS and LAN groups, suggesting that factors affecting female heights did not vary greatly across geographic regions during Late Antiquity. This finding indicates a substantial difference in how males were experiencing the growth period in northern and southern Late Antique contexts and attests to heterogeneous living environments during growth. Why males and not females are demonstrating this large shift in growth is worthy of further exploration.

5.3.1 Migration. A prominent theme in Late Antiquity is the idea of mass migrations of Germanic peoples crossing over the Rhine and specifically, although not exclusively, into Northern Gaul (Halsall 2007; Wickham 2005). Given the location of the LAN sample (many not far from the Rhine border), in addition to historical and archaeological evidence for migrations during this period, migration seems a likely explanation for the observed increase in male femoral lengths. Further, there is evidence in both past and more contemporary populations that societal collapse provokes migrations and this might even be considered a feature of post-collapse society (Härke 2007; Kurin 2016). However, there are several problems with this explanation for the observed trends. Large changes in height are more reflective of an improvement in environmental conditions during the growth period than they are of genetic differences between peoples, as evidenced through both past and contemporary peoples (Perkins et al. 2016; Roberts and Cox 2003; Schweich 2005). Studies examining stature in migrant communities, as well as separated twin studies, have found that stature is plastic, moving with the conditions the child grew up in, rather than reflecting parents' previous environments or genetic influence (Eveleth and Tanner 1990; Perkins et al. 2016). Because the present data are analyzed at the population level, systemic influences of living environment, nutrition, emotional stress, disease and their interrelated effect on health or stature are more likely to be identified than genetic influences, which are more readily apparent at the individual level (Cardoso et al. 2019; Perkins et al. 2016). Jongman et al. (2019) in their vast analysis of changes in height throughout the Roman Empire ultimately concluded that migration was not an explanation for their observed results, where patterns of increasing height occurred in too many of their regional subsets for migration to have occurred everywhere. Further, this study shows that for both females and males the first quartile (lowest femoral lengths) have quite similar values between groups (Fig. 7). If the populations in northern Gaul were totally new or different, we might expect the whole population to be offset higher or lower. However, most of the differences between groups exist in the upper third and fourth quartiles (highest femoral lengths). This suggests that although all tested populations had individuals with short/faltered growth, there are more individuals in Late Antique populations attaining tall heights. While there may have been some migration, a more likely explanation is that the conditions affecting growth improved during Late Antiquity and in particular in the north of Gaul. This same pattern is evident in the non-adults as well, further suggesting that the change in femoral length cannot be explained by migration alone. Naturally this does not preclude migration and certainly some admixture seems possible and even probable. There is currently no isotopic or DNA data available to investigate migration within the samples studied here.

5.3.2 *Alternative explanations.* The data have highlighted that conditions during the Gallo-Roman period were adversely affecting health, but this period was not the key focus of the manuscript. As a result, it is only briefly summarized here and remains a promising avenue for future research and study. One hypothesis for the observed increase in male femoral lengths in the Late Antique North involves the role of nutrition in growth, where protein and vitamins A and D play critical roles (Perkins et al. 2016). Perhaps populations living in the north of Gaul during Late Antiquity had better access to higher quality food resources than individuals in the South during Gallo-Roman or Late Antique periods. Koepke and Baten (2008), Koepke (2014) and Scheidel (2012) have argued that ‘Germanic’ populations from North western Europe were consuming higher quantities of milk and beef and that this is the reason for their increased height in comparison with Mediterranean populations (rather than migration). Although the lack of increase in female femoral length could be signaling differential access to food resources based on sex. Another possibility is that collapse, or catastrophe did occur and was so severe that it wiped out the people who would have comprised the shortest sector of the population (Scheidel 2012). By this logic, many individuals with stunted growth or short femoral lengths are observed in the Roman period because they were able to survive metabolic insufficiencies, illness or environmental stress at the expense of tall height. Studies of later industrial periods (DeWitte et al. 2016; Quade and Binder 2018; Vercellotti et al. 2014) have identified the possibility of ‘healthier’ populations preserving the short proportions of their populations, leading to overall reduced average adult stature. Although this hypothesis is intriguing, it is not well supported by the distribution of adult femoral lengths or the non-adult data in this analysis, where higher percentages of Gallo-Roman children had stunted growth and more severely stunted growth than Late Antique populations. The Gallo-Roman sample does not merely retain a larger percentage of individuals with shorter femoral lengths but appears to have shorter femoral lengths overall. The longer femoral lengths in the LAN group especially indicates that more individuals within the sample were able to achieve taller heights, suggesting improved living conditions throughout the growth period. Differences in urbanization between the periods also likely have contributed to these observed results.

5.4 Limitations and future directions

Intended as an exercise in thinking about collapse in archaeological societies in a different way, the present research has several important limitations. The broad dating of cemetery sites in Late Antiquity

is an acknowledged problem (Esmonde Cleary, 2011), which influences the ability to interpret these results with greater temporal precision. Further, individuals from burial populations represent samples of samples, and are therefore not representative of the living population. Non-adults in particular, represent only those individuals who died at a particular age group. Additionally, because sex could not be estimated in non-adults, this may affect the reliability of the data. These are, however, limitations common to many bioarchaeological analyses. The samples analyzed represent an urban bias for Roman sites when compared to Late Antiquity and this may also have a bearing on the results. This bias is, however, common to most studies of this transition; unfortunately, the skeletal samples available to bioarchaeologists are rarely optimal. Furthermore, those buried in these cemeteries, which were located outside of the town walls, were not necessarily urban dwellers but could have hailed from the rural hinterlands or further afield (e.g. Gowland and Redfern 2010).

Methodologies for assessing femoral length or height-for-age in non-adults make use of modern reference samples. As a result, finding that children had reduced growth in antiquity compared with modern children is not surprising, as the sample consists of individuals who failed to survive into adulthood. Although important, these issues also represent broader problems inherent in the bioarchaeology of children (Lewis 2007). Another limitation has to do with difficulties in setting criteria which are specifically linked to societal collapse. Not all negative secular change is associated with societal collapse. Times of marked political instability, economic and socio-political crises have also resulted in increased prevalence of stunting (Bogin and Keep 1998; Ellison and Kelly 2005). The Soviet collapse occurred over the course of just a few short years, a period of time that would be challenging to identify archaeologically if a similarly rapid collapse occurred during Late Antiquity. However, there is evidence that some effects have the potential to be passed down through generations, through epigenetic mechanisms (Gowland 2015), which has the potential to be an exciting area of future research. Further analysis of urban/rural divides, mortality rates, and additional skeletal indicators of stress or infectious disease (which were beyond the scope of the present research) would greatly contribute to the present study, possibly highlighting the role of more specific pathological conditions or nutritional deficiencies in patterns of growth and growth disruption in Gallo-Roman and Late Antique Gaul. Higher rates of several conditions potentially visible in human skeletal remains such as tuberculosis and anemia were noted during the collapse of the Soviet Union (Stillman 2006) and might

make interesting points of intersection for future analyses. Despite the challenges, it is important to continue to engage with modern data and populations as well as new theoretical frameworks.

6. Conclusion

Through an examination of patterns of health during a known societal collapse (The Soviet Union), this study has identified several features of culturally mediated change on health. Health as indexed by femoral lengths and height-for-age were assessed from skeletal remains from Roman and Late Antique Gaul according to these tenets to clarify whether 'catastrophe' or 'continuity' hypotheses of Late Antique transition was supported. The 'model' was found to lack sufficient specificity to identify if populations in Gaul experienced societal collapse during Late Antiquity. However, the tenets did appear to be successful in identifying culturally mediated influences on health, where health during the Gallo-Roman period was negatively affected. Non-adults from Gallo-Roman contexts displayed more individuals with stunted growth and more severe degrees of stunting than either Late Antique South or North contexts. Adult female and male femoral lengths were longest in the Late Antique North sample, attesting to geographic variability during Late Antiquity. Although the model generated for this research failed to achieve its ultimate goal of identifying the effect of societal collapse on health, it has presented an interesting and ultimately effective way to assess the effects of culturally-mediated changes on health, which serves a beneficial, if slightly different purpose.

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Supplemental Information

Table S 1. Dental and skeletal age determinations for the four individuals under the age of two years

Group	Individual	Dental Age (mean of range)	Femur Length Age (mean of range)
Gallo-Roman South	Arles le Cirque IRP 2216	3 weeks	3 weeks
Gallo-Roman South	Arles le Cirque IRP 1588	2mnths	28 weeks gestational
Gallo-Roman South	Arles le Cirque IRP 2283	6mnths	Birth
Gallo-Roman South	Arles le Cirque IRP 1570	6mnths	1.5mnths

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Height and Health in Roman and Post-Roman Gaul, a Life Course Approach

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Abstract:

Large-scale analyses of skeletal remains from the Roman period have often found an increased prevalence of growth stunting and reduced adult stature in comparison with preceding and later eras. However, when assessed from skeletal remains, a relative reduction in stature is indicative of childhood physiological stress, but can also reflect enhanced survivorship (an adaptive response to stressors). This study explores growth and health in Roman (1st-2nd c) and Post-Roman (4th- 7th c) Gaul through an examination of non-specific stress indicators (reduced femur length, dental enamel hypoplasia, cribra orbitalia, tibial periosteal reactions and carious lesions) in 844 skeletons. Rates of DEH and tibial periosteal reactions were significantly higher in the Gallo-Roman sample and rates of CO and caries were significantly higher in Post-Roman samples. Small femoral length was not correlated with mortality in any of the groups. DEH presence was correlated with earlier mortality in the Gallo-Roman context, whereas CO presence was associated with earlier mortality in the Post-Roman samples. This suggests that Roman and post-Roman populations included individuals that were affected by early life stressors, but these patterns manifested in different ways, presumably due to variation in risk factors both within the body (intrinsic) and external to it (extrinsic - socio-cultural, environmental). The intertwined and often synergistic relationships between these risk factors, including early life environment, nutrition, settlement structure and social stress are highlighted.

Keywords: Late Antiquity, Growth, Intermittent stress of low lethality, DOHaD

The impact of Roman practices on living conditions and health has received much scholarly attention. Some research has emphasised improvements in water supplies and sanitation, and increased economic activity, food diversity and trade networks, as factors positively impacting health status during this time (Dermody et al., 2014; Hitchner, 2012; Jongman et al., 2019; Kron, 2019, 2005; Lo Casio, 2006). Other work has argued that Roman urbanisation, high population density and disease loads (and possible food shortages) negatively affected health (Frier, 1977; Harper, 2016; Morley, 2004; Porter, 1999; Scheidel, 2015; Walter Scheidel, 2012a, 2012b; Scobie, 1986). Bioarchaeological studies demonstrate a pattern of reduced adult height across the Roman Empire when compared to both preceding and succeeding periods (Cleymans, 2019; Giannecchini and Moggi-Cecchi, 2008; Gowland, 2017; Gowland and Garnsey, 2010; Gowland and Walther, 2019; Koepke, 2014; Koepke and Baten, 2008; Redfern, 2008; Redfern and DeWitte, 2011; Roberts and Cox, 2003; Walter Scheidel, 2012b; Stead et al., 2006). However, when assessed from skeletal remains, reduced stature is indicative of childhood physiological stress, but can also reflect enhanced survivorship (DeWitte and Hughes-Morey, 2012; Klaus and Tam, 2009; Vercellotti et al., 2014; Wood et al., 1992). As such, deeper contextualisation of growth data is important to understanding how health and height were being impacted during the Roman and Post-Roman periods. Further, growth disruption (and reduced adult stature) could stem from early life stressors and/or reflect recurrent periods of stress throughout the developmental period (Pezo-Lanfranco et al., 2020). This study examines skeletal stress indicators (long bone growth, dental enamel hypoplasia, cribra orbitalia, tibial periosteal reactions and carious lesions) in 844 individuals from multiple sites from Roman and Post-Roman Gaul to identify potential patterns in health during the Roman period. Some analysed lesions relate specifically to stress during childhood (e.g. growth, enamel hypoplasia and cribra orbitalia), whilst others may occur up until the point of death (tibial periosteal reactions and carious lesions). This study considers health across the life course and the effects of early life adversity on morbidity and mortality, to improve our understanding of health in Roman Gaul.

1.1 Research Context

Gaul (modern-day France, Belgium, parts of Germany, Italy and Switzerland) occupied a unique position within the Roman Empire (Fig. 1). As an early trading partner and the first province north of the Alps to be conquered and colonised (late second century BCE), southern Gaul (Gallia Narbonensis) became deeply connected with Roman structures, trade and cultural ideals

(Hitchner, 1999; Woolf, 1998). Northern Gaul was conquered much later (58-51 BCE) and while it was integrated into the Empire, it remained a frontier zone, providing protection from and connectivity to 'barbarian' borderlands (Woolf, 1998). Roman integration was not a uniform process, although there are often great similarities in the monumental architecture of Romanised cities (baths, forum, layout) (Aldrete, 2004). Conquered or assimilated peoples often retained aspects of their culture or language, becoming integrated to varying degrees into the wider Roman Empire (Cool, 2006; Kron, 2019; Mathisen, 1992). Southern Gaul tended to be wealthier with more lavish villas and was more densely urbanised than northern regions (Woolf, 1998). Along with Roman urban centres came military protection (and disturbance), exotic goods and Roman cultural ideals and socio-political structures. Sanitation systems, including fresh water supplied through a system of aqueducts, public baths, regulations on keeping drains clear and the selling of spoiled food were implemented (Porter, 1999). Vast communication networks facilitated travel, trade, access to new resources and technologies, but also the transmission of pathogens (Harper, 2016; Porter, 1999). The cultural and physical connectivity of southern Gaul with Roman structures and practices meant that Roman cultural and socio-political practices became more strongly embedded in the South in comparison with the North (Bonifay et al., 1998; Démians d'Archimbaud, 1994; Wickham, 2005).

From the early 4th century, Roman authority and political control in northern regions was eroded through political intrigue, military defeats, civil wars and usurpations and increasing 'barbarian' presence and influence (Halsall, 2004; Wickham, 2005). Urban areas contracted in size, traditional Roman construction methods and layouts were abandoned, systems of production, and communication and trade that had been established in the early empire deteriorated, reorienting what had been a large imperial network back to local forms of production and politics (Humphries, 2009; Mathisen, 2011; McCormick, 2015; Theuvs, 2009; Van Ossel, 2006; Ward-Perkins, 1996; Wilkinson, 2015). Houses became more simplified, public buildings and monumentalism were no longer invested in, and in some cases, were actively stripped away. Water supply and disposal systems were not maintained and eventually fell into disrepair and disuse (Bailey, 2016). Population density is thought to have dramatically decreased (Ando, 2008). This 'transition' is thought to have occurred more gradually in southern Gaul in the 4th and 5th centuries, as reflected by continued trade and Roman investment in the region. Roman power bases (capitals/prefects) in Gaul were consolidated to southern territories when those in the north became too difficult to effectively manage (Laes and Vuolanto, 2016; Wickham, 2005; Yoon, 2016). By the end of the 7th century, all of Gaul displayed markedly decreased wealth, social complexity and less integration

into distant communication networks in comparison with the Roman period (Harries, 1994; Wilkinson, 2015). These events and trends highlight the diversity of Gaul during the Roman and Post-Roman periods, signalling the potential utility in examining health in southern and northern Gaul in relation to society-level changes occurring during these time periods. If features of Roman lifeways, such as urban living structures, higher population density and diet through trade networks (access to resources) were beneficial, then health and height are likely to have declined in the Post-Roman period, especially in northern regions. If, however, these practices were negatively influencing height and health in Gaul, then the opposite might be demonstrated.

1.2 Height and Health in the Western Roman Empire

Across the Western Roman world there is evidence of reduced adult stature, as compared to prior and later periods (Giannecchini and Moggi-Cecchi, 2008; Gowland, 2017; Gowland and Garnsey, 2010; Gowland and Walther, 2019; Koepke, 2016, 2014; Koepke and Baten, 2008; Redfern, 2008; Redfern and DeWitte, 2011; Roberts and Cox, 2003; Walter Scheidel, 2012b; Stead et al., 2006). A person's potential for height is genetically dictated, but the ability to express or achieve that potential is mediated by environmental conditions, disease load and nutrition during childhood (Bogin, 1999a; Stinson, 2012; Vercellotti et al., 2014). On a population level, systemic influences of environment, nutrition, emotional stress, disease and their interrelated effect on health or stature are more likely to be identified than genetic influences (Cardoso et al., 2019; Perkins et al., 2016; Steckel, 1995). As such, stature and growth are often used as an indicator of childhood health and wellbeing, as prolonged nutritional deficiencies and illness can negatively influence adult height (Goodman, 1991; Hoppa and Fitzgerald, 1999; Saunders and Hoppa, 1993; Steckel and Rose, 2002; WHO, 1998). Although growth disruption can take place at any time within the developmental period (prenatal-20 years for the femur- Scheuer and Black, 2000), delays in growth most often begin in utero or during the weaning period (Hoffman and Klein, 2012). Early childhood is a sensitive and precarious period of life, as growth processes are energetically demanding and there is high tissue turnover. This makes infants particularly sensitive to environmental conditions and fluctuations (Lewis, 2007). Growth stunting present by the age of two years can be retained through to adulthood, resulting in reduced adult stature (Kuzawa and Quinn, 2009). As a result, faltered growth in the Roman period could have had its origins in infancy and early childhood, highlighting the importance of early life nutrition and environment.

In modern and past populations, stunted growth and reduced adult stature are associated with a reduction in immune function and increased morbidity and mortality throughout the life course, suggesting that populations with high degrees of growth stunting are more deeply affected by illness (Barker, 2012; Barker et al., 2002; McDade, 2012; Steckel, 2009, 2005; Steckel and Rose, 2002). However, when examining 'health' or stress states from human skeletal remains, reduced stature can be interpreted as a sign of survival, where more individuals with short stature were able to survive early life stressors (The Osteological Paradox) (Bogin, 1999b; DeWitte and Hughes-Morey, 2012; Klaus and Tam, 2009; Vercellotti et al., 2014; Wood et al., 1992). The recording and analysis of additional skeletal stress markers can provide critical insights into the timing, duration and cause of poor health and growth disruption within a population, helping to identify relationships between stature and enhanced or reduced frailty (Cameron and Demerath, 2002; Cohen et al., 1994; Goodman, 1993; Tanner, 1981). This approach has been exemplified in a number of previous studies (Gowland and Newman, 2017; Klaus and Tam, 2009; Newman and Gowland, 2015; Watts, 2013, 2011). Examining multiple stress indicators that develop at different life stages permits a longitudinal analysis, even from cross-sectional data (Klaus and Tam, 2009; Watts, 2013; Vercellotti et al., 2014; Roberts and Steckel, 2018; Agarwal, 2016; Temple, 2019). For example, dental enamel defects can only form during the period of enamel development (from around six months to approximately nine years of age for the 2nd molar). Like growth, dental enamel defects are non-specific (could be caused by different types of insult or stress), but because they can only form during a limited period of time, they can help to identify when in the life course individuals and populations were affected. A life course approach, incorporating several skeletal stress indicators can augment growth data and may help to characterise the effects of Roman practices on health in Gaul.

The present study aims to build upon previous research to better understand the influence of Roman practices on health, and changes occurring from the Roman to Post-Roman period in Gaul. Patterns in growth disruption (femur length), early life stress indicators (DEH, CO) and later health outcomes (mortality, caries and tibia PR) are investigated. The selected stress indicators provide information about health from multiple stages across the life course. The data are explored in relation to several factors affecting health during the Roman period to provide appropriate context for the observed results. These include the influence of Roman practices on diet, repressive social hierarchies, urbanisation and higher population density. The separation of northern and southern regions of Gaul permits the examination of differences between the two regions based on different levels of integration in the Roman world and divergent trajectories in the Post-Roman period.

2 Materials and Methods

The skeletal remains of 844 Individuals from 13 assemblages were analysed for non-specific signs of physiological stress, including growth disruption (diaphyseal and adult maximum femur length), dental enamel hypoplastic defects (DEH), cribra orbitalia (CO), periosteal reaction of the tibiae (Tibia PR) and carious lesions (caries). Individuals were categorised into one of three groups (Gallo-Roman South, Post-Roman South, Post-Roman North), dependent on the date and location of their archaeological context (Table 1, Fig. 1). Sites that displayed typical Gallo-Roman monumental or building features and burial rituals (Charon's obol, sarcophagi, feasting vessels) or 'Post-Roman' rituals (row graves, weapon burials, jewellery) were prioritized. The Gallo-Roman South group includes individuals from two sites, one an artisanal community (Saintes, Rue Jacques Brel) and the other an urban context (Cirque Romain, Arles). Skeletal data for the Post-Roman South group derived from six archaeological sites located south of the Loire River. The Post-Roman North group is composed of individuals from five sites north of the Loire River. Both 'urban' and rural cemetery sites were included in the Post-Roman groups. Due to the prevalence of cremation as a funerary practice and preservation biases, it was not possible to obtain sufficient data from northern regions during the Gallo-Roman period. This limits the interpretations and scope of this analysis.

Both non-adult (<18 years old) and adult (>18 years old) individuals were examined in this research. For non-adults, age-at-death was determined by the stage of dental development (AlQahtani et al., 2010). Adult age-at-death estimations were based on degenerative changes in the pelvis (Brooks and Suchey, 1990; Lovejoy et al., 1985; Schmitt et al., 2002) and dental wear (Brothwell, 1981). Only adult remains were assessed for sex estimation, using sexually dimorphic features of the skull and pelvis (Bruzek, 2002; Phenice, 1969). To expand small sample sizes, individuals determined to be female or probable female were considered in the analysis as 'female' and likewise male and probable male individuals were pooled as male.

Table 1. Sites included in the present research

Site	Date	Context	Reference	Non-adults	Adults	Total Inds.	Group
Cirque Romain, Arles	2-4 th c	Urban	(Sintès, 1989)	27	47	74	Gallo-Roman South (GRS)
Saintes, Rue Jacques Brel	1-2 nd c	Urban	(Baigl et al., 1997)	22	60	82	
				49	107	156	
La Grande Bastide de Cadarache	4-7 th c	Rural	(Pouyé et al., 1994)	27	79	106	Post-Roman South (PRS)
Colombier Vaison-la-Romain	5-6 th c	Urban	(Carru, 1991)	15	65	80	
Les Clavelles	6-7 th c	Rural	(Boiron, 1993)	5	7	12	
Rues de Toulon	4-7 th c	-	(Pouget et al., 2002; Salicetti, 1998)	2	17	19	
Saint-Martin (La Brillane)	4-5 th c	Rural	(Boiron, 1993)	1	9	10	
La Granède	4-7 th c	Rural	(Saint-Pierre, 2010)	1	10	11	
				51	187	238	
Le Clos des Cordeliers	5-6 th c	Rural	(Guignier, 1997)	16	40	56	Post-Roman North (PRN)
St Martin de Fontenay	4-7 th c	Rural	(Pilet et al., 1994)	45	186	231	
Fontoy	4-7 th c	Rural	(Seilly, 1995)	23	97	120	
Rue du Tombois	4 th c	Urban	(De Filippo et al., 2000)	8	27	35	
Cutry	5-7 th c	Rural/Villa	(Liéger and Cussenot, 1997)	1	7	8	
				93	357	450	
			Total	193	651	844	

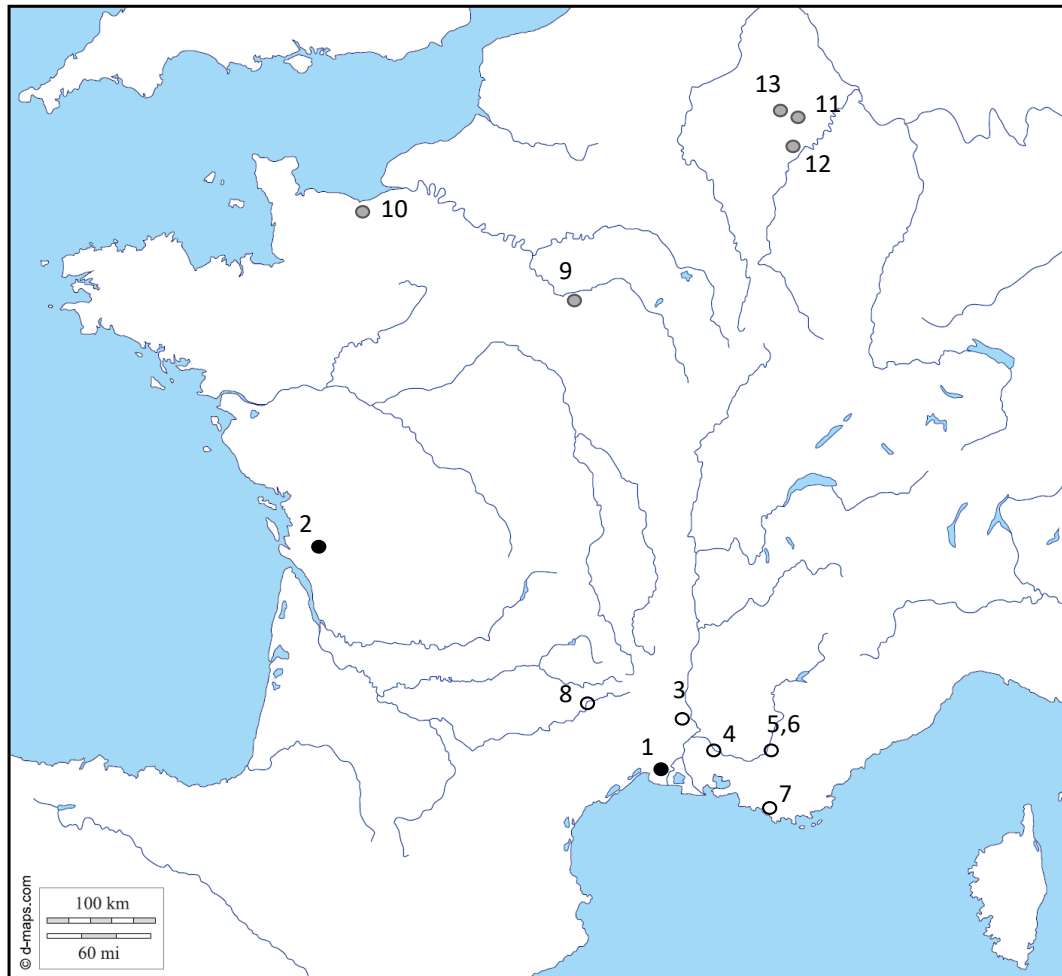


Fig. 1. Map of sites assessed in this analysis. Black dots indicate Gallo-Roman South, white dots indicate Late Antique South and gray dots indicate Late Antique North. 1= Arles Cirque, 2= Saintes, Rue Jacques Brel, 3= La Grande Bastide de Cadarache, 4= Vaison la Romain. 5= Les Clavelles, 6= Saint-Martin (La Brillane), 7= Rues de Toulon, 8= La Granède, 9= Le Clos des Cordeliers, 10= St Martin de Fontenay, 11= Fontoy, 12= Rue du Tombois, 13= Cutry

2.1 Non-adult systemic stress

Growth disruption, DEH, CO, Tibia PR and caries were investigated in this analysis as these are considered to be ‘reliable indicators of general health’ and reflect health during different stages of the life course (Redfern and DeWitte, 2011; Roberts and Cox, 2003; Steckel and Rose, 2002; Watts, 2013). Individuals were included in this analysis if they had adequate preservation to estimate age-at-death and at least one of the non-specific stress indicators assessed in this study. Results are presented as both crude prevalence rate (CPR), or the percentage of individuals displaying a lesion, and true prevalence rate (TPR), or the percentage of observable bone elements or teeth displaying a lesion. Statistical analyses, including Kruskal-Wallis non-parametric and chi-squared tests, were

applied to identify significant differences between groups in femoral length, CPR and TPR of the pathological conditions. The CPR and TPR of each pathological condition are considered in respect to age-at-death categories. Mann-Whitney U tests were used to examine the difference in mean age-at-death for individuals with and without growth disruption (comparatively small femoral length), DEH and CO to identify possible correlations between early mortality and these indicators of early life stress. Statistical significance was set at 0.05.

2.1.1 Growth disruption

For non-adults and adults, growth disruption was assessed through the maximum length of the femur. The femur develops from the 7th-8th week in utero until the late teens or early twenties, when epiphyseal fusion occurs (Scheuer and Black, 2000). Femoral length therefore reflects growth and potential growth disruption throughout the developmental period. To assess small height-for-age, or potential growth disruption, skeletal growth profiles were created, where dental age was plotted against age determinations based on femoral diaphyseal lengths (Cardoso, 2007). Because dental development is the least impacted by the environment (Cardoso, 2007; Lewis and Garn, 1960; Liversidge et al., 1998), dental age estimates were used as a baseline against which to assess femoral growth. The mean of the dental age range was used in this analysis in common with other growth studies (Mays et al., 2008; Newman and Gowland, 2015). For non-adults, the diaphyseal length of the femur, without inclusion of the epiphyses, was measured. In cases where epiphyses were partially fused, no measurement was taken.

For adults, the maximum length of the femur was considered as a proxy for stature, as regression formulae for stature remain problematic due to population variability in body proportions (Klein Goldewijk and Jacobs, 2013; Vercellotti et al., 2009). Short stature (or long bone length) is typically identified as being two standard deviations below the mean or median of a reference population (WHO, 1998). This calculation can be problematic in studies of skeletal remains, which often involve small sample sizes. Following similar analyses, short stature or disrupted growth was counted as 'present' for adult individuals that were below the median value for their sex within their respective group (Pezo-Lanfranco et al., 2020). Adult male and female femoral lengths were considered separately. Femora were measured to the nearest millimetre using an osteometric board by Paleotech. Following standard practice, left femora were preferentially selected in all adult and non-adult analyses of femoral length.

2.1.2 Dental enamel hypoplasia (DEH)

Dental enamel hypoplasias are commonly assessed in paleopathology as an indicator of non-specific physiological stress during childhood and development (Guatelli-Steinberg and Lukacs, 1999; Hillson, 1996; King et al., 2005). Enamel hypoplasia or defects form during periods of environmental or metabolic stress (illness, nutritional deficiencies or deprivation), where ameloblast function is inhibited, leaving an almost indelible mark of the stress episode (Fig. 2)(Goodman and Rose, 1990; King et al., 2005). Anterior and posterior permanent teeth were assessed for DEH presence. Anterior teeth develop between one and six years of age, while posterior tooth crowns develop until around nine years of age (2nd molar) (AlQahtani et al., 2010). DEH presence would therefore reflect systemic stress between the ages of six months to nine years. Methods of estimating age-of-development for DEH are available (Hillson and Bond, 1997), but become problematic in macroscopic analyses due to imprecision in current methods for estimating the timing of DEH development (Ritzman et al., 2008). Although DEH can result from multiple aetiologies, including genetic influences, trauma and biological stressors both systemic and acute, the presence of DEH on multiple teeth suggests systemic origins (Klaus, 2020). Only individuals who displayed DEH on a minimum of three teeth were considered to have DEH present, to avoid the inclusion of DEH based on trauma or genetic influences (Goodman and Rose, 1990). In this analysis, DEH (and carious lesions) were assessed in permanent dentitions using a bright light and magnifying glass. Where present, the number of observable DEH events were counted and recorded for each tooth.

2.1.3 Cribra orbitalia (CO)

Cribra orbitalia (CO) is characterised by an outgrowth of the diploë and a thinning of the outer table of the eye orbits in an effort to expand hematopoietic marrow surface area and produce more red blood cells (Brickley, 2018; Ortner, 2003). The lesion is frequently assessed in palaeopathological studies, despite controversies surrounding its aetiology (Gowland and Western, 2012; Klaus, 2020; McIlvaine, 2015; Piperata et al., 2014; Walker et al., 2009). CO has an important relationship with diet, disease load, several forms of anaemia (iron deficiency, haemolytic and megaloblastic) and specific pathological conditions including thalassaemia, rickets, scurvy and malaria (Gowland and Western, 2012; McIlvaine, 2015; Oxenham and Cavill, 2010; Piperata et al., 2014; Smith-Guzmán, 2015; Walker et al., 2009). Although similar appearing lesions can develop during adulthood as a result of inflammation of the eyes (Wapler et al., 2004) or malaria (Gowland and Western, 2012; Smith-Guzmán, 2015), CO is most often developed during early childhood between the ages of six

months and four years, with healed or healing lesions retained into adulthood (Blom et al., 2005; Brickley, 2018). CO is here assessed as a non-specific indicator of physiological stress (Belcastro et al., 2007; Brickley, 2018; Goodman and Martin, 2002; Redfern and DeWitte, 2011; Roberts and Cox, 2003; Steckel and Rose, 2002). Cribra orbitalia was recorded using the Stuart-MacAdam (1991) method but was analysed on a presence/absence basis only. Individuals had to have a score of '3' for CO to be counted as present (Watts, 2013). Although state of healing was not assessed, care was taken to distinguish expansion of the diploë from new bone formation on the outer orbit surface, which can be indicative of scurvy, or vitamin c deficiency (not recorded as CO).

2.2 Adult systemic stress

2.2.1 Carious lesions (Caries)

Carious lesions develop from the bacterial demineralization of tooth structures, associated with diets high in carbohydrates and sugars and limited dental hygiene (Hillson, 2001; Larsen, 1997), but can also be affected by malnutrition (Walter et al., 2016) and hormonal fluctuations (Lukacs and Largaespada, 2006). Dental caries have been associated with overall poor health, as well as specific conditions including cardiovascular disease, asthma, liver disease, and growth stunting (DeWitte and Stojanowski, 2015; Glodny et al., 2013; Johnston and Vieira, 2014). In this way, their frequency can be indicative of overall health status in addition to dietary influences. Caries can occur at any age in which tooth structures are exposed to the oral environment. Because only permanent teeth were considered in this analysis, the earliest development would be at approximately six years of age when the first permanent molars begin to erupt (AlQahtani et al., 2010). However, dental caries are age-progressive lesions, meaning that their presence and severity are positively correlated with age (Larsen, 1997; Prowse, 2011). As such, it is important to consider caries frequency in relation to the age structure of the sample. Because dental health and caries in particular can reflect dietary practices (Prowse et al., 2008; Redfern and DeWitte, 2011; Roberts and Manchester, 2005), changing prevalence of caries could indicate the influence of potential shifts in diet from Roman to Post-Roman samples. Within this analysis, carious lesions were recorded as present if a point of demineralized enamel or other tooth structure was present (Hillson, 2001).

2.2.2 Periosteal reaction (Tibia PR)

Periosteal reaction refers to new bone formation on the outer most surface of the bone in response to damage or inflammation of the periosteum, stemming from trauma, chronic infectious or inflammatory conditions (Fig. 2) (DeWitte, 2014; Klaus, 2014; Larsen, 1997; Ortner, 2003; Roberts and Manchester, 2005; Roberts, 2019; Weston, 2011, 2008). Despite complications in determining specific aetiologies, this lesion, and in particular when it appears on the shaft of the tibiae, has been associated with increased frailty and premature mortality (DeWitte, 2014; DeWitte and Stojanowski, 2015; DeWitte and Wood, 2008; Klaus, 2014). Although some research has cautioned against the use of these lesions as a non-specific stress indicator (Weston, 2011, 2008), they can still be informative about general frailty at the time of death or in the period preceding death, depending on the type of new bone observed (DeWitte, 2014; DeWitte et al., 2016; Klaus, 2014). Tibia PR can occur at any point during the life course. Periosteal reaction of the tibia was recorded if woven or lamellar new bone formation was present on the diaphyseal shaft of the tibiae. The location, type of bone formation and degree of healing were noted. Only the tibiae were systematically examined for periosteal new bone formation as the tibia is most commonly affected by these lesions (Klaus, 2014; Larsen, 1997).



Fig. 2. Images of several non-specific stress indicators assessed in this research. A. Cribrra orbitalia in the right orbit of Sepulture 84, Cadarache. B. Multiple dental enamel hypoplasias in Individual 12 from Saintes, Rue Jacques Brel: C. Periosteal reaction of the tibia: woven bone in Individual 97 from Sainte, Rue Jacques Brel

3 Results

3.1 Demographics

All groups had age distributions broadly consistent with expectations for attritional burial samples (Fig. 3) (Margerison and Knüsel, 2002). As with many archaeological samples, there is an underrepresentation of infant individuals, especially within the Post-Roman South group. This is likely the result of differential burial practices for the very young and excavation biases. There is a higher proportion of young adults (18-35 years) in both of the Post-Roman groups (30.2%, 30.8%) than in the Gallo-Roman group (17.9%). Sex was estimated for adult individuals (18+ years), yielding slightly more males than females in the Gallo-Roman group and slightly more females than males in both Post-Roman groups (Fig. 4).

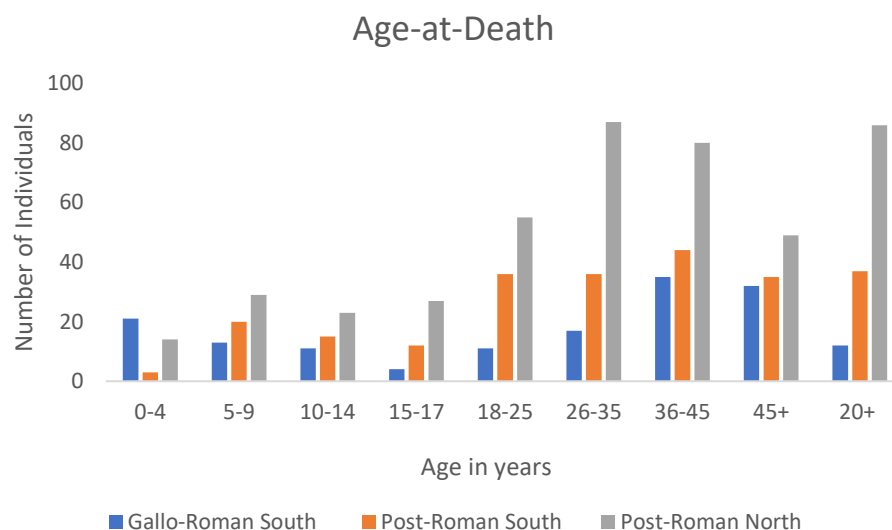


Fig. 3 Age distribution of Gallo-Roman South, Post-Roman South and Post-Roman North groups

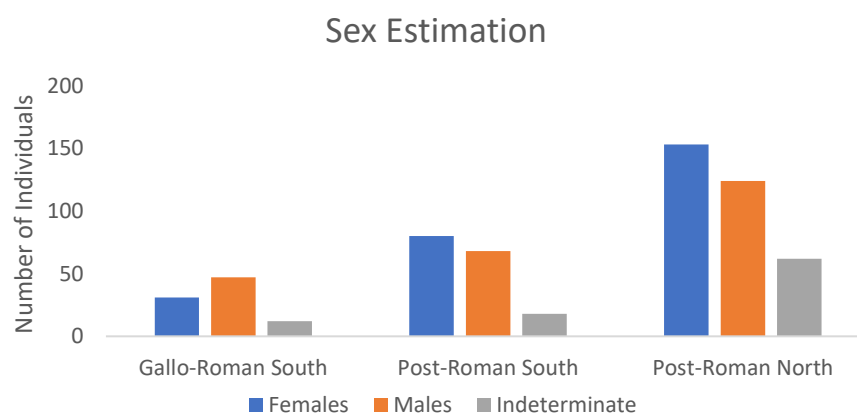


Fig. 4 Sex estimates for adult individuals (18+ years) in this analysis

3.2 Growth disruption

Skeletal growth profiles permit analyses of differences in femoral length-for-age and potential growth disruption. All analysed sample populations revealed dental ages that were nearly always estimated to be older (except 3 individuals, where dental and femoral age were estimated to be the same) (Fig. 5). This would suggest that nearly all non-adult individuals, regardless of context, were experiencing some degree of environmental stress, which was inhibiting linear growth. Differences between dental and femoral age were not statistically significant between groups ($P=0.879$). Only four individuals aged 2 years or younger had teeth and femora adequately preserved for measurement, all of which derived from the Gallo-Roman context, preventing comparison with the other groups. Three of these four individuals displayed small height-for-age, indicating delayed growth. Although fusion of the femoral epiphyses can commence from as early as 10-12 years of age (Scheuer and Black, 2000), it is noteworthy that all groups have multiple adolescent individuals that show no signs of epiphyseal fusion.

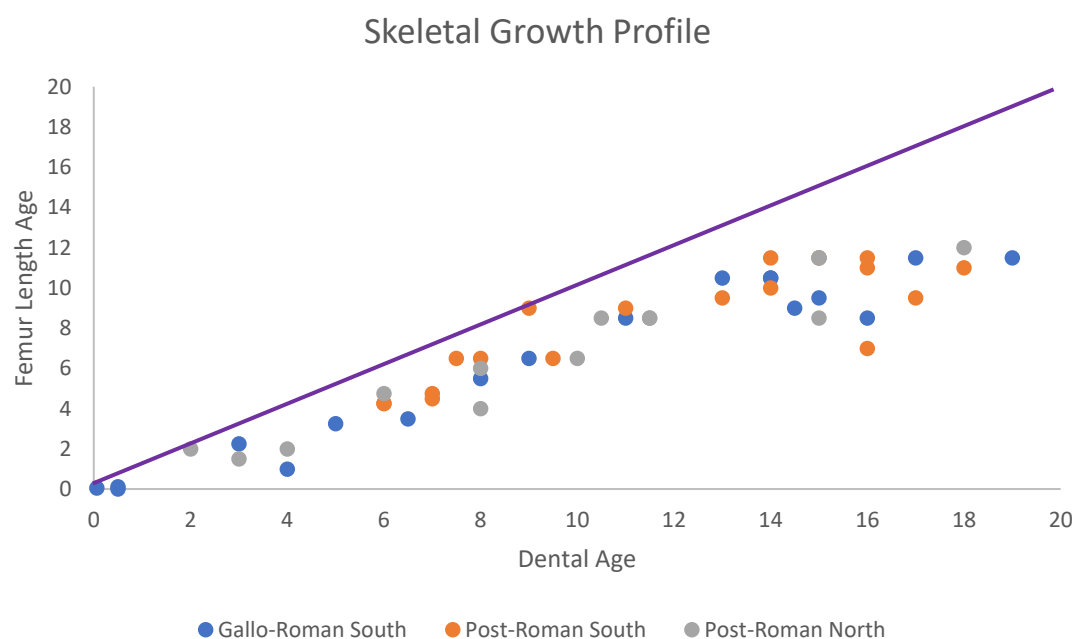


Fig. 5 Skeletal growth profile displaying age based on femoral length against age based on dental mineralization. Purple line displays a 1:1 ratio, when femoral and dental age are the same

Gallo-Roman females and males display the lowest mean and median femoral lengths (Fig. 6, Table 2). Average female Post-Roman femoral length only slightly increased, 0.6 cm and 1.1 cm in the south and north respectively. These differences were not statistically significant ($p=0.315$). Male

average femoral length only increased in the Post-Roman north group; however the increase of 1.8 cm was statistically significant ($p=0.001$).

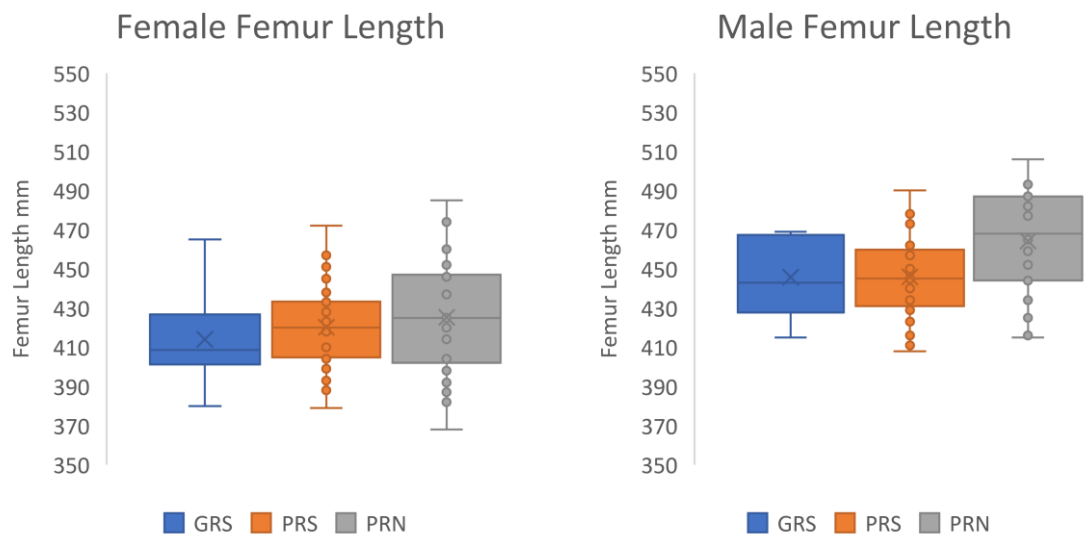


Fig. 6 Box and whisker plot of maximum femoral lengths. The line equals the median, the X is the mean, the box is quartiles 2 and 3 and whiskers are the maximum and minimum values, not including outliers. Additional dots are outliers

3.3 Systemic stress indicators

Analysis of DEH revealed statistically significant differences between groups in both CPR and TPR, with the Gallo-Roman South group displaying the highest prevalences ($p<0.001$) (Table 2, Fig. 7). The Gallo-Roman South group also had significantly higher proportions of individuals with multiple DEH (2, 3 and 4) 'lines' or events than Post-Roman groups ($p=0.001$) (Table 3). With respect to Tibia PR, the Gallo-Roman sample was again the most severely affected with a significant difference in CPR ($p= <0.001$), although TPR results were not significant ($p=0.153$) (Table 2, Fig. 7). For both CO and caries, significant differences were found in TPR comparisons between groups, where disease prevalence was highest in the Post-Roman North group (Table 2, Fig. 7). Individuals from the PRN context present the highest CPR in CO and caries, but these results were not significant. The Post-Roman South context had the lowest frequencies of DEH and Tibia PR in CPR and TPR analyses. The Post-Roman South groups falls in-between the other groups in CPR and TPR of CO and caries TPR. Distributions of pathological conditions present similar patterns between the CPR and TPR of DEH, CO and Tibia PR. However, the distribution of carious lesions differs between CPR and TPR, indicating that although many Gallo-Roman individuals had at least one carious lesion, they had fewer teeth overall presenting this disease.

Table 2 Crude and True Prevalence Rates of non-specific stress indicators

Group		DEH		CO		Tibia PR		Caries		Mean Adult Femur Length mm	
		CPR	TPR	CPR	TPR	CPR	TPR	CPR	TPR	F	M
Gallo-Roman South	Affected n (n/N)	35 (22.4%)	196 (8.8%)	11 (7.1%)	13 (7.1%)	24 (15.4%)	72 (38.3%)	60 (38.5%)	147 (6.6%)	414	446
	Total (N)	156	2223	156	174	156	188	156	2223	12	14
Post-Roman South	Affected n (n/N)	20 (8.4%)	136 (5.3%)	23 (9.7%)	41 (13.3%)	8 (3.4%)	30 (27.8%)	80 (33.6%)	259 (10.1%)	420	446
	Total (N)	238	2573	238	308	238	108	238	2573	58	48
Post-Roman North	Affected n (n/N)	61 (13.6%)	400 (7.2%)	54 (12.0%)	80 (16.6%)	22 (4.9%)	74 (32.0%)	184 (40.9%)	625 (11.2%)	425	464
	Total (N)	450	5558	450	483	450	231	450	5558	28	31
P-Value		<0.001	<0.001	0.197	0.011	<0.001	0.153	0.175	<0.001	0.315	0.001

n= number affected individuals or bone elements; N=number of individuals or observable bone elements in group, F=female, M=Male

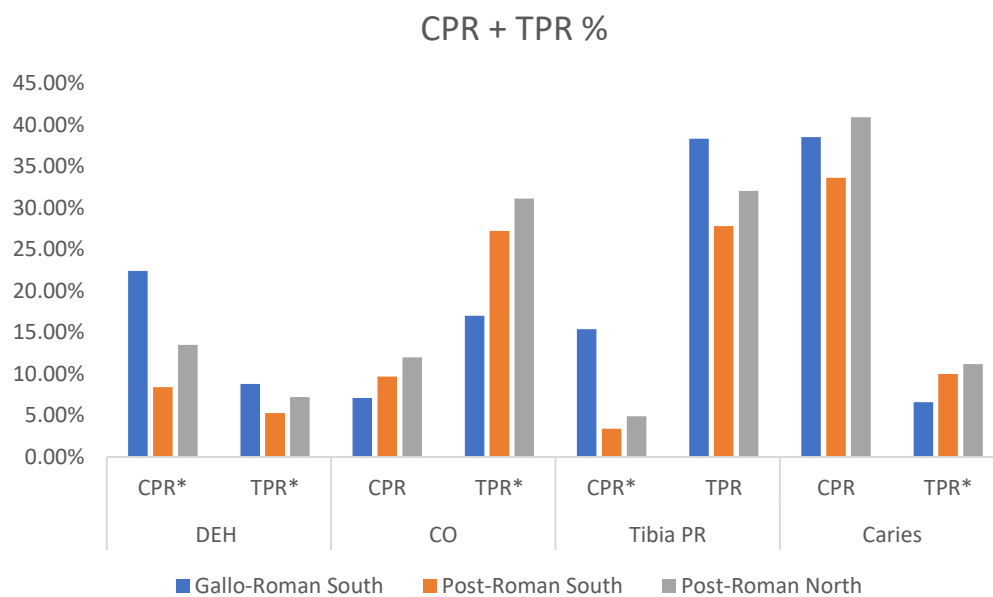


Fig. 7 Crude and true prevalence rates of pathological conditions in the Gallo-Roman South, Post-Roman South and Post-Roman North groups. Asterisk* indicates a statistically significant difference between groups.

Table 3 Number of DEH events per tooth

Number of DEH events per Tooth CPR						
	0	1	2	3	4	Total Inds.
Gallo-Roman	106 (67.9%)	33 (21.2%)	11 (7.1%)	5 (3.2%)	1 (0.6%)	156
Post-Roman South	201 (84.5%)	31 (13.0%)	5 (2.1%)	0 (0.0%)	1 (0.4%)	238
Post-Roman North	337 (74.9%)	95 (21.1%)	13 (2.9%)	4 (0.9%)	1 (0.2%)	450

3.4 Mortality and age-at-death categories

Mann-Whitney U tests of mean age-at-death for individuals with and without early life stress indicators revealed the following results (Table 4). In the Gallo-Roman sample, DEH presence was associated with earlier mean age-at-death ($P=0.007$) but was not associated in either of the Post-Roman groups. In contrast, CO prevalence was correlated with mean age-at-death in Post-Roman samples and not in the Gallo-Roman sample. Short adult femur length was not associated with age-at-death in any of the groups.

Table 4 Mann-Whitney U p-values

Group	DEH	CO	Short adult femur length
Gallo-Roman South	0.007	0.120	0.793
Post-Roman South	0.936	<0.001	0.373
Post-Roman North	0.572	0.013	0.061

The distribution of non-specific stress indicators across age-at-death categories reveals patterns in morbidity, although due to small samples sizes within each category these were not tested for statistical significance. In the Gallo-Roman context, DEH frequency is quite consistent (3-4%) across most age-at-death categories and is higher than both Post-Roman groups (Fig. 8). In PRS and PRN, very few occurrences of DEH were observed in non-adult individuals, with a higher proportion in adults (18+) in CPR and TPR (Figs. 8-9). For all contexts, CPR and TPR of CO demonstrate a peak in the 5-9-year-old age category but this was also prevalent in Post-Roman adult age categories, especially in the north (Figs. 8-9). Both CPR and TPR of Tibia PR are higher in the Gallo-Roman group than both Post-Roman groups in nearly every age category (Figs. 8-9). Post-Roman proportions of individuals displaying this pathological lesion are quite low in all age categories. CPR and TPR of carious lesions were found to increase with age in all groups, as would be expected for an age-progressive pathology (Figs. 8-9).

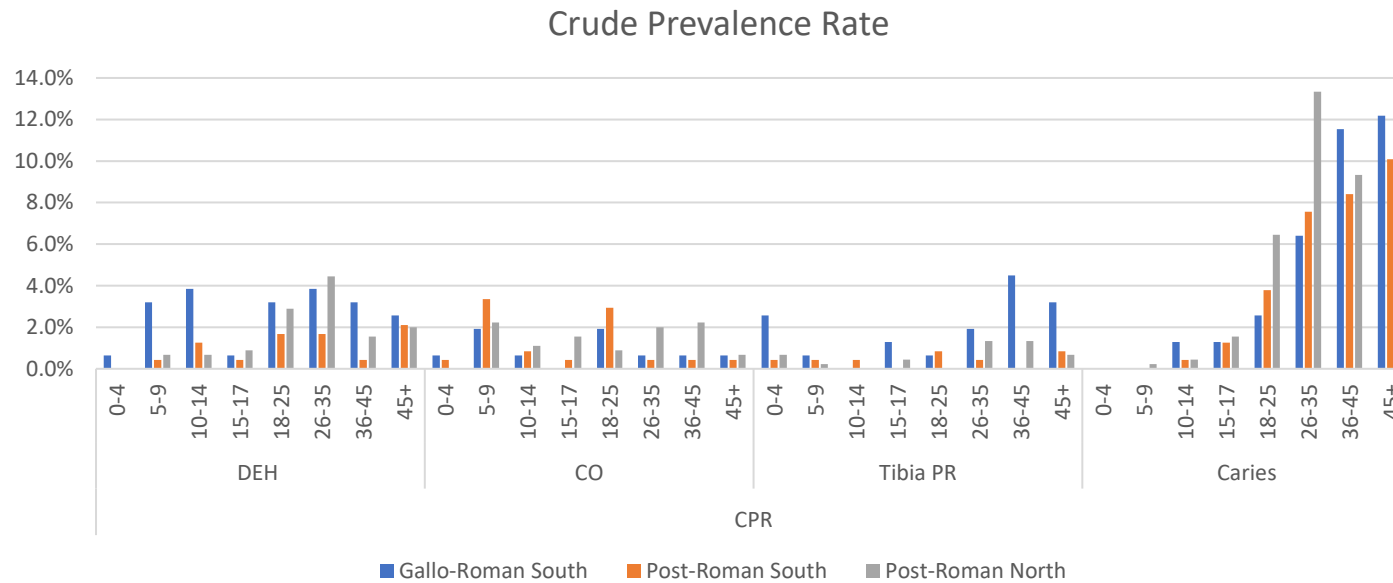


Fig. 8 Crude prevalence rate of non-specific stress indicators across age-at-death categories

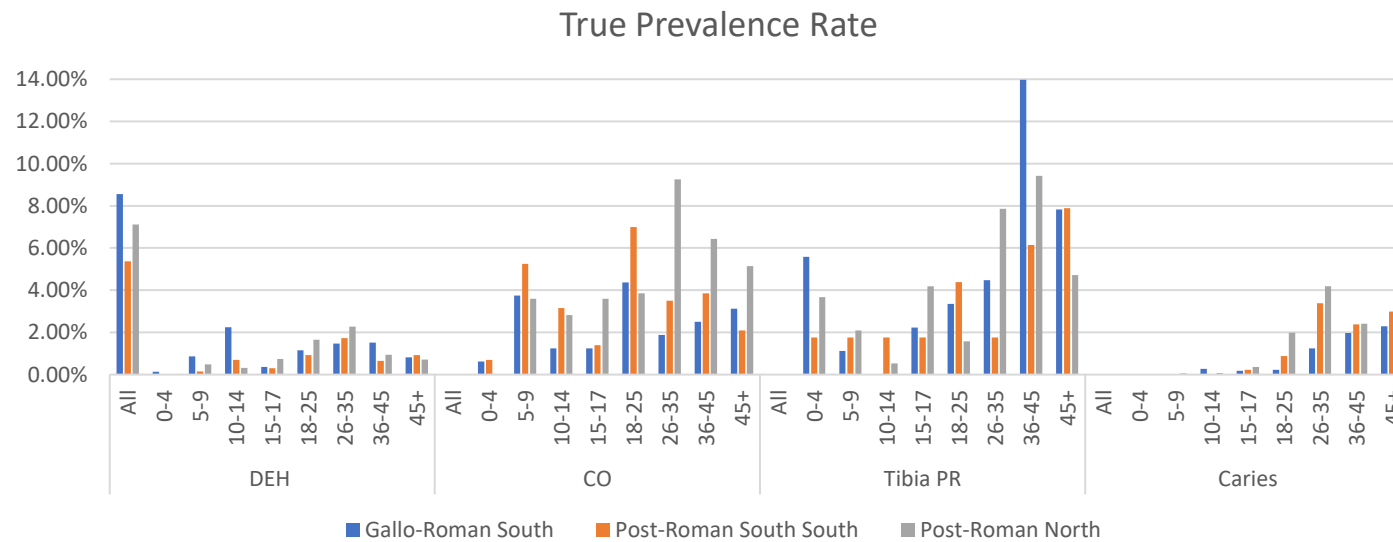


Fig. 9 True prevalence rate of non-specific stress indicators across age-at-death categories

4 Discussion

Non-specific stress indicators were examined in multiple skeletal collections from Roman and Post-Roman Gaul to assess patterns in growth and health across the life course, elucidating the effects of Roman practices on health. This analysis revealed somewhat conflicting results. Adult Gallo-Roman males and females had smaller femoral lengths, but differences between dental and femoral age in non-adults were not significant between groups ($p=0.879$). Frequencies of DEH and Tibia PR were significantly higher in the Gallo-Roman sample and DEH presence was correlated with earlier mortality. In both Post-Roman samples, frequencies of CO and caries were significantly higher and CO presence was associated with earlier mortality. Small adult femur length was not associated with mortality in any of the groups. These results suggest that both Roman and Post-Roman samples experienced heightened frailty stemming from early life stressors, but the relationship with growth was less clear. Factors affecting health across the life course appear to have manifested in different ways between the groups, presumably due to variation in biocultural environments. These data are discussed in relation to the contextual and environmental factors impacting health throughout the life course in Roman and Post-Roman Gaul.

4.1 Life Course

4.1.1 Growth and early life adversity

Smaller adult femoral lengths were observed in the Gallo-Roman sample, aligning with previous research on height and health in the Roman Empire (Giannecchini and Moggi-Cecchi, 2008; Gowland, 2017; Gowland and Garnsey, 2010; Gowland and Walther, 2019; Koepke, 2016, 2014; Koepke and Baten, 2008; Redfern, 2008; Redfern and DeWitte, 2011; Roberts and Cox, 2003; Walter Scheidel, 2012b; Stead et al., 2006). However, small femoral length was not associated with early mortality, indicating that growth data alone did not help to clarify whether Roman practices were negatively affecting health in Gaul. Within other analyses of multiple skeletal stress indicators including growth, significant relationships or correlations were not always found where anticipated (Armelagos et al., 2009; Floyd and Littleton, 2006; Ribot and Roberts, 1996; Watts, 2013). Recent work has highlighted that the timing, duration and frequency of stress events affects the expression and severity of future health outcomes (Floyd and Littleton, 2006; Garland, 2020; Temple, 2019, 2014; Worthman and Kuzara, 2005). The earlier the stressor exposure, the more likely it is to manifest in negative adult health outcomes (Floyd and Littleton, 2006; Garland, 2020).

In addition to short femoral lengths, the Gallo-Roman South context had significantly higher proportions of individuals with DEH, higher numbers of teeth with DEH and more individuals displaying multiple DEH events. These individuals also had younger adult mortality (increased frailty). This indicates that the Gallo-Roman sample was exposed to early life adverse environments (before the age of nine), which affected mortality and could have impacted linear growth, contributing to the comparatively small femoral lengths observed in this analysis. Although the specific age of DEH development was not recorded in this analysis, the timing of lesion development is still more 'restricted' than femur development (6months-9 years vs 7-8 weeks gestational-20 years). An examination of co-occurrence between short femur length and DEH would be beneficial, but preservation rendered sample sizes too small for substantive analysis. In both Post-Roman groups, frequency of CO increased in comparison with the Gallo-Roman sample and was also correlated with early mortality. Because CO usually manifests before the age of four, this lesion typically represents the presence of early life stressors (Brickley, 2018). However, male and female femur lengths increased in the Post-Roman samples. These findings indicate that individuals within each group experienced early life adverse environments, although the skeletal manifestations were different.

4.1.2 Later life health outcomes

Although growth stunting most often begins in the womb or infancy, the femur continues to grow until the late teens or early twenties, resulting in a comparatively long developmental period. During this time, an individual may be exposed to a variety of favourable or un-favourable environmental conditions, which may augment or hinder growth processes. Therefore, although all groups experienced early life health insults, perhaps later childhood environments influenced the observed growth outcomes. 'Catch-up' or compensatory growth can occur in childhood or adolescence if negative conditions and/or dietary deficiencies improve, or if the growth period is prolonged (Bogin, 1999a; Tanner, 1981). It is therefore possible that individuals within this analysis could have experienced early life stressors (as evidenced through DEH and CO) that negatively influenced growth, but that conditions sufficiently improved to permit survival and compensatory growth (to varying degrees). In the Gallo-Roman and both Post-Roman groups, several adolescents, and even older adolescents (16+ years) demonstrated no signs of epiphyseal fusion of the femur. Delayed fusion could be indicative of catch-up growth processes (Cameron and Demerath, 2002). However, these individuals died in adolescence, suggesting that they were ultimately unsuccessful in reaching maturity. Additionally, these data are cross sectional, rather than longitudinal. Catch-

up growth can exert a penalty on later health outcomes, as rapid compensatory growth consumes resources that might otherwise have gone to other systems and organs (Barker, 2012; Barker et al., 2011). None of the groups demonstrated a mortality penalty or advantage associated with femur length. This would suggest that if catch-up growth explains the differences in Gallo-Roman and Post-Roman growth patterns, it did not cause (detectable) negative later life outcomes in Post-Roman groups.

Recurrent periods of non-lethal stress could prevent catch-up growth and continue to divert resources away from normal growth processes (Pezo-Lanfranco et al., 2020). As such, the small adult femoral lengths observed in the Gallo-Roman sample could stem from early life stressors and also reflect regular or chronic periods of stress, which prevented catch-up growth (Pezo-Lanfranco et al., 2020). Examining the different growth patterns in males and females provides some support for this interpretation of the results. Females are thought to be more 'buffered' from infection, disease and growth disruption than males, where environmental stressors create greater disruptions to male skeletal growth (DeWitte, 2010; Stinson, 2012, 1985). Within this analysis, female femoral lengths increased slightly (0.6 cm and 1.1 cm) from the Gallo-Roman to Post-Roman period. Male femoral lengths notably increased in the Post-Roman North group (1.8 cm). This could indicate that environmental stressors were suppressing growth in Gallo-Roman (and Post-Roman south) samples. If these pressures were reduced or relieved in the Post-Roman North, it could explain the increase in femoral lengths, but also differences in the magnitude of this increase between the sexes. In addition to overall smaller femur lengths and higher DEH frequencies, Gallo-Romans had higher crude prevalence rates of Tibia PR than the Post-Roman groups. This may represent increased frailty stemming from early life stressors or indicate the regular or chronic exposure to stressors not just during development, but throughout the life course. TPR of periosteal reaction of the tibiae were not significant, but do maintain the same overall pattern as CPR, with Gallo-Romans showing higher prevalences.

The distribution of stress indicators across the burial samples might also support hypotheses that suggest recurrent stress exposure during the Roman period in Gaul. Many diseases, infections or acute stressors lead to death before the skeletal manifestation of disease (Ortner, 2003). The age distribution of several pathological lesions shows that although some Gallo-Roman individuals succumbed to illness in childhood, many others who had experienced one or more stress episodes lived to adulthood (Figs. 8-9). Skeletal stress indicators demonstrate a degree of resilience, as the person must have survived (for a period of time) for the manifestation of the lesion (Ortner, 2003).

Several Gallo-Romans had multiple DEH events, which implies repeated stressor exposure, but also the survival of these periods of physiological stress. A high proportion of Tibia PR was also found in the Gallo-Roman sample across most age groups. There is a consistent proportion of individuals with DEH (around 3%) in each age-at-death category. In contrast, in the Post-Roman samples, the majority of individuals affected by DEH are over 18 years old (Figs. 8-9). In addition to longer femoral lengths, DEH presence in Post-Roman adults could suggest that these 'survivors' do indeed represent a more 'robust' portion of the population.

4.1.3 'Intermittent stress of low lethality'?

Small adult femur lengths in combination with stress indicators from across the life course in the Gallo-Roman sample could be reflecting early life adverse environments and also suggest regular and persistent negative environmental conditions throughout development (which prevented opportunities for catch-up growth as seen in Post-Roman samples). Following a recent study, it is argued that the Gallo-Roman data fit a newly coined model of 'intermittent stress of low lethality' defined as 'the adaptation to recurrent metabolic insults of low impact that allows survival to reproductive age with relative success, overcoming environmental aggressions in physiological, physical and cognitive terms' (Pezo-Lanfranco et al., 2020, p. 22). Complicating interpretations, exposure to early life stressors specifically during the first 1000 days after conception can make an individual more susceptible to poor health outcomes in later life (the Developmental Origins of Health and Disease paradigm) (Barker, 2012; Barker et al., 2002, 2011; Kuzawa and Quinn, 2009). The ability and energetic cost to survive a stressor in early childhood could have reduced the body's ability to mount an effective immune response later in life, potentially leading to increased/earlier morbidity and mortality (Goodman and Redclift, 1988). This means that later life health outcomes could represent increased frailty from early life trade-offs or represent newly introduced stressors but the two are not mutually exclusive. As such, Tibia PR seen in the Gallo-Roman sample could represent new or continual exposure to stressors, or represent individuals who were 'frailer', based on previous stress exposures in early life. Teasing apart this relationship may not be possible. However, because both Gallo-Roman and Post-Roman groups demonstrated early life stressors that impacted later mortality, this study does provide some evidence of DOHaD, indicating that individuals who survived early childhood stressors did so at the expense of mortality in adulthood. The effects of early life stressors on later health outcomes can be mitigated (positively or negatively) by cultural and environmental conditions (Amoroso et al., 2014; Garland, 2020; Temple, 2019). It is then worth considering how Roman practices, especially those surrounding urban

environments and population density, were contributing to the observed patterns in height and health.

4.2 Health in the Gallo-Roman and Post-Roman Periods

Within this study, the Gallo-Roman sample demonstrated smaller adult femoral lengths and higher rates of DEH and Tibia PR across several age-at-death categories, suggesting early life stressors and potentially recurrent episodes of stress across the life course. In both Post-Roman groups, the high frequency of CO and its relationship with earlier mortality highlights the continued presence of early life stressors in this later time period, but also suggests a change. Different factors appear to be creating conditions that are having divergent impacts on health during Gallo-Roman and Post-Roman time periods with some regional variability. It has been suggested that features of Roman lifeways, such as urban living structures (houses and workplaces) and higher population density negatively affected health, despite improvements in water supplies and sanitation, and increased economic activity (Frier, 1977; Harper, 2016; Morley, 2004; Porter, 1999; Scheidel, 2015, 2012, 2009; Scobie, 1986). Features of 'Roman' cultural and socio-political life are thought to have been more strongly present in southern Gaul and supposedly retreated more gradually than in northern regions.

4.2.1 Urbanisation and Population Density

Several studies from across the Western Roman Empire have attributed perceived dips in health to high degrees of urbanisation and population density, resulting in overcrowding and insalubrity (Gowland, 2017; Griffin, 2017; Jongman et al., 2019; Redfern and Roberts, 2005; Redfern and DeWitte, 2011; Walter Scheidel, 2012a). These conditions would have increased pathogen exposure and pathogen sustainability, including viruses, bacteria and parasites (Aldrete, 2004; Morley, 2004; Scheidel, 2015; Scobie, 1986). Although Roman towns often included a system for waste disposal, public facilities (baths, aqueducts) and flowing water, waste disposal and management in Roman cities was highly likely to have been inadequate and variable and could have led to food and water contamination and illness (Aldrete, 2004; Morley, 2004; Porter, 1999; Scobie, 1986). Housing within Roman cities could also have contributed to negative health outcomes through overcrowding within small spaces, the use of indoor fires for warmth and food preparation, as well as poor ventilation (Scobie, 1986). Additionally, high levels of immigration to larger urban centres would have increased pathogen exposure, but also the number of vulnerable

people within one place (Morley, 2004; Redfern et al., 2018; Scheidel, 2003). The same Roman road and communication networks that permitted travel, trade and access to new food sources, also could work to transmit and spread disease (Harper, 2017).

Previous examinations of health between Roman urban and rural settlements have yielded mixed results, with some indicating pronounced 'urban penalties' (Killgrove and Tykot, 2017; Pitts and Griffin, 2012; Redfern et al., 2015; Rohnbogner and Lewis, 2016) and others no observable differences (Redfern et al., 2010). The considerable variation in the size and population of cities across the Roman world could explain these conflicting findings (Kron, 2019). Within this study, the Gallo-Roman sample is composed of individuals from two major urban centres (Arles and Saintes). As a result, it is very possible (and even likely) that the present results are reflecting Roman urban influences on height and health. Although acute conditions would have led to death before the skeletal manifestation of disease, short femoral lengths, heightened DEH and Tibia PR observed in the Gallo-Roman sample might then have a relationship with repeated exposure to chronic infectious diseases, promulgated through Roman settlement structures and heightened population density. This seems especially possible as the Gallo-Roman sample had many individuals with signs of repeated stress exposure (multiple DEH, short femoral length, Tibia PR). Although there are many possible (and synergistic) aetiologies, growth disruption, DEH and Tibia PR can result from infection, especially when there are additional nutritional deficits (Resnick and Nakamura, 1995; Roberts, 2019). In the Post-Roman period, several features that might have created the repeated and regular exposure to pathogenic stressors declined. This includes the focus on urban living structures and high population density, but also trade networks (and possibly migrants) (Kiple, 1993; McNeill, 1998; Morley, 2004). Similar to studies of rural environments in Roman Britain (Redfern et al., 2015; Rohnbogner, 2015; Rohnbogner and Lewis, 2016, 2017), both Post-Roman samples in this study displayed high levels of CO, indicating a different manifestation of early childhood stress from Roman urban centres.

4.2.2 Diet

Several studies have proposed that changes in diet between Roman and Post-Roman periods are the root cause for the observed patterns in growth and non-specific stress indicators (Koepke, 2014; Koepke and Baten, 2008; Lightfoot et al., 2012; Walter Scheidel, 2012a). Isotopic, zooarchaeological and archaeobotanical data have suggested diets were more diverse during the Roman period because of expanded trade routes, access to a wider variety of food and food

production techniques (Bakels and Jacomet, 2003; Lightfoot et al., 2012; Mion et al., 2016; Müldner, 2013; Prowse et al., 2004; Redfern et al., 2010; Zech-Matterne et al., 2017). Cribra orbitalia and caries were assessed as non-specific stress indicators but have a relationship with diet and disease load (in addition to specific pathological conditions). Analysis of CO and caries revealed comparatively higher prevalences in the Post-Roman groups. Caries frequency increased, especially when considered in respect to age distributions between the samples, as Post-Roman populations are more heavily dominated by young individuals (young females). All else being equal, we would expect age-dependent diseases to be higher in populations with higher proportions of older individuals. These findings could suggest differential dietary influences on health in Roman and Post-Roman Gaul. A high prevalence of carious lesions is associated with diets high in sugar and carbohydrates, as well as poor dental hygiene (Hillson, 2001). Isotopic analyses of diet (carbon and nitrogen) have found that as Roman authority declined, diet became more heavily reliant on millet and other cereals (even within Gaul) (Lightfoot et al., 2012; Mion et al., 2016). This could contribute to observed changes in the frequency and patterns of carious lesions in this study.

There is concurrence of CO around the 5-9-year-olds in Roman and Post-Roman contexts. Although the aetiology of CO is debated, when iron deficiency anaemia is its origin, the lesions usually occur before the age of 11, as a result of the change from red to yellow bone marrow in the frontal bone (Lewis, 2017). Diets based on cereals have higher phytates, which act to inhibit iron absorption and could be related to iron deficiency anaemia (Facchini et al., 2004). In this way, the isotopic evidence of heavily cereal based diets in northern Post-Roman Gaul (Mion et al., 2016) could be contributing to the observed frequencies of CO. However, only severe and chronic cases of anaemia will result in CO (Wapler et al., 2004) and disease load can also affect iron absorption due to the increased demand for iron to fight off infection (Stuart-Macadam, 1991). Other factors and illnesses, including malaria (Gowland and Garnsey, 2010; Gowland and Western, 2012), healed lesions from childhood, or aetiologies grounded in adulthood, such as inflammation of the eyes (Wapler et al., 2004) also remain possibilities. The timing of lesion development cannot be isolated beyond saying that it occurred before the age of death, especially as CO most often develops before the age of four (Brickley, 2018). Ultimately, the development of CO and caries is likely to have been the result of multiple factors acting synergistically, including diet, pathogen load and cultural or hygienic practices (Walker et al., 2009).

4.2.3 Social Stress

‘Social stress’ is another factor that may have affected height and health in the Roman period. Increasingly, bioarchaeologists are being asked to consider possible psycho-social stressors as important influences in childhood and adult health outcomes (Rodney and Mulligan, 2014; Temple, 2019). Despite the economic benefits of being integrated into the Roman Empire, psycho-social stressors accompanying rigid hierarchical structure with greater degrees of inequality or social stratification could have had negative consequences for health (Gowland, 2017, 2015; Gowland and Redfern, 2010; Griffin et al., 2011; Redfern, 2008; Redfern and DeWitte, 2011; Roberts and Cox, 2003; W. Scheidel, 2012). The biological mechanisms and pathways that are triggered in response to physiological stressors can also be triggered by psycho-social stressors (Hypothalamic-pituitary-adrenal axis) (Edes and Crews, 2017). In this way, the body’s response to both physical and emotional stressors can influence growth, immune function, and potentially mortality. Within modern populations, health is more negatively affected in societies with greater inequality (Thayer and Kuzawa, 2011) and ‘taller’ stature has been associated with more equal societies (Gowland, 2017; Rohnbogner, 2017). DEH formation has also recently been associated with social stressors (in addition to physiological stressors) (Sandberg et al., 2014; Temple, 2019). These observations coupled with the higher rates of DEH and smaller femoral lengths observed in the Gallo-Roman sample provides some support for social stress hypotheses. If Roman lifeways were stabilizing and reinforcing pathological hierarchies, then it seems possible that the inequities were relieved by the developments associated with the reduction of Roman authority in the Post-Roman period, and could have contributed to changing patterns in skeletal stress indicators. However, isotopic or other biochemical data from the skeleton might be more useful in isolating stress as a causative factor for poor health in the Roman period.

4.3 Limitations

There are several important limitations within the present analysis. The first of which is the absence of data from Gallo-Roman north contexts. The addition of these data would be invaluable for supporting or re-interpreting the present results. Further, the Gallo-Roman South group is composed of individuals from two large and important urban areas, heightening the potential influence of urban practices within this group. Recent research has also stressed the importance of migration in Roman and Post-Roman periods with significant implications for health (Redfern et

al., 2018; Redfern and DeWitte, 2011). Isotopic analyses of migration (and diet) were beyond the scope of the present analysis but remains an important avenue for future research.

5 Conclusion

Skeletal stress indicators from across the life course were analysed to assess the effects of Roman practices and lifeways on health in Gaul. Early childhood stressors impacted both Gallo-Roman and Post-Roman samples with negative effects on mortality. However, the skeletal manifestations of both early life stressors and later health indicators were different between diachronic periods. Gallo-Roman individuals may have been more regularly exposed to infectious pathogens throughout childhood, maintaining a negative living environment and inhibiting opportunities for catch-up growth, resulting in smaller femoral lengths ('intermittent stress of low lethality'). This could be the result of overcrowding and insalubrity in urban settlement structures. Post-Roman groups demonstrated longer femoral lengths and lower frequencies of DEH and Tibia PR. Higher rates of CO and caries may have been influenced by dietary changes between the periods. The intertwined and often synergistic relationships between early life environment, nutrition, settlement structure and social stress is highlighted, helping to further understandings of life experiences during the Roman and Post-Roman periods.

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Title: Desperately Seeking Stress: A pilot study of cortisol in archaeological tooth structures

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Abstract:

Objectives

Cortisol is a glucocorticoid hormone produced through activation of the Hypothalamic Pituitary Adrenal (HPA) axis. It is known as the 'stress hormone' for its primary role in the body's stress response and has been the focus of much modern clinical research. Within archaeology, only a few studies have analyzed cortisol in human remains and these have been restricted to hair (Webb et al., 2010; 2014; 2015). This study examines the utility of dentine and enamel, which survive well archaeologically, as possible reservoirs for detectable levels of cortisol.

Materials and Methods

Sixty-nine teeth from 65 individuals from five Roman and Post-Roman sites in France were tested via competitive ELISA to assess and quantify the cortisol concentrations present within tooth dentine and enamel.

Results

In both tooth dentine and enamel, detectable concentrations of cortisol were identified in multiple teeth. However, concentrations were low and not all teeth yielded results that were measurable through cortisol ELISA. Differences in cortisol values between dentine and enamel could suggest different uptake mechanisms or timing.

Discussion

These results suggest that cortisol is incorporated within tooth structures and merits further investigation in both modern and archaeological contexts. Analysis of the results through LC-MS would verify current results and might yield values that could be better integrated with published cortisol studies. Future studies of cortisol in tooth structures would greatly expand the research potential of cortisol in the past and could have implications for studies of human stress across deep time.

Keywords: Glucocorticoid hormones, Bioarchaeology, Dentine, Enamel, ELISA

Research Highlights

- Archaeological tooth structures are analyzed for cortisol concentrations
- Dentine and enamel in multiple teeth yielded detectable levels of cortisol
- Cortisol in tooth structures merits further investigation in modern and archaeological contexts

Tweetable Summary and Image

Cortisol is incorporated and preserved within archaeological tooth structures



The detrimental impact of 'stress' on the body has been an important focus of study within the clinical literature. In bioarchaeology, the subject of more generic 'health stress' is also a primary concern, with a considerable body of research directed towards non-specific skeletal indicators (see Klaus, 2014; Reitsema & McIlvaine, 2014; Temple & Goodman, 2014). However, studies addressing stress experiences within different societies and over time have been limited by methodological constraints. Cortisol has previously been identified and analyzed in human hair from archaeological contexts; however, hair preserves only in exceptional circumstances (Webb et al., 2010; Webb, White, Van Uum, & Longstaffe, 2015a, 2015b). To gain a broader understanding of 'stress' in the past, this study aims to adapt and develop a new method for analyzing cortisol hormone concentrations (indicative of stress) from dental tissues (Nejad, Jeong, Shahsavarani, Sung, & Lee, 2016). Given the high survival of teeth in archaeological contexts, cortisol concentrations from teeth has the potential to provide an important new avenue for research on stress in the past.

1.1 Cortisol

Studies assessing stress and irregularities in stress response in contemporary human and animal populations routinely test cortisol concentrations. Cortisol, often referred to as the 'stress hormone', is the primary adrenal chemical messenger produced by the Hypothalamic Pituitary Adrenal (HPA) axis in the presence of a stressor (Charmandari, Tsigos, & Chrousos, 2005). Cortisol prepares the body to respond to a threat, prioritizing processes serving immediate energetic needs (cardiac output, glucose and red blood cell production), and diverting energy away from those biological processes that are secondary to immediate survival (growth, digestion, reproduction) (Panagiotakopoulos & Neigh, 2014; Sapolsky, Romero, & Munck, 2000). As such, activation of the HPA axis and heightened cortisol secretion are an adaptive and important part of the human stress response, promoting survival (Beehner & Bergman, 2017). However, when chronically activated by stressors, the HPA axis can become dysregulated, resulting in abnormal cortisol secretion and negative effects on the body. Cortisol inhibits inflammatory and allergic reactions, has immunosuppressive effects (decreases antibody production and the proliferation of immune B-cells, T-cells), can reduce growth in children (inhibits growth hormone, modulation of osteoclast, osteoblast and osteocyte function), cause osteoporosis in adults (degradation of collagen, reduction of calcium), delay wound healing by reducing fibroblast proliferation, and also impacts metabolic processes through gluconeogenesis (releasing amino acids from proteins in skeletal

muscle and bone), glycogenolysis and lipolysis (Canalis, 2005; Panagiotakopoulos & Neigh, 2014; Sapolsky et al., 2000). Assessing cortisol concentrations in human tissues therefore can be informative about relative 'stress experience' (stressors an individual or population encountered). This data can contribute towards a greater understanding of human responses to differing social and environmental stressors in the past.

In addition to the stress response, cortisol has important regulatory functions in cardiovascular, metabolic, and immunological systems (Charmandari et al., 2005). Without appropriate levels of cortisol, humans cannot survive (Dallman & Hellhammer, 2011). Outside of the stress response, the HPA axis has a natural circadian rhythm, secreting the highest levels of cortisol approximately 30-45 minutes after waking and then decreasing throughout the day, reaching the lowest levels during sleep (Dallman and Helhammer, 2011). To synthesize cortisol, the HPA axis must be activated, initiating a hormone cascade beginning in the brain. The hypothalamus produces and transfers corticotropin-releasing hormone (CRH) to the anterior part of the pituitary gland, stimulating the production of adrenocorticotrophic hormone (ACTH). The ACTH is then transported throughout the body via the blood stream and detected by hormone-specific receptors in the adrenal gland, instigating the synthesis of glucocorticoid hormones, of which, cortisol is the most abundant. Cortisol travels through the bloodstream in both active (unbound) and inactive (bound to the protein transcortin or albumin) forms (Gow, Thomson, Rieder, Van Uum, & Koren, 2010). From the blood stream, unbound cortisol passes through cell membranes to activate glucocorticoid receptors in the cytoplasm, where the complex is translocated into the cell nucleus, binding to glucocorticoid-response elements and modulating the transcription of target genes (Gow et al., 2010; Greaves, Jevalikar, Hewitt, & Zacharin, 2014). Although free or unbound cortisol makes up only a small proportion of total cortisol, usually 10% or lower, it is the free cortisol that acts upon and regulates systems within the body (Dallman and Hellhammer, 2011). The production of cortisol is tightly controlled through a negative feedback loop, where upon the arrival of cortisol back in the pituitary gland, the hormone cascade is suppressed (Dickerson & Kemeny, 2004; Sapolsky et al., 2000). The diurnal rhythm of the HPA axis and, therefore, cortisol secretion, is not uniform across the life course or between sexes, with the normal rhythm achieved at around three months of age (Gunnar & Donzella, 2002). Other major changes in cortisol production arise from reaching developmental thresholds such as adrenarche, puberty, pregnancy and menopause (Greaves et al., 2014).

1.2 Cortisol in Bioarchaeology

Because stressors and the stress response have a significant impact on health and wellbeing, the study of stress is important in bioarchaeological analyses of past populations. Bioarchaeological methods are most often indirect and non-specific measures of stress (growth disruption, dental enamel hypoplasia, cribra orbitalia) that require an unknown 'threshold of stress' to be met for development of the lesions in the skeleton (Goodman & Rose, 1990). The non-specificity of these skeletal and dental responses is problematic for interpretations of stress. Recent research has begun to explore cortisol and its role within the HPA axis in relation to skeletal stress markers and bone growth in archaeological populations (Gowland, 2017; Klaus, 2014; Reitsema & McIlvaine, 2014; Rodney & Mulligan, 2014; Scott, Choi, Mookherjee, Hoppa, & Larcombe, 2016; Webb et al., 2010, 2015a, 2015b; Weston, 2011). Investigations of cortisol in archaeological hair have yielded successful results, demonstrating cortisol preservation over hundreds of years (Webb et al., 2010, 2015a, 2015b). The cortisol concentrations found in archaeological hair provide a measure of chronic 'stress' that is direct, quantifiable and comparable with modern stress studies, circumventing some of the challenges in analyzing indirect stress indicators. Although progressive and exciting, analyses of cortisol from archaeological hair have several limitations. Some research has indicated that cortisol is removed from hair when washed (even just with water) (Davenport, Tiefenbacher, Lutz, Novak, & Meyer, 2006; Hamel et al., 2011; Meyer & Novak, 2012). More problematic is that very few archaeological individuals have hair preserved for analysis thereby severely limiting the application of this method. A recent study by Nejad and colleagues (2016) successfully detected cortisol from modern tooth dentine, suggesting that cortisol can be found in archaeological tooth structures. The ability to assess cortisol from teeth would have important implications for future research as teeth represent some of the best-preserved elements of the body in bioarchaeological contexts. Additionally, tooth structures have a much lower potential for contamination in the burial and post burial environment than hair or other skeletal elements (Turner-Walker, 2007), and are not subject to leaching in the same way as hair. Obtaining a more direct measure of this stress hormone in the past has the potential to provide a more nuanced understanding of the relationship between skeletal stress indicators and allows a more direct comparisons with clinical measures in modern populations.

This study seeks to develop and test a new method for assessing stress in archaeological human remains and has the following aims and objectives:

1. To determine if cortisol concentrations can be obtained from archaeological dentine or enamel through ELISA
2. To investigate possible correlations between cortisol concentrations in dentine and enamel dental tissues
3. To assess cortisol concentrations and variation based on biological sex

2. Materials and Methods

To conduct the cortisol analysis, 69 teeth were selected from 65 individuals from five Roman and Post-Roman sites in France (Table 1). Of the 69 teeth, 29 were sampled twice, to test dentine and enamel concentrations within the same tooth, for a total of 96 samples. The skeletal collections are in the care of three laboratories: De la Préhistoire à l'Actuel : Culture, Environnement et Anthropologie (PACEA), Bordeaux; the Centre de recherches archéologiques et historiques anciennes et médiévales (CRAHAM), Caen; and the Centre de Conservation et d'Etudes de Lorraine (CCEL), Metz. Teeth from both male and female individuals were selected.

Table 1. Sites where teeth were collected

Site	Location	Dating	Inds	Teeth	Dentine samples	Enamel samples	Total samples	Site Source	Lab [†]
Saintes, Rue Jacques Brel	Saintes	1-2 nd c	10	11	11	10	21	Baigl et al., 1997	PACEA
La Granède	Millau	4-7 th c	4	4	2	4	6	(Saint-Pierre, 2010)	PACEA
Fontoy	Thionville	4-7 th c	18	18	15	15	30	(Seilly, 1995)	CCEL
Rue du Tombois	Metz	4 th c	9	9	5	9	14	De Filippo et al., 2000	CCEL
Saint Martin de Fontenay	Caen	4-7 th c	24	27	27	0	27	Pilet, 1994	CRAHAM
Total			65	69	60	38	98		

[†]PACEA=De la Préhistoire à l'Actuel : Culture, Environnement et Anthropologie ; CCEL= Centre de Conservation et d'Etudes de Lorraine ; CRAHAM= Centre de recherches archéologiques et historiques anciennes et médiévales

Individual teeth were chosen based on several criteria, with a preference for permanent second molars wherever possible. The teeth selected had to be:

- Permanent teeth that began development after 4 months of age to exclude teeth that might have been affected by the period when the HPA axis is still developing and has yet to reach adult rhythms and values
- Free from pathological lesions or dental wear that might expose the dentine to the oral environment during life or the burial environment after death.

To test whether cortisol concentrations could be obtained from archaeological tooth structures, a method that identified cortisol in modern dentine (Nejad et al., 2016) was adapted and developed. Sixty-five individuals were tested for cortisol concentrations, with 38 enamel samples and 60 dentine samples deriving from a total of 69 teeth. For adolescents included in this analysis, age-at-death was determined by the stage of dental development (AlQahtani, Hector, & Liversidge, 2010). Adult age-at-death estimations were based on degenerative changes in the auricular surface and pubic symphyses (Brooks & Suchey, 1990; Lovejoy, Meindl, Pryzbeck, & Mensforth, 1985; Schmitt, Murail, Cunha, & Rougé, 2002) and dental wear (Brothwell, 1981). Sex estimates were based on sexually dimorphic features of the skull and pelvis (Brothwell, 1981; Bruzek, 2002; Phenice, 1969).

2.1 Tooth sample preparation

Before destructive sampling, each tooth was recorded and photographed on each of its five surfaces (occlusal, mesial, distal, lingual, buccal) in accordance with ethical guidelines for the destructive analysis of archaeological human skeletal remains (BABAO, 2019). To assess cortisol concentrations, the teeth were cleaned and prepared before subsequent ELISA (enzyme-linked immunosorbent assay) analysis. These processes are a modified version of the methods proposed by Nejad et al., (2016). Each tooth was washed in isopropanol to remove any contaminants present on the tooth surface and left to dry. Once dry, the tooth was bisected from crown to root using a diamond-tipped saw to expose the dentine. Using a rosehead dental burr, 150 mg of dentine were drilled out of the tooth in a fine powder, avoiding circumpulpal dentine to prevent any possible pulp remnants. Enamel samples were abraded with a dental burr to produce a chip of core enamel of 300 mg. The enamel was then ground into a powder. To prevent contamination between the samples, all tools were washed in ultrapure water, placed in an ultrasonic bath for five minutes and then dried with acetone in between sampling each tooth. Aliquots of dentine (150 mg) and enamel

(300 mg) were weighed into microcentrifuge tubes and 1 ml of methanol was added to the samples. The tubes were then left to incubate for 24 hours, with slow rotation at room temperature to elute the cortisol. After incubation, the samples were transferred to clean microtubes and dehydrated using a nitrogen stream. All samples were frozen until the day the ELISA was performed.

2.2 ELISA

A competitive ELISA salivary cortisol kit by Salimetrics (USA) was used to assess and quantify the cortisol concentrations present in the tooth dentine and enamel. Currently, there is no kit developed specifically for the analysis of cortisol in any tooth or bone tissue; however salivary kits have been successfully used to analyze both modern dentine (Nejad et al., 2016) and archaeological hair (Webb et al., 2010; 2015a; 2015b). This is a competitive ELISA immunoassay kit. On the day of analysis, samples were re-constituted with 30 µl of phosphate buffer. Cortisol conjugated to horseradish peroxidase for the antibody binding sites are coated on a microtitre plate. After incubation, unbound components are washed away. Bound cortisol enzyme conjugate is measured by the reaction of the HRP enzyme to the substrate tetramethylbenzidine (TMB), producing a blue color. Stopping the reaction with an acidic solution yields a yellow product. The optical density is read on a standard plate reader at 405-450 nm. The amount of cortisol enzyme conjugate detected is inversely proportional to the amount of cortisol present in the sample. The ELISA kit was run according to all specifications made by the manufacturer. A standard curve was generated for each kit based on standards and controls, and fourth order polynomial curve fit regressions were produced to define the cortisol concentrations within each sample. Student t-tests and Mann-Whitney U-tests were used to analyze differences between the sexes and tooth structures as appropriate.

3. Results

Teeth were selected from 25 females, 21 males and 19 individuals of indeterminate sex. Age estimations followed standard age categories (18-25, 26-35, 36-45 and 45+ years) and are presented here by the mean of their respective age range (18-25 = 21.5 years) for visual clarity. Two individuals could only be aged as 'adult' (18+ years) and are placed at the far right of the plot ('adult') (Fig. 1).

Two ELISAs were performed, one for dentine and the other for enamel. Concentration sensitivity of the Salimetrics salivary cortisol kits were $>0.007 \mu\text{g/dL}$ with an assay range of $0.012\text{--}3.000 \mu\text{g/dL}$, as determined by the kit manufacturer. Of the 96 tooth samples tested for cortisol concentrations, 32 (16 dentine and 16 enamel samples) yielded results detectable through ELISA (Fig. 1), the remaining 64 samples produced values below the $0.007 \mu\text{g/dL}$ concentration sensitivity threshold. In only two of the 29 teeth tested for both dentine and enamel cortisol, did both tissues yield detectable concentrations. In both cases, the dentine values were higher than enamel values (Fig. 1). No other clear patterns were observed. Data variation was up to 10%.

Comparisons between valid dentine and enamel concentrations (32 samples) were performed using independent sample T-Test in SPSS with significant results ($P < 0.001$) (Table 2). Differences in cortisol concentrations between males, females and indeterminate individuals were not significant in either dentine ($P = 0.808$) or enamel ($P = 0.407$) (Mann-Whitney) (Table 2).

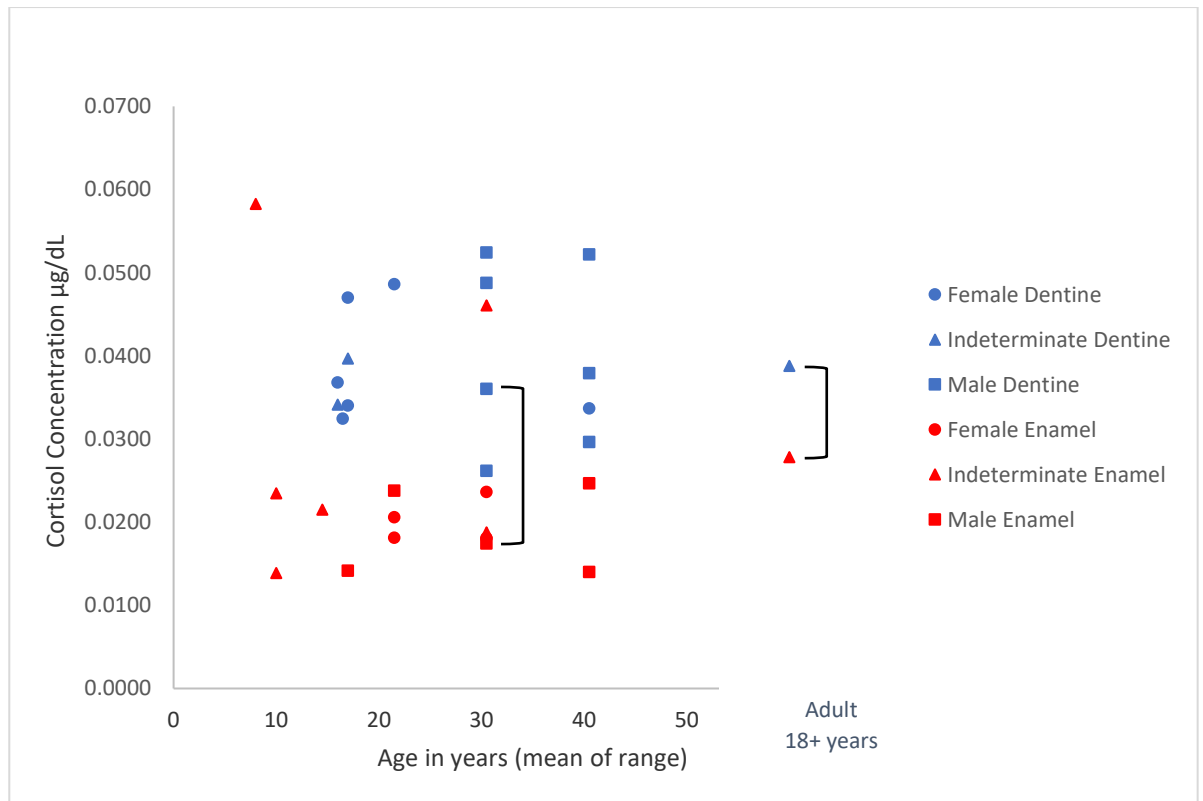


Fig. 1 Tooth cortisol concentration (µg/dL) per 300 mg tissue sample, plotted against age-at-death mean of range. Red symbols denote enamel and blue symbols are dentine values. Circles are female, triangles are indeterminate sex, and squares are male individuals. Brackets indicate representative cortisol concentrations from the same tooth.

Table 2. Detectable cortisol concentrations (mean) (µg/dL)

	Female	Indeterminate	Male	p-Value	Total
Dentine	0.0388	0.0375	0.0404	0.808	0.0393
Enamel	0.0201	0.0300	0.0188	0.407	0.0240

4. Discussion

Results of this study suggest that cortisol can be detected in archaeological tooth material. Although this finding is encouraging, the results are less straightforward than those obtained from either modern tooth dentine (Nejad et al., 2016) or archaeological hair (Webb et al., 2010; 2015a; 2015b). In common with other studies (Nejad et al., 2016; Webb et al., 2010, 2015a, 2015b), these results have not yet been validated with Gas or Liquid Chromatographic Mass Spectrometry, but this is an important next step to identify any cross reactivity within the assay between cortisol and other steroids or metabolites (Fraser et al., 2010; Wheeler & Barnard, 2010). In the absence of the possibility to perform this additional analysis, the results are cautiously interpreted in terms of their potential for future analyses. Although the observed cortisol concentrations were low, some patterns in the data do emerge. Values were broadly consistent, with only two individuals showing any marked difference from group averages. This result indicates that despite the low concentrations detected, differences between individuals and groups may be observed, rendering the method useful in assessing stress, especially with further development.

Clear differences were observed between dentine and enamel concentration values ($P < 0.001$), indicating a potential divergence in uptake mechanism or timing. As with hair, the mechanisms for incorporating cortisol in tooth structures are not yet understood, but are based on studies that have used human hair and/or teeth to assess exposure to drugs, toxins and pollutants (Altshuler, Halak, Landing, & Kehoe, 1962; Andra, Austin, & Arora, 2015; Chiesa et al., 2017). It is hypothesized that free cortisol circulating in the bloodstream is taken up into the structures during periods of growth or development (Haustein, Thiele, & Stangel, 1994; Klima, Altenburger, Kempf, Auwärter, & Neukamm, 2016; Klima, Huppertz, Altenburger, Auwärter, & Neukamm, 2015; Meyer & Novak, 2012; Nejad et al., 2016; Spinner et al., 2014; Van Uum et al., 2008). As such, it is suggested that cortisol concentrations in dentine and enamel would reflect cortisol in the blood during development of the tooth structures. Dentine and enamel have different properties that would affect the mechanisms and timing of cortisol incorporation in the different tissues (Cippitelli et al., 2018; Klima et al., 2016), which could explain observed differences in this study. Enamel is composed of 96% inorganic materials and once mineralized is isolated from the blood supply and does not remodel (Lee, Seo, Park, Bae, & Cha, 2017). As a result, any chemical or analyte retrieved from the enamel is likely to derive from the period of childhood when that part of the tooth was mineralized (Rubin, 2018). Tooth specific patterns of enamel formation have been correlated with biological age (AlQahtani et al., 2010; Moorrees, Fanning, & Hunt Jr, 1963a, 1963b), localizing the

period during which exposure could have taken place, but also revealing limitations in the amount of time chemical signals could be incorporated into enamel (Rubin, 2018). Concentrations of other biochemicals obtained from enamel have been low in comparison with dentine and other types of tissue potentially because of its high mineral content and limited window of exposure (Klima et al., 2016). Dentine is avascular with no blood supply and is composed of approximately 70% inorganic, 20% organic materials (including proteins and proteoglycans) and 10% water (Lee et al., 2017; Orsini et al., 2009; Turner-Walker, 2007). Once formed (approximately 3-4 days), dentine undergoes very little remodeling (Beaumont & Montgomery, 2016) and like enamel, should capture exposure to biochemical concentrations during a discrete period of development (Andra et al., 2015). Studies have found drugs in higher concentrations in tooth dentine than in enamel, likely because of the less mineralized nature of dentine (accepts molecules more easily) ((Klima et al., 2016, 2015; Näsström, 1996).

Alternatively, it is possible for exogenous substances to become incorporated in tooth structures after mineralization. Some studies have been able to detect drugs in dental hard tissues, when drug usage was known to have occurred close to the time of testing/death (Houari, Liodice, Jedeon, Berdal, & Babajko, 2016; Klima et al., 2016). Unless the highly mineralized structure of enamel has been degraded in some way (ex. carious lesions), drug incorporation via oral fluids has been reportedly quite low (although detectable) in drug users (Klima et al., 2016, 2015). Dentine is a more complicated tissue to consider. Despite its avascularity, dentine has a relationship with dental pulp (and thereby the blood supply) through dentinal tubules. Dentinal tubules could transmit chemicals or substances in the still living, enervated pulp to the dentine (Ghazali, 2003; Spinner et al., 2014) and the inverse from dentine to dental pulp and blood supply (Pashley, 1979). Higher concentrations of drugs in tooth dentine (compared with enamel) are purportedly the result of its relationship with dental pulp through the dentinal tubules (Ghazali, 2003; Klima et al., 2016, 2015; Näsström, 1996). That enamel cortisol levels identified in this study were significantly lower would seem to suggest that as with hair, free cortisol circulating in the blood gets trapped in enamel during formation, and is largely unaffected thereafter (especially as damaged or degraded teeth were excluded from analysis). However, it is not entirely clear whether dentine cortisol levels reflect circumstances during the development of the tooth or an amalgam of exposure across a lifetime. Based on the results of this analysis, tooth dentine and enamel generate different concentrations of cortisol, even from within the same tooth. However, because only two teeth sampled for both dentine and enamel generated detectable concentrations within the assay,

future research should explore this relationship in more detail. It is worth noting that in both cases, the dentine values were higher than enamel values.

4.1 Sex-based differences

No differences in cortisol concentrations between the sexes were observed in either of the dental tissues. This could be a result of the small sample size or the overall low values obtained in this analysis. Sex based differences in HPA axis and cortisol concentrations are thought to develop at puberty, but reported results are not consistent (Kirschbaum, Wüst, & Hellhammer, 1992; Raven & Taylor, 1996). Nejad et al. (2016) also did not find differences between male and female cortisol concentrations in their analysis of modern tooth dentine. If cortisol is being deposited within the dental tissues during mineralization, the results are reflecting cortisol exposure before puberty and might explain the lack of difference between male and female cortisol concentrations in both this analysis and in modern dentine.

4.2 Low concentrations detected

The concentration values obtained in this study were low in comparison with modern dentine data (Nejad et al., 2016), archaeological hair concentrations (Webb et al., 2015b) and modern standards from hair, saliva, blood and urine (Aardal & Holm, 1995; Deutschbein et al., 2011; Gonzalez et al., 2019). Not all of the samples in this analysis met the minimum detection threshold of the ELISA cortisol kits. Although this finding is not exclusive to this study (Gow et al., 2010), it is not clear why the values are low. Accordingly, there are several possible explanations for these results with implications for future analyses. Cortisol may not be as readily deposited within tooth structures as in other tissue types. If metabolized too rapidly, biochemicals or compounds cannot be incorporated into the growing structure (Greff et al., 2019), and this includes hair as well as teeth. Circulating cortisol is thought to have a half-life of 80 minutes in the body, which may not be long enough for detectable volumes to become consistently incorporated into dental structures (Greff et al., 2019; Isaac et al., 2017). However, cortisol is constantly in circulation, relatively small in size (362 Da) and lipophilic, characteristics that predispose and increase the likelihood of deposition within tooth dentine and enamel (Greff et al., 2019; Haustein et al., 1994; Klima et al., 2016, 2015; Spinner et al., 2014). Because the mechanisms for incorporation are not yet understood, it may be that the time window for potential exposure during amelogenesis and odontogenesis is more limited than for hair or other tissues. Cortisol concentrations from modern dentine suggest that

detectable quantities of cortisol can be present within the tissue, seemingly refuting hypotheses that cortisol is too rapidly metabolized to be incorporated into dental tissues (Nejad et al., 2016). Further, there is evidence that enamel and dentine can be influenced by hormones and exogenous chemicals (Ahlgren, 1968; Houari et al., 2016). Ameloblasts (enamel forming cells) have been found to contain glucocorticoid hormonal receptors depending on their developmental stage (Houari et al., 2016). It has even been suggested that amelogenesis is regulated by endogenous steroid hormones, affecting the quality, hardness and mineralization of the enamel (Houari et al., 2016; Pawlicki, Knychalska-Karwin, Stankiewicz, Jakób-Dolezal, & Karwan, 1992). Hydrocortisone (a synthetic variant) has been found to retard dentine formation under experimental conditions (Ahlgren, 1968). Studies of drug concentrations within dental hard tissues (Cattaneo, Gigli, Lodi, & Grandi, 2003) have been criticized for not adequately removing pulp tissues before processing, potentially confounding reported results (Rubin, 2018; Spinner et al., 2014). Although Nejad et al. (2016) reported multiple cleaning processes, they do not specify whether the pulp chambers of sampled teeth were cleaned. It is, therefore, possible that their reported values are in fact reflecting cortisol concentrations from dental pulp, containing a blood and nerve supply, in addition to tooth dentine¹. This could explain why their reported values were higher than the values obtained purely from tooth dentine or enamel in this study. Further analyses would be necessary to explore this explanation of results.

Alternatively, tooth cortisol could have degraded during decomposition, in either the burial or post-burial environments. Obtained cortisol concentrations from modern tooth structures (7.92 ± 0.91 ng/mg) (Nejad et al., 2016) were markedly higher than results in the present analysis. Although cortisol is a stable natural steroid, long-term exposure to 37°C and above can lead to significant degradation, and this is worth considering in the future (ie. historic climate factors, including temperature, humidity, and effects on biological markers) (Khonmee et al., 2020). It is possible that higher cortisol concentrations in modern analysis were a result of the inclusion of dental pulp and blood supply, and lower environmental temperature exposure. Again, further testing of cortisol degradation should clarify these findings. However, excellent preservation of cortisol in archaeological hair from comparable time periods (1-1000 AD) has been reported (Webb et al., 2010, 2015a, 2015b). As hair is rarely preserved, it may be that burial conditions and post-burial treatment are better for individuals with hair than individuals decomposed to only skeletal material. For hair to be preserved archaeologically, certain burial conditions must be present and

¹ It is also not clear in the Nejad et al. (2016) study if dentine was separated from enamel prior to analysis. From the wording of the text, it seems likely that after cleaning, the entire tooth was ground down to generate the one gram of tooth powder

because of their rarity, skeletons or mummies with preserved hair are more likely to be handled more delicately by fewer people than entirely skeletonized individuals. In clinical analyses, however, cortisol can withstand multiple heating and cooling cycles without appreciable decomposition until reaching a heat of 220 °C (Hamel et al., 2011). It is highly unlikely that the individuals in this analysis, excavated and stored in laboratories, had ever experienced such high heats, leaving no other trace. It is thought that teeth undergo very little diagenetic change in post burial environments and can maintain chemical substances, protecting them from alteration or degradation within the hard tooth structures (Cippitelli et al., 2018; Lee et al., 2017; Spinner et al., 2014). Although ideal for preservation over long periods of time, the structure of both dentine and enamel can make the extraction of organic chemicals challenging (Lee et al., 2017). Perhaps the low values in this study are attributable to challenges in separating out cortisol bound to hard dental tissues, as has been found in drug analysis of hair (Spinner et al., 2014). Again, future analyses should test for cortisol degradation and may be able to identify or overcome some of these challenges.

As with hair, cortisol within tooth structures reflects chronic stress levels, averaging out normal functioning cortisol and acute stress events (Russell, Koren, Rieder, & Van Uum, 2012). Cortisol or its animal equivalent (corticosterone) is only produced by mammals, and although external animal or human corticosterone/cortisol infused fluids or fats could be present in burial environments, several cleaning steps were undertaken to remove possible external contaminants from the samples. Dentine and core enamel would only have been exposed to the burial environment if the tooth was damaged or degraded. Other related steroid hormones, and cortisone, a precursor and metabolite of cortisol, could display cross-reactivity with antibodies on the ELISA plate. Gas or Liquid Chromatographic Mass Spectrometry GC/LC/MS techniques can identify these different hormones, which would clarify this issue further. However, the cortisol ELISA utilized in this study displays high sensitivity and selectivity for human cortisol, with no detectable cross-reactivity (<0.004%) to related steroids. Minor-cross reactivity is possible with some synthetic steroids. This is not expected to be an issue within this study, as the teeth date to Roman and Post-Roman periods and precautions were taken to avoid modern pharmaceutical contamination. Although this study has generated promising results, several steps need to be taken to further refine the method, for appreciable conclusions to be drawn. The first step is to validate the result of the assays using GC/LC/MS or other methods for controlling cross-reactivity (Fraser et al., 2010; Wheeler & Barnard, 2010). Once validated, further experimentation on potential uptake mechanisms and different methods of extraction have enormous potential to advance the method and perhaps permit a

reduction in the minimum required sample (e.g. hair- 10-15mg; Van Uum et al., 2008). This method allows the identification of stress in skeletal individuals in a different way, which has the potential to be more quantitative and direct than current macroscopic methodologies. Future studies will consider cortisol concentrations in relation to various qualitative pathological indicators, including growth disruption and dental enamel hypoplasia.

5. Conclusion

In both tooth dentine and enamel, measurable concentrations of cortisol were identified in multiple teeth. However, concentrations were very low ($0.02\ \mu\text{g/dL}$ – $0.04\ \mu\text{g/dL}$) and not all teeth yielded results that were detectable through cortisol ELISA methodologies. These results suggest that cortisol is deposited within tooth structures and merits further investigation in both modern and archaeological contexts. Future testing for cortisol degradation and analysis of the results through GC/LC-MS would verify results and may yield values that could be better integrated with published cortisol studies. This study has acted as a proof of concept, and these results expand the research potential of cortisol in the past and could have implications for studies of human stress across deep time.

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Cortisol, Stress and Paleopathology

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Abstract:

Stress impacts health and wellbeing through allostatic load, affecting morbidity and mortality. However, the relationship between stress, frailty, immunity and disease has generated interpretive challenges for palaeopathological analysis. Cortisol, known as ‘the stress hormone’, facilitates physiological response to stressors, thereby acting as a key pathway to bodily manifestations of adversity. Cortisol concentrations therefore have the potential to act as a direct indicator of stress and one that may not be subject to the same interpretive limitations as traditional skeletal stress indicators. Recent research has successfully detected cortisol concentrations in archaeological tooth structures. Here we review the pathophysiology of cortisol and its relationship with commonly recorded skeletal stress indicators (mortality, growth disruption, DEH, CO, periosteal reaction, carious lesions) and provide preliminary results of possible correlations in an archaeological sample of 29 individuals. Results did not reveal clear patterns between dental cortisol and skeletal stress markers, frustrating attempts to use them as a straightforward frailty indicator or signal of early life stress. Although too early for conclusive interpretations, this research illustrates how cortisol could be functioning within the development of skeletal stress indicators, highlighting the complexity of cortisol’s many functions within the body. Future analyses should continue to consider how external stressors become embedded biologically and explore cortisol’s potential to reveal hidden heterogeneity in frailty.

Keywords: DEH, Growth, HPA Axis, Frailty, Skeleton

The effects of 'stress' on the body and its impact on health and well-being is a primary concern in modern populations. Stress is linked to chronic diseases that are highly prevalent in many post-industrial societies today (e.g. cardiovascular disease, metabolic syndrome, diabetes). Stress also influences immune function and susceptibility to pathological agents, and this has important implications for health in the past, when infectious diseases were a primary cause of morbidity and mortality. Within palaeopathological research, several skeletal and dental lesions are commonly assessed as indicators of non-specific physiological stress, including growth disruption, dental enamel hypoplasia (DEH), cribra orbitalia (CO), periosteal new bone formation (NBF) as well as mortality patterns. The glucocorticoid hormone cortisol plays a critical role in the biological stress response, communicating the presence of and preparing the body to respond to physiological and psychosocial stressors. Accordingly, cortisol participates in some of the regulatory, metabolic and immunological actions that result in the manifestation of skeletal stress lesions. Cortisol has been successfully assessed in hair from archaeological contexts (Webb et al., 2015a, 2015b, 2010), but hair tends only to be preserved in exceptional circumstances. Recent studies have successfully retrieved cortisol from modern (Nejad et al., 2016) and archaeological teeth (Quade et al., 2020). Given the recent introduction of a method for assessing cortisol concentrations from archaeological tooth structures, an exploration of cortisol is warranted. This study aims to review the basal role that cortisol plays in the development of skeletal stress indicators and uses the data generated from Quade and colleagues (2020) to explore the correlation between cortisol and traditional indicators of stress within archaeological samples from Roman (1st-2nd c) and Late Antique (4th-7th c) Gaul.

1. Stress

'Stress' is the result of stimuli (stressors) moving the body out of homeostasis, and thereby eliciting a physical reaction (stress response) (Huss-Ashmore et al., 1982; Selye, 1950). When functioning properly, the stress response is adaptive, promoting survival through the facilitation of physical reaction and adaptation to avoid or cope with threats (Beehner and Bergman, 2017). However, when stress events are repeated or prolonged, the biological stress response pathway can be negatively affected, with adverse effects on overall health. This cumulative damage, or wear and tear, is known as allostatic load (Edes and Crews, 2017; McEwen, 2012). The Hypothalamic-Pituitary-Adrenal (HPA) axis is a critical part of the biological stress response, which can become dysregulated as a result of allostatic load. HPA axis dysregulation reduces an organism's ability to adequately or appropriately respond to stressors and can manifest as loss of sensitivity (resulting

in either an excessive or blunted response) and/or recovery from stressors can be delayed or prolonged (McEwen, 2012). Dysregulation of the HPA axis results in an over or underexposure to its primary adrenal product, the glucocorticoid hormone cortisol. When cortisol levels are dysregulated, cortisol's homeostatic and allostatic actions become maladaptive and can have damaging effects on tissues and organs (Dickerson and Kemeny, 2004; McEwen, 2012; Sapolsky et al., 2000). Therefore, excessive or chronic exposure to stressors affects health in two ways: (1) the stress response becomes less efficient, making the organism more vulnerable to stressors; (2) dysregulated levels of cortisol have negative consequences on bodily systems, degrading tissues with prolonged exposure (McEwen, 2012). The stress response is largely non-specific, activating the same physiological response pathway regardless of the type of stressor (Sapolsky et al., 2000; Selye, 1950). Stressors have been categorised as physiological (extreme temperatures, food or resource scarcity, illness/disease burden, trauma), psychosocial (social disruption, subordination, loneliness), or both acting synergistically (Avitsur et al., 2009; Dhabhar, 2011; Nyberg et al., 2012; Sapolsky et al., 2000; Yang and Glaser, 2002). Through the HPA axis pathway, external stressors become internalised within the body, impacting health and wellbeing.

1.1.Cortisol

Cortisol is produced and secreted by the HPA axis in a regular circadian pattern, but also in response to stressors. In 'un-stressed' and 'stressed' states, the primary role of cortisol is to maintain or regain homeostasis (balance within the body) through up- or downregulating the actions of cells and tissues (Greff et al., 2019). Cortisol's regulatory actions in cardiovascular, metabolic and immunological systems are crucial for survival and normal body functioning (Dallman and Hellhammer, 2011). Within the diurnal rhythm, cortisol suppresses overactive immune or inflammatory responses, maintains blood glucose levels within appropriate ranges, and modulates cardiac output. In the presence of a stressor, cortisol prepares the body to respond to a threat by prioritizing processes serving immediate energetic needs (glucose and red blood cell production, cardiac output) and diverting energy away from biological processes secondary to immediate survival (growth, digestion, reproduction) (Panagiotakopoulos and Neigh, 2014). Although adaptive in the short term, chronic over exposure to cortisol results in growth and reproductive suppression, damage to the brain (hippocampus), and the progression of some chronic diseases, including cardiovascular disease, diabetes, hypertension and premature death (Beehner and Bergman, 2017; Dickerson and Kemeny, 2004; Panagiotakopoulos and Neigh, 2014) (see Table 1 for summary of the effects of overexposure to cortisol). Glucocorticoids are best known for their

immunosuppressive and anti-inflammatory actions, which have been harnessed to treat inflammatory diseases (asthma, rheumatoid arthritis, lupus) and facilitate successful organ transplantations (Klein, 2015). Many glucocorticoid actions and properties have been studied through supraphysiological levels used in clinical settings. However, when the HPA axis becomes dysregulated, endogenous cortisol can yield 'identical effects' to those seen in clinical research settings (Klein, 2015; Newton, 2000; Scheschowitsch et al., 2017).

Problems with glucocorticoids are often discussed in terms of overexposure (hypercortisolism), but too little cortisol (hypocortisolism) can also have negative health effects. These include muscle weakness, hypotension, vasodilation, decreased cardiac size and output, hypoglycaemia, hypersensitivity to insulin, normochromic anaemia, an overgrowth of lymphoid tissues and an overactive immune system (McKay and Cidlowski, 2003; Sharpley et al., 2012). Somewhat paradoxically, hypocortisolism can be induced when the HPA axis has been overactivated for an extended period of time, as overstimulation can lead to malfunctions in the secretion of cortisol or glucocorticoid receptor (GR) sensitivity (Sharpley et al., 2012). To avoid adverse health consequences, balanced levels of cortisol as well as other glucocorticoid hormones need to be maintained.

Table 1. Effects of hypercortisolism on the body

Ultimate effects	Tissue/ system	Proximate effects
Depression Altered cognition Dementia Psychosis/Neurosis	Brain	• Cell death in hippocampus • Reduces GR sensitivity in the brain
Cardiovascular Disease	Cardiovascular	• Hypertension (High blood pressure)
Decreased Growth Suppression of appetite and digestion Delays puberty	Metabolic Endocrine	• Gluconeogenesis • Hyperglycaemia • Stimulates lipolysis and lipid mobilisation • Inhibits growth hormone secretion • Affects thyroid hormone • Interacts with sex steroids (oestradiol, testosterone) • Reduces synthesis of other hormone receptors
Suppression of reproduction Osteoporosis Muscle atrophy	Musculo-skeletal	• Inhibits epiphyseal plate maturation • Prevents maturation of and instigates apoptosis of osteoblasts and osteocytes • Prolongs life of osteoclasts • reduced bone mineral density • inhibits collagen synthesis
Peptic ulcers	Gastro-intestinal	• Increases gastric acid secretion • Decreased calcium resorption
Hyperglycaemia Suppressed inflammatory reaction Slowed Wound Healing Immunosuppression	Anti-Inflammatory Hematologic	• Prevents migration of inflammatory cells to injury sites • Inhibition of lymphocyte, neutrophil and monocyte production • Inhibition of collagen breakdown processes • Increase haemoglobin and red cell content • Increase leukocytes • Decrease lymphocytes, monocytes, basophils through apoptosis or relocation of cells
Increased risk of infection	Immunological	• Atrophy of lymphoid tissues • Decrease lymphocyte proliferation and cytokine production • Inhibits immunoglobulin synthesis

1.2.Stress in palaeopathology

Stress is a foundational topic and integral theme within bioarchaeological and palaeopathological research of health in the past (Goodman and Leatherman, 1998; Larsen, 1997; Reitsem and McIlvaine, 2014; Temple and Goodman, 2014). Although understanding stress and health in response to differing social and environmental conditions is a primary goal within the discipline (Goodman et al., 1984; Goodman and Leatherman, 1998; Huss-Ashmore et al., 1982; Temple and Goodman, 2014), several important challenges continually emerge from within the literature:

(1) Health encompasses mental and emotional states (WHO, 1998) that may be challenging to assess through skeletal markers. This necessitates careful distinction between 'health' and 'stress' in palaeopathological research (Reitsema and McIlvaine, 2014; Temple and Goodman, 2014).

(2) Stress is used as a proxy for health in the past (Goodman and Armelagos, 1989; Goodman and Redclift, 1988), but has an imperfect and complex relationship (Piperata et al., 2014; Reitsema and McIlvaine, 2014; Tanner, 2014).

(3) Hidden heterogeneities in frailty, or susceptibility to morbidity and mortality, influence health outcomes, complicating interpretation of skeletal stress markers and their significance for larger patterns of stress experience in the past (the osteological paradox) (Cohen et al., 1994; Goodman and Martin, 2002; Wood et al., 1992).

Exploration of the pathophysiological processes underlying the development of skeletal stress markers is one approach that has been used to address the osteological paradox and understand skeletal lesions in relation to specific stressors (Edes and Crews, 2017; Klaus, 2014; Ragsdale and Lehmer, 2012; Walker et al., 2009; Weston, 2011). Following a pathophysiological approach, this study reviews the role of cortisol within or underlying several commonly assessed skeletal stress markers (mortality, growth disruption, DEH, CO, NBF, caries). Previous research (Beaumont et al., 2015; Beaumont and Montgomery, 2016; Scott et al., 2016) has already begun to analyse stress on a biomolecular level, with important consequences for interpreting stress and health and wellbeing in the past. However, physiological pathways of stress are not routinely discussed on an endocrine level in relation to non-specific stress indicators in palaeopathology (see notable exceptions: Edes and Crews, 2017; Gowland, 2017; Klaus, 2014; Nyberg et al., 2012; Temple, 2019; Webb et al., 2010, 2015a, 2015b; Weston, 2011). Cortisol concentrations provide a direct and sensitive indicator of stress in modern populations and could be important for examining the interplay between stress, health and social or environmental conditions in the past. Furthermore, it has been argued that through the mechanism of cortisol, stress connects large scale cultural or social environments with individual biology (Nyberg et al., 2012). Although many factors, including other hormones, molecular signalling factors and proteins have a substantial and sometimes more significant effect on the development of skeletal stress indicators than cortisol, the goal of this analysis is to present stress processes in greater detail and complexity (rather than being reductionist).

2. Materials and Methods

Twenty-nine individuals were assessed for skeletal stress markers typically examined in palaeopathological analyses, including age-at-death (mortality), growth disruption, DEH, CO, tibial NBF, and carious lesions. A total of 32 samples from 28 teeth (16 dentine and 16 enamel samples) from these same 29 individuals were analysed for cortisol concentrations. The individuals were selected from one Roman (1st-2nd c) and four Late Antique (4th -7th c) sites in Gaul (Table 2). Permission for destructive analyses and the presence of permanent teeth, free from wear or pathological conditions exposing tooth dentine were necessary for inclusion in this analysis. Insofar as possible, individuals with and without evidence of each pathological condition were selected.

Table 2. Description of individuals and teeth included in this analysis

Site	Dating	Individuals (n=)	Teeth (n=)	Dentine Samples (n=)	Enamel samples (n=)	Total samples (n=)	Site Source
Sainte, Rue Jacques Brel	1-2 nd c	5	5	2	4	6	(Baigl et al., 1997)
La Granède	4-7 th c	1	1	1	1	2	(Saint-Pierre, 2010)
Fontoy	4-7 th c	10	10	4	6	10	(Seilly, 1995)
Rue du Tombois	4 th c	5	4	1	5	6	(De Filippo et al., 2000)
Saint Martin de Fontenay	4-7 th c	8	8	8	0	8	(Pilet et al., 1994)
Total		29	28	16	16	32	

Following standard practices, age-at-death in adults was estimated based on degenerative changes to the auricular surface (Lovejoy et al., 1985; Schmitt et al., 2002) and pubic symphysis (Brooks and Suchey, 1990) of the pelvis. For non-adult individuals, age-at-death estimates were generated from dental developmental stage (AlQahtani et al., 2010). DEH was assessed macroscopically, where presence/absence, type of defect and number of defects on a tooth were recorded. CO was scored according to Stuart-McAdam (1991), but was only considered on a presence/absence basis, where a minimum score of ‘three’ was required to record the lesion as present. Periosteal reaction of the tibia was recorded as present when new bone formation was observed. The type of new bone formation (woven, mixed, lamellar) and stage of healing were recorded (Weston, 2009). Carious lesions were assessed using a bright light and dental probe. Only clear areas or points of demineralisation of tooth structures were scored (Hillson, 2001).

A detailed description of the cortisol analysis method can be found in Quade and colleagues (2020). The analysis is summarised here. Selected teeth were first washed in isopropanol to remove contaminants before sectioning and the removal of dentine and/or enamel. The sampled tissue was then ground into a powder and placed in 1 mL of methanol for 24 hours to elute the cortisol. After elution, the samples were dehydrated using a manifold nitrogen stream and frozen until the day of analysis via ELISA (enzyme-linked immunosorbent assay). All tools were washed in ultrapure water and dried with acetone between sampling to prevent cross-contamination.

A competitive ELISA salivary cortisol kit by Salimetrics (USA) was used to assess and quantify the cortisol concentrations present in the tooth dentine and enamel. On the day of analysis, samples were re-constituted with 30 µl of phosphate buffer. The ELISA kit was run according to all specifications made by the manufacturer and wells were read in a Thermo Scientific Multiskan FC ELISA plate reader at 405 or 450 nm. A standard curve was generated for each kit based on standards and controls, and fourth order polynomial curve fit regressions were produced to define the cortisol concentrations within each sample.

3. Results and Discussion

The relationship between cortisol, several commonly utilised skeletal stress indicators (mortality, growth disruption, DEH, CO, NBF) and carious lesions is discussed to explore implications for assessing frailty and stress in human skeletal remains. Where possible, preliminary cortisol data are included to further discussion on observed cortisol concentrations and skeletal stress indicators. Small sample sizes precluded the application of statistical analyses to these data but remains a promising avenue for future research.

3.1. Mortality Patterns

The ultimate adverse health consequence is death, and dysregulated levels of cortisol have been associated with premature or excessive mortality in modern populations. In both Cushing's Syndrome and Addison's disease, disorders defined by hyper- and hypocortisolism respectively, premature or excessive mortality is reported, especially if left untreated (Clayton, 2010; Erichsen et al., 2009). However, typically it is not cortisol dysregulation itself, but rather the long-term effects of chronic elevation or depression that result in increased mortality (cardiovascular disease,

diabetes, immunosuppression/increased risk of infection) (Clayton, 2010; Erichsen et al., 2009). Cortisol's immunosuppressive properties are particularly relevant to the study of past populations, when infectious disease would have had a large impact on mortality. Chronically elevated cortisol concentrations reduce adaptive and innate immune response and thereby resistance to infection from viral, bacterial and mycotic pathogens (Janicki-Deverts et al., 2016; Pedersen et al., 2011; Sapolsky et al., 2000; Yang and Glaser, 2002). Mediators of immune response are inhibited, including cytokine, interleukin1 and lymphocyte participation and leukocyte recruitment (Elenkov and Chrousos, 1999; Fraser et al., 2010; Sapolsky et al., 2000). Cortisol also suppresses inflammatory and allergic reactions, by reducing blood histamine levels and antibody production (reduces B-cells, T-lymphocytes and T-cells) (Donatti et al., 2011; Greff et al., 2019). In otherwise healthy individuals, the increased risk for infection arises in just days (Janicki-Deverts et al., 2016) with molecular immune changes identified within as little as five minutes of stressor onset (Marsland et al., 2002). Further, the relationship between increased risk of infection and glucocorticoids (GCs) is dose-responsive, increasing with GC concentration (Akcalı et al., 2014; Janicki-Deverts et al., 2016; Smit et al., 2016). This means that stressors do not necessarily have to be 'extreme' or chronic to elicit changes in the immune system, but the 'degree' or frequency of stressors remain important factors in morbidity and mortality.

Although specific diseases have particular aetiologies, cortisol *modulates* pathogen susceptibility, illness duration and severity (Marmot, 1996). Therefore, a heightened prevalence of stressors (psychological or physiological) puts an individual at greater risk of disease development and premature mortality (Janicki-Deverts et al., 2016; Pedersen et al., 2011; Yang and Glaser, 2002). Stress has been shown to affect immune function in healthy and ill individuals (Norbiato et al., 1997). The speed of HIV to AIDS progression has been reported to increase with high degrees of stress and limited social support (the reverse has also been documented) (Yang and Glaser, 2002). In animals, an association between crowding and increased risk of developing tuberculosis after exposure was found (Glaser et al., 1999). As such, cortisol has a connection with frailty or susceptibility to pathogens or conditions that result in skeletal stress lesions and premature mortality, making it potentially useful in palaeopathology. Based on clinical literature, dysregulated levels of cortisol (high or low) are correlated with earlier/premature age-at-death. Cortisol concentrations from enamel are most likely reflecting cortisol exposure during the discreet window of amelogenesis when the enamel was being formed (Quade et al., 2020). Thereby, a relationship between enamel cortisol concentrations and mortality would indicate if cortisol concentrations could be used as an early life stress or frailty indicator (Temple and Goodman, 2014; Wood et al.,

1992). However, preliminary data reveal no apparent relationship between dental cortisol concentration and mortality patterns in either dentine or enamel (Fig. 1). These results could be an artefact of small sample size or result from inconsistencies in the new method. Uptake mechanisms for cortisol in tooth structures are not yet fully understood and may also be contributing to the data in as of yet unknown ways. In future analyses with larger data sets, Kaplan-Meier survival analysis would be beneficial to statistically test relationships between dental cortisol concentration and mortality.



Fig. 1 Enamel and dentine cortisol concentrations and mortality

3.2. Growth disruption

Growth disruption is a key metric for stress, health and wellbeing in past and present populations. Glucocorticoids play a role in normal bone maintenance and turnover (Kino et al., 2012), but downregulate growth and remodelling processes with chronic overexposure (Canalis, 2005). Cortisol negatively influences bone growth, mineral density and repair in multiple, synergistic ways, involving interaction with other endocrine and metabolic structures. High cortisol concentrations decrease the formation and maturation of chondroblast and osteoblast (collagen and bone forming) cells and encourage their premature apoptosis (Fig. 2) (Canalis, 2005; Cruess, 1983; Donatti et al., 2011). Because chondroblasts are thusly unable to form type I collagen, there is reduced osteoid matrix for existing osteoblasts to mineralise. Simultaneously, cortisol extends the normal lifespan of osteoclast (bone resorbing) cells, causing increased bone destruction, as the

osteoclasts remove osteoid tissue that has not been adequately mineralised by osteoblasts (Canalis and Delany, 2002; Cruess, 1983; Jia et al., 2006). Osteocytes, which maintain healthy bone tissues through repair and phosphate metabolism, are also subject to increased apoptosis in response to high levels of cortisol. Hypercortisolism affects circulating calcium levels, by inhibiting calcium absorption from the gastrointestinal tract and stimulating its excretion, resulting in less bioavailable calcium for bone growth and maintenance (Kinoshita et al., 2008; Lanna et al., 2002; Mahgoub et al., 1997; Mazziotti et al., 2006). In addition to metabolic concerns, this loss of calcium can have significant effects on growth, where patients undergoing lengthy GC therapies are supplemented with calcium and vitamin D to prevent or overcome negative growth effects (Donatti et al., 2011). Further, cortisol inhibits growth hormone secretion and can affect bone maturation (Cruess, 1983; Donatti et al., 2011; McKay and Cidlowski, 2003). The pubertal growth spurt, development of secondary sexual characteristics and perhaps even puberty itself can be delayed in response to high cortisol concentrations (Mushtaq and Ahmed, 2002). Glucocorticoids can alter the maturation and structure of the epiphyseal growth plate, leading to thinning of the growth plate and premature fusion of the long bones (Azmy and Abdallah, 2013; Cruess, 1983). In children, the combined actions of cortisol can have a cumulative, compounding effect resulting in an almost total cessation of growth, net loss of bone and growth stunting (Canalis and Delany, 2002; Panagiotakopoulos and Neigh, 2014).

The relationship between stress, stunted growth and poor health outcomes has been extensively studied in paleopathology, medical anthropology and clinical research. Stunted growth, as evidenced through skeletal remains, has been correlated with skeletal stress indicators, including DEH, NBF and early mortality in a wide range of locations and time periods (Larsen, 1997; Newman and Gowland, 2017; Pezo-Lanfranco et al., 2020; Pinhasi et al., 2006). In modern populations, growth stunting is similarly associated with a high incidence of stressors and negative health outcomes (Kelly et al., 2012; Mason and Narad, 2005; Rodney and Mulligan, 2014). There is a clear association between elevated basal cortisol levels (from endogenous and exogenous sources) and growth disruption (Chrousos, 2000; Gunnar and Donzella, 2002; Kelly et al., 2012; Mason and Narad, 2005; Nyberg et al., 2012). In children with Cushing's Disease or taking long-term corticosteroid treatment, delays in growth and puberty are common, with some effects sustained into final adult stature (Donatti et al., 2011; Kelly et al., 2012; Mushtaq and Ahmed, 2002). Therefore, not only are heightened cortisol levels, stressors and stunted growth correlated, but cortisol acts as a pathway for stressors to impact growth and health. Importantly, cortisol's immunosuppressive actions also render an individual more susceptible to infection, compounding

the risk of growth faltering or stunting as energetic/metabolic resources are redistributed away from growth (Nyberg et al., 2012; Sapolsky et al., 2000; Tanner, 2014). This suggests another way in which GCs can affect growth beyond their direct effects on skeletal tissues. Synergistic relationships between cortisol levels, growth, nutrition and pathogen load would clearly have impacted health in the past and require further study.

External stressors can become biologically embedded through overactivation of the HPA axis and elevated cortisol levels, resulting in adverse health effects including growth and developmental faltering. Although growth and stature are strongly influenced by genetic makeup, growth is plastic, responding to environmental conditions during development (Cardoso et al., 2019; Eveleth and Tanner, 1990; Perkins et al., 2016). Growth stunting or short adult stature can reflect trade-offs in response to stressors, where the ability to survive metabolic deficiencies, illness or environmental stress compromises height (Barker et al., 2002). Thereby, a population with reduced height could reflect a high prevalence of stressors. Alternatively, it has been argued that tall stature (on a population level) can reflect high selection pressures that effectively remove individuals who would have comprised the shortest sector of the population had they survived (DeWitte et al., 2016; DeWitte and Hughes-Morey, 2012; Quade and Binder, 2018; Vercellotti et al., 2014). Examination of dental cortisol in relation to patterns of growth and maturation could help to clarify these problems in interpreting heterogenous frailty. Due to preservation constraints, preliminary data were not robust enough in this study for analysis of patterns in growth and obtained cortisol concentrations. Further analyses of growth stunting and dental cortisol concentrations would be an extremely promising avenue for future research. However, it is important to note that cortisol is not 'in charge' of growth but is merely one hormone along one pathway contributing to potential growth arrest or delay (Klaus, 2014). Many other hormones (parathyroid, sex hormones), molecular signalling factors (RANK, RANKL) and proteins have a substantial and sometimes more significant effect on skeletal growth than glucocorticoids (Klaus, 2014)¹. In future analyses, multiple factors and influences on growth will need to continue to be considered.

¹ Although in the case of RANKL, as described by Klaus (2014), GCs impact RANKL receptor expression (Mazziotti et al., 2006)

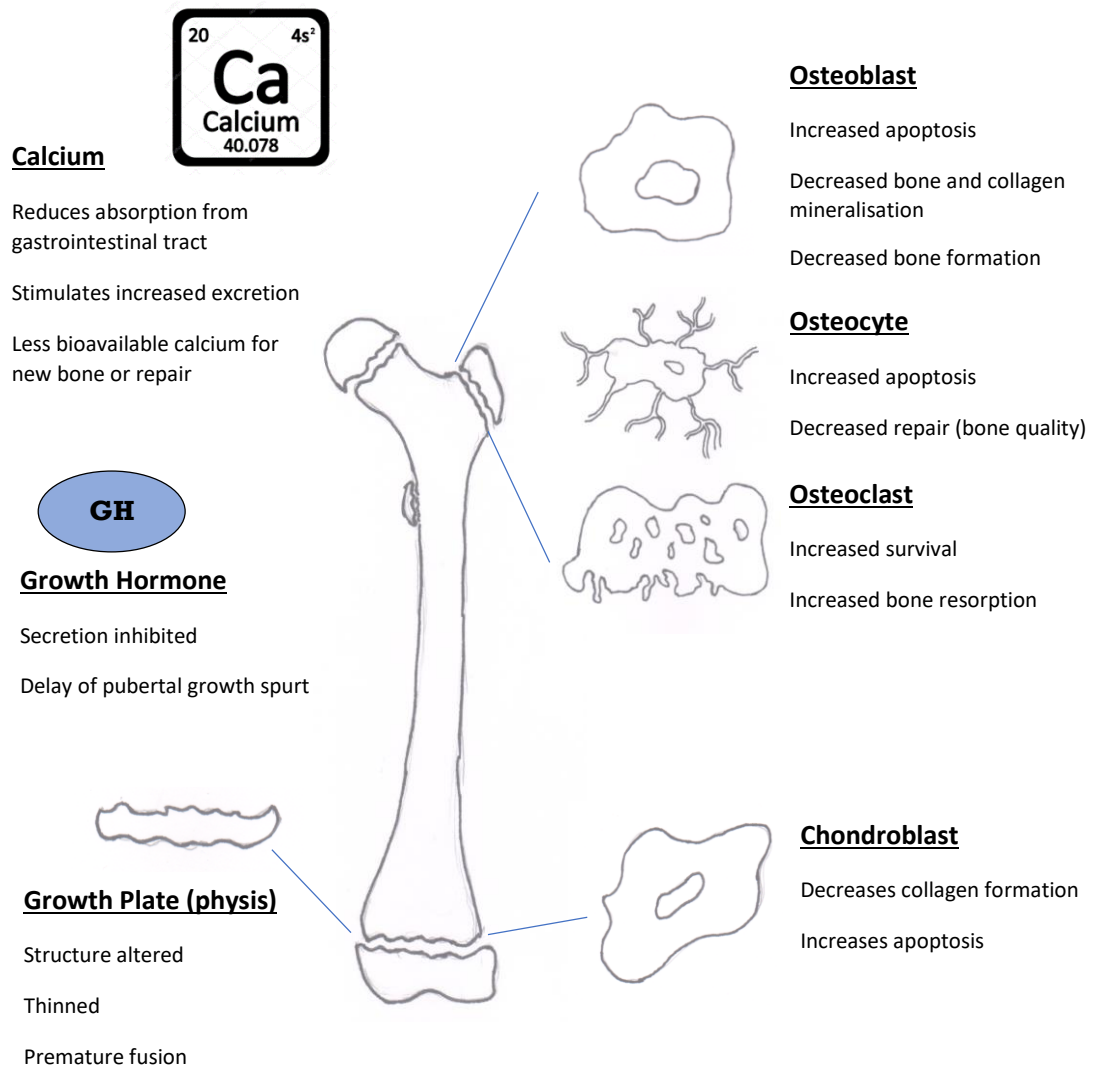


Fig. 2 Effects of hypercortisolism on growth

3.3. Dental enamel hypoplasia

Dental enamel hypoplasia (DEH) are defects that form in enamel during the development of a tooth as a result of genetic, traumatic or systemic insults to health (illness, nutritional deficiencies or deprivation) (Fig. 3) (Goodman and Rose, 1990; Hillson, 2014). Although psychosocial and environmental stressors are known to result in DEH formation in children (Kelly et al., 2012; Rodney and Mulligan, 2014), hypercortisolism has not been explored as a direct causative mechanism in DEH formation in the same way as in growth suppression. A handful of studies have found evidence linking increased prevalence of DEH with administration of corticosteroid therapies (Bublitz et al., 1981; Guergolette et al., 2009; Mastora et al., 2017; Wogelius et al., 2010) and increased cortisol

reactivity has also been associated with thinner and softer enamel (Boyce et al., 2010). In these cases, it has been suggested that hypercortisolism could be affecting ameloblasts in a similar fashion to osteoblasts, by reducing their formation and activity (Pawlicki et al., 1992). Further research would be necessary to explore this direct relationship between DEH formation and dysregulated cortisol concentrations (Mastora et al., 2017). Hypercortisolism could underlie and/or exacerbate other factors contributing to DEH formation, such as increased risk of infection from a suppressed immune system and decreased levels of circulating calcium (Ajlan, 2015; Kinoshita et al., 2008; Mahgoub et al., 1997). Development of DEH has been correlated with hypocalcaemia (lower-than-average levels of blood plasma calcium) during tooth formation, particularly in individuals suffering from rickets (vitamin D deficiency) (Foster et al., 2014; Kinoshita et al., 2008; Klaus, 2020; Mazziotti et al., 2006; Nikiforuk and Fraser, 1979). Vitamin D, parathyroid hormone and cortisol all affect calcium homeostasis, and it may be that GCs only act as a significant factor in hypocalcaemia in individuals whose calcium homeostasis is already compromised through rickets or other conditions (Kinoshita et al., 2008; Mazziotti et al., 2006; Nikiforuk and Fraser, 1979). Although beyond the scope of this analysis, the relationship between rickets, DEH and cortisol levels could be an interesting avenue of future research.

As one of the most commonly assessed non-specific stress indicators within palaeopathology, correlations between dental cortisol concentrations and increased DEH frequency would be informative on several levels. However, preliminary data do not show a clear pattern between dentine or enamel cortisol concentrations and presence or absence of DEH (Fig. 4). There are individuals with and without dental defects that display high and low cortisol concentrations. Interestingly, the two individuals with markedly high enamel cortisol concentrations both have DEH on several teeth. These data are far from conclusive but could suggest a concurrence between biochemical and macroscopic indicators of stress in extreme cases. However, other individuals within this analysis displayed DEH, but had similar enamel and dentine cortisol concentrations to those without DEH. This could reflect differences in the timing of stress events. Like DEH, cortisol concentrations (from enamel in particular) are thought to reflect cortisol exposure during mineralisation. If the period of development of the tooth selected for cortisol analysis did not overlap with the stress event or conditions that resulted in DEH formation, the enamel defect and cortisol level may reflect 'stress' from different times, when conditions could have been dissimilar. It has also been suggested that the minimum threshold for DEH development differs based on ameloblast and rate of enamel deposition, where anterior teeth are more sensitive than posterior teeth (Goodman and Rose, 1990; Wright, 1997). A study of defect formation timing in conjunction

with cortisol concentration could help to explore this explanation of the data. Additional studies and data could clarify relationships between DEH formation and ‘extreme’ cortisol concentrations.

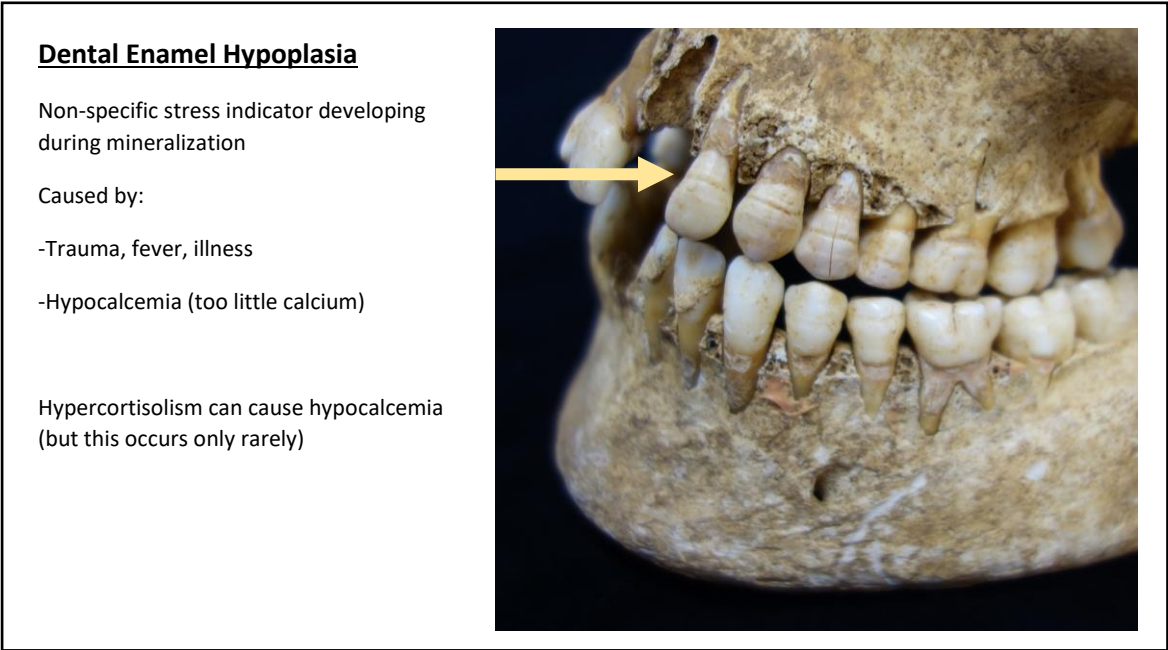


Fig. 3 Summary of Dental Enamel Hypoplasia

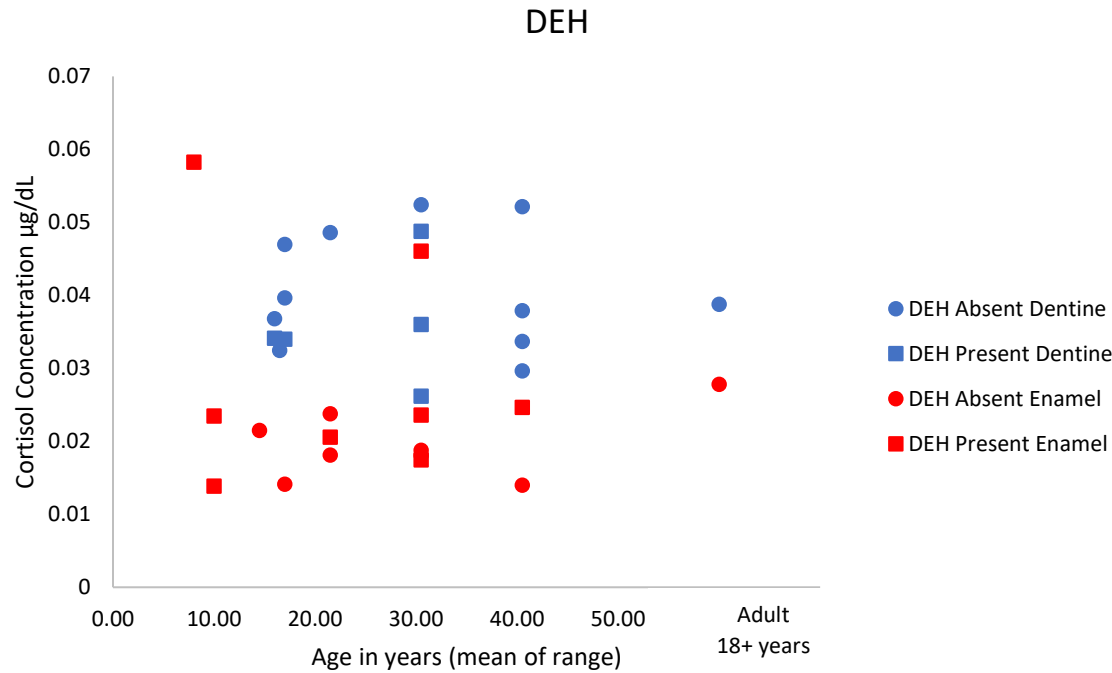


Fig. 4 Enamel and dentine cortisol concentrations and dental enamel hypoplasia

3.4. Metabolic conditions

Cortisol is primarily a metabolic mediator, with regulatory actions on blood glucose levels, transport and food disposal. Blood glucose levels must be maintained so that there is adequate energy for brain function and also should be able to increase rapidly, in the case of sudden energetic needs (Sapolsky et al., 2000). To confront or escape a threat, cortisol increases the amount of circulating glucose (energy) by initiating gluconeogenesis (the conversion of amino acids from proteins in bone and muscle tissues into carbohydrates), proteolysis and lipolysis (Dallman and Hellhammer, 2011; Dickerson and Kemeny, 2004; Sapolsky et al., 2000). In cases of overexposure to cortisol, these actions can lead to an overproduction of glucose, to the detriment of several systems. Although glucocorticoids initially increase muscle ability to perform work, in larger concentrations or over time, overactivation of gluconeogenesis can lead to muscle weakness and even atrophy (McKay and Cidlowski, 2003). Lipid metabolism is also affected, causing a redistribution of fat from the appendages to the torso and face, contributing to distal limb weakness (Fraser et al., 2010; McKay and Cidlowski, 2003). Within the blood, hypercortisolism can result in hypertension and a 'diabetic-like state' because of the increased blood glucose (McKay and Cidlowski, 2003). Indicators of metabolic disorders in palaeopathology have naturally been restricted to those detectable within the skeleton, including scurvy, rickets, osteoporosis, Paget's disease, porotic hyperostosis and cribra orbitalia (Brickley, 2018; Brickley et al., 2020; Crandall and Klaus, 2014; Klaus, 2020; Kozłowski and Witas, 2012). As with DEH (also considered a metabolic disruption), there is no known correlation between cortisol dysregulation and specific metabolic conditions commonly considered in palaeopathology. As previously stated, it may be that cortisol's immunosuppressive effects merely contribute to overall susceptibility to pathogens that can result in the development of these lesions.

3.4.1. Cribra orbitalia

Cribra orbitalia (CO) is an interesting metabolic stress indicator to consider in relation to cortisol, given its prevalent usage within palaeopathology and controversial aetiology (McIlvaine, 2015; Oxenham and Cavill, 2010; Stuart-Macadam, 1991; Walker et al., 2009). CO manifests as a thinning of the outer table and expansion of the diploë in the orbits, in the effort to expand hematopoietic marrow surface area and produce more red blood cells (RBC) (Fig. 5). CO has an important relationship with diet, disease load, several forms of anaemia (iron deficiency, haemolytic and megaloblastic) and specific pathological conditions including thalassaemia, rickets, scurvy and

malaria (Gowland and Western, 2012; McIlvaine, 2015; Oxenham and Cavill, 2010; Piperata et al., 2014; Walker et al., 2009). Regardless of specific aetiology, when RBC production is insufficient or deficient, the hormone erythropoietin is secreted, stimulating increased RBC production (erythropoiesis). When erythropoietin production is sustained over a period of time, then hematopoietic marrow hypertrophy and CO can develop (Stockmann and Fandrey, 2006). When GC levels are dysregulated, erythropoiesis is affected with potential implications for CO (Ganguli et al., 2002). Although the influence of cortisol on erythropoietin is unclear, elevated glucocorticoid levels increase red blood cell production through the enhancement of erythroid progenitor proliferation and can affect erythropoietin receptors (Ganguli et al., 2002; Kelly et al., 2000; Klein et al., 2011; Voorhees et al., 2013). Cushing's Syndrome (excessive GCs) has been associated with increased levels of red blood cells, haemoglobin and haematocrit (Bauer et al., 1999; Ganguli et al., 2002). GCs become particularly important to erythropoiesis under stressful conditions such as hypoxia, blood loss or severe anaemia (Ganguli et al., 2002; Sjögren et al., 2015). Interestingly, certain types of Addison's disease (insufficient GC production) can cause anaemia (Bauer et al., 1999; Ganguli et al., 2002), which should then stimulate 'stressed' erythropoiesis.

The relationship between cortisol levels, erythropoiesis and anaemia as a potential aetiology for CO is clearly complex. Glucocorticoids have functions that can be causative, modulatory and restorative to anaemic states. Although low GC levels as in Addison's Disease can result in anaemia, which can lead to CO, a high prevalence of stressors and therefore high GC levels can also result in CO, as there is a continued demand for red blood cells. However, there is an additional factor to consider; glucocorticoid receptors (GR). In the continued presence of excessive GC, GR stops 'accepting' the signal and downregulate the influence of stressors, thus protecting the body (Sapolsky et al., 2000). As such, a straightforward relationship between dental cortisol concentrations and CO is unlikely and will require caution in interpretation. Only one individual within the preliminary data had CO and detectable cortisol concentrations (Fig. 6). This individual died in adolescence and had cortisol concentrations on the lower end of what was detectable from dentine. This could indicate a low cortisol/anaemia interaction, but the small sample size precludes any real interpretation. As before, the synergistic relationship between GCs, immunosuppression, erythropoiesis, infectious agents and nutrition in relation to CO needs to be considered in future studies.

Metabolic Effects of Cortisol

Increases blood glucose levels through:

- gluconeogenesis
- proteolysis
- lipolysis

Facilitates erythropoiesis during 'stress' (blood loss or anemia)

Cribra orbitalia?

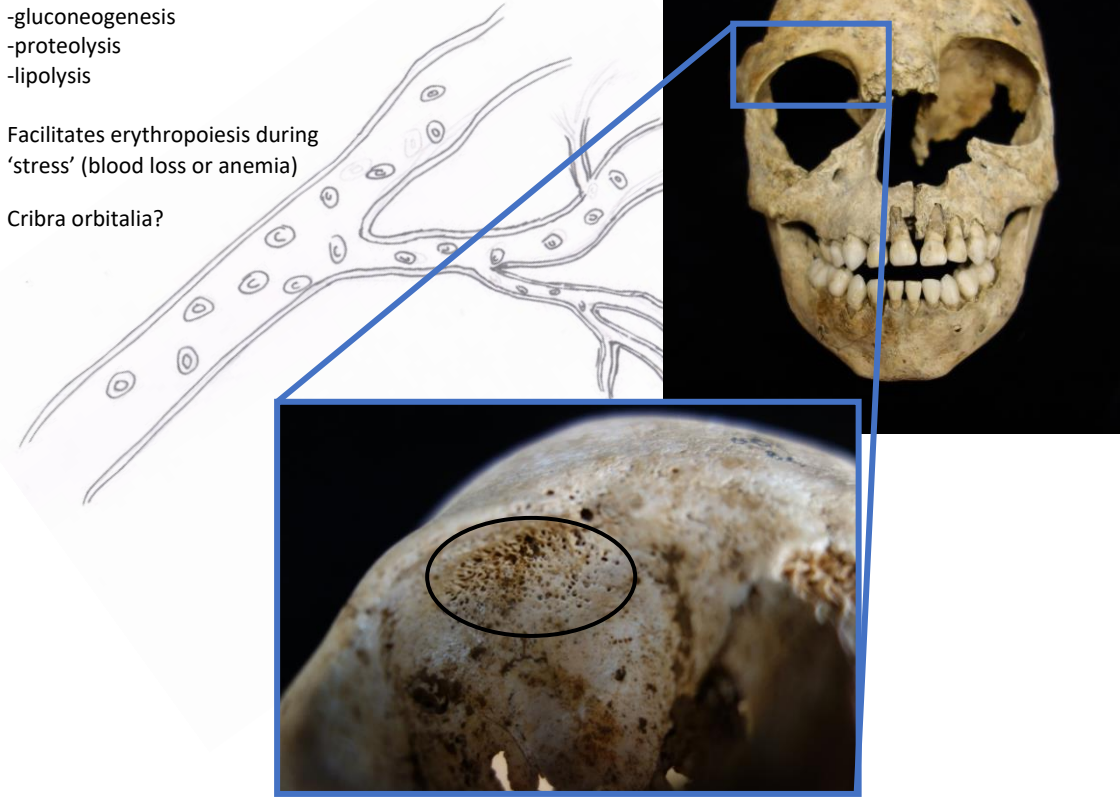


Fig. 5 Summary of the effects of hypercortisolism on metabolism

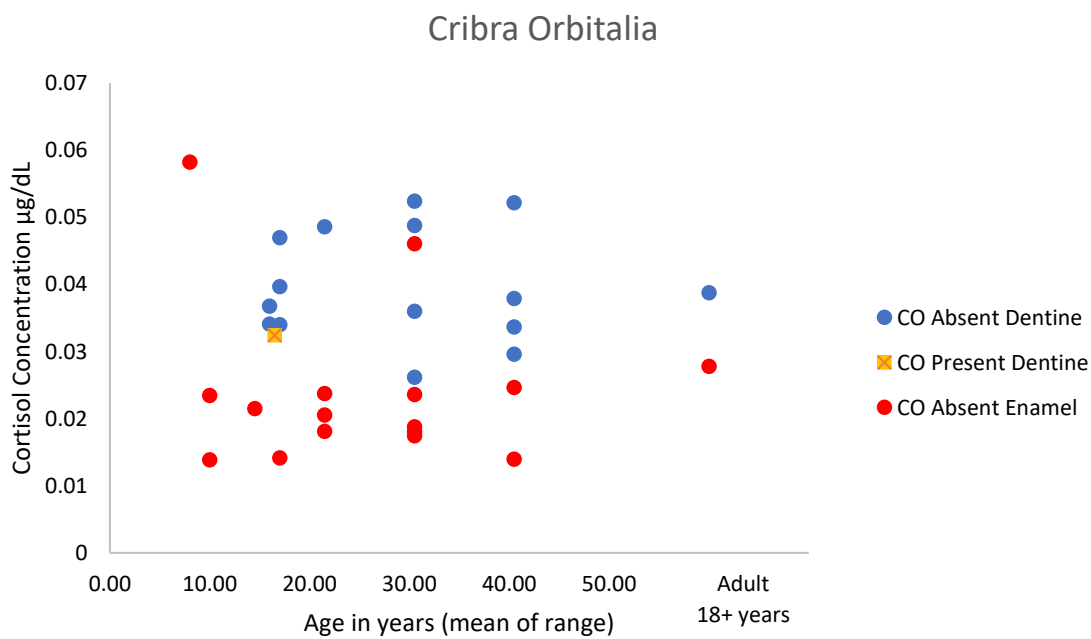


Fig. 6 Enamel and dentine cortisol concentrations and cribra orbitalia

3.5. New bone formation

Periosteal new bone formation (NBF) is a form of healing in response to local trauma to the periosteum as a result of infection, inflammation, or trauma (Fig. 7) (Ortner, 2003; Ragsdale et al., 1981; Weston, 2009). Despite recommendations against it (Weston, 2011), periosteal NBF is often utilised as a non-specific marker of physiological stress, specifically when present on the tibiae (DeWitte, 2014; DeWitte et al., 2016; DeWitte and Wood, 2008; Klaus, 2014). The tibia is the least vascularised and least shielded by soft tissues, making it sensitive and predisposed to form these lesions (Larsen, 1997). Cortisol has been discussed within palaeopathology in relation to periosteal reactions of the tibiae (Klaus, 2014; Weston, 2011). Although glucocorticoids suppress bone growth in response to stressors (Weston, 2011), Klaus (2014) argued that not only can periosteal NBF occur while an organism is stressed, but that periosteal NBF is a 'component of stressor-derived inflammation' (p. 298). Inflammation is a response to injury or infection, where cells of the immune system that are distributed throughout the body are transported to the site of infection/inflammation by increasing blood supply to the infected area through vasodilation and capillary permeability (Chrousos, 2000). Cortisol is well known for its anti-inflammatory actions, preventing migration of inflammatory cells to injury sites, inhibiting lymphocyte, neutrophil and monocyte production and affecting cytokine expression and release (upregulates anti-inflammatory and downregulates pro-inflammatory) (Elenkov and Chrousos, 1999; Janicki-Deverts et al., 2016). However, on a local level, stress can exert both pro and anti-inflammatory effects, as influenced by the tissue being affected and the type and presence of antigens or their receptors (Chrousos, 2000). Inflammation itself can activate the HPA axis and the effect of GR and GR resistance may be important in this interaction (Chrousos, 2000).

Because NBF of the tibiae is commonly used as a frailty and skeletal stress indicator, a relationship between dental cortisol concentrations and periosteal NBF could be informative about frailty across the life course. In enamel, the time of cortisol incorporation would, in most cases, be offset from time of development of NBF. In this way, if an individual demonstrated dysregulated cortisol levels during childhood (development of the tooth) and periosteal reaction of the tibiae later in life, a more constant experience of high frailty or the impacts of early childhood stressors on later health outcomes might be interpreted. Preliminary data seem to suggest that (with one exception) periosteal reaction of the tibiae is found more consistently in individuals with cortisol concentrations on the lower end for their respective tissue (Fig. 8). Although this could be an artefact of small sample size and requires further investigation, it could be that individuals with higher cortisol concentrations are in fact reflecting anti-inflammatory effects.

produced by oral bacteria (Fig. 9). These lesions have been associated with diets high in carbohydrates and sugars (Larsen, 1997), as well as poor hygiene practices and fluctuations or differences in hormones (Hillson, 1996; Lukacs and Largaespada, 2006). In modern populations, increased caries prevalence has been associated with hypercortisolism (Boyce et al., 2010; Caruso et al., 2018; Pani et al., 2013), although results are not always consistent (Kambalimath et al., 2010). As an infectious lesion, the immunosuppressive actions of cortisol could facilitate the spread of carious lesions (Boyce et al., 2010; Rohnbogner and Lewis, 2016). However, the convergence of low socio-economic status, heightened cortisol levels and frequency of carious lesions may ultimately be more related to behaviours surrounding stress, diet and hygiene, than cortisol concentration itself (Boyce et al., 2010; Pani et al., 2013). Within adult populations, corticosteroid treatments have resulted in increased plaque formation and a reduced salivary flow rate, both of which contribute to increased caries formation (Barbosa et al., 2012). Cortisol has also been shown to encourage the growth rate of periodontal bacteria (*P. gingivalis*) in a dose dependent manner in in vitro experimentation (Akcali et al., 2014). In both dentine and enamel, most individuals with higher cortisol concentrations had one or more carious lesions (Fig. 10). However, there are multiple individuals with low cortisol concentrations that also have carious lesions. Although this analysis has a larger number of individuals to assess, there is no clear pattern. It would be interesting to investigate cortisol data alongside dietary isotopic and caries data to identify possible correlations between stress, diet and negative health outcomes in the past.



Fig. 9 Carious lesions

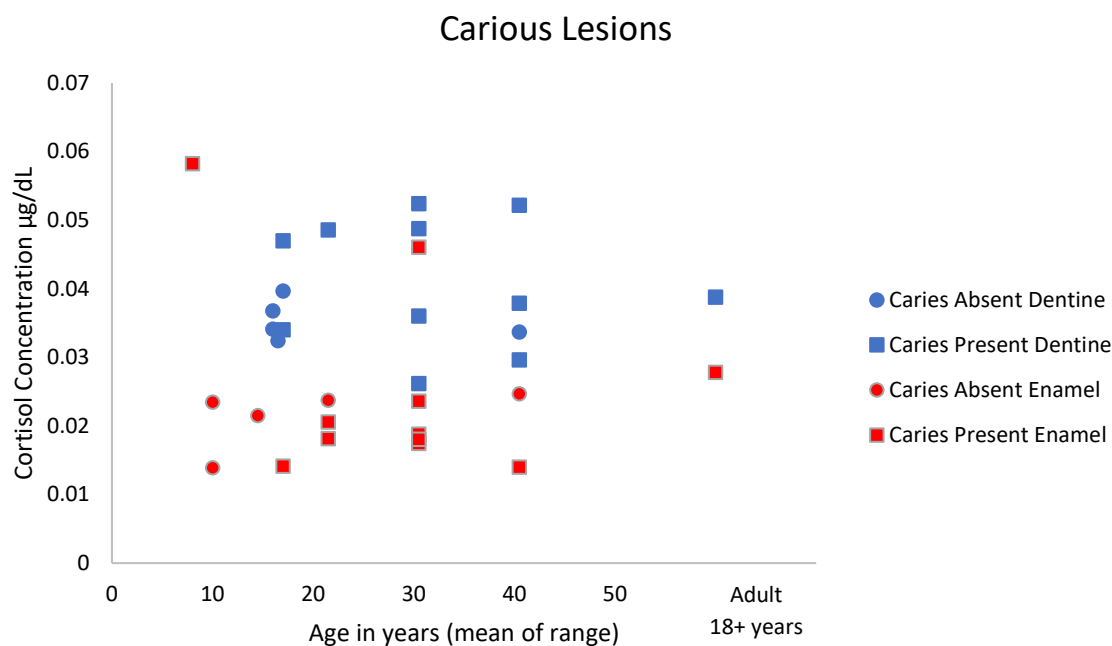


Fig. 10 Enamel and dentine cortisol concentrations and carious lesions

4. Implications

This review of cortisol in relation to commonly examined skeletal stress indicators highlights the complexity of mechanisms of stress and health. Instead of aligning with macroscopic skeletal stress indicators, preliminary cortisol concentrations did not follow observable patterns. Although further research is necessary as sample sizes were small, it is possible to consider how cortisol could act as a frailty indicator and potential reasons why cortisol levels may not align with skeletal stress indicators.

4.1. Frailty Indicator?

Identifying hidden heterogeneity in frailty as highlighted in the osteological paradox (Wood et al., 1992), has proven challenging to incorporate and implement in investigations of stress experience in the past (DeWitte and Hughes-Morey, 2012; Marklein et al., 2016; Piperata et al., 2014; Wilson, 2014). In modern populations, a relationship between elevated levels of cortisol, increased frailty, morbidity and mortality has been identified in infants (Aucott et al., 2008) and in older individuals (Baylis et al., 2013; Holanda et al., 2012; Varadhan et al., 2008). It has been suggested that disrupted HPA (and thereby cortisol) activity could be the ‘underlying pathophysiology of frailty’,

whereby blunted cortisol reactivity contributes to how an individual eventually becomes 'frail' (Johar et al., 2014, p. 467). Accordingly, it was hypothesized that cortisol levels might provide information about differential degrees of risk for negative health outcomes, or frailty. However, preliminary results did not reveal clear relationships between cortisol concentration, mortality, or frequency of DEH, CO, NBF or carious lesions. Two individuals with enamel cortisol concentrations notably higher than the rest (two standard deviations above the mean) did display DEH, suggesting a concurrence in extreme cortisol values and DEH. This finding demonstrates that additional data and further research may reveal greater clarity in relationships between skeletal stress indicators and cortisol concentrations. The general lack of a relationship between the obtained cortisol values and skeletal indicators of stress in this study remains difficult to interpret and may ultimately reflect the limitations of small sample sizes. Clearly, cortisol has many and varied roles within the body, and its relationship with skeletal manifestations of stress is complex, requiring more data and research. Further testing of the cortisol method and a more solid understanding of uptake mechanisms, especially regarding the timing and duration of uptake, are also required.

4.2. Other factors in the stress response

Further complicating the interpretation of the results of this study, cortisol concentrations alone are not the only determinants of the body's response to stress. Cortisol has complex relationships with other structures, hormones, proteins and genetics. These interactions can make it challenging to identify the direct effects of cortisol on the body, even within modern populations (Pedersen et al., 2011). For stressors to have a biological impact, cortisol must be 'received' into the bodily structures to enact changes or responses. It does this by connecting with glucocorticoid receptors (NR3C1), located in almost every bodily tissue (Donatti et al., 2011). Glucocorticoid receptor concentration, variety and sensitivity, therefore, have a large impact on quantities of circulating free cortisol and an individual's biological stress response (Cohen et al., 2012; Oakley and Cidlowski, 2013). Sensitivity and response to glucocorticoids can be highly variable on cellular, tissue and individual levels and can even change within the same tissue over time (Oakley and Cidlowski, 2013). Some cases of pathological degrees of hypo or hypersensitivity to glucocorticoids can stem from glucocorticoid receptor variation and alterations (Oakley and Cidlowski, 2013). Further, glucocorticoids can affect their own receptors' ability to translate hormone signals by downregulating receptor sensitivity, protecting the body from heightened cortisol concentrations (glucocorticoid resistance) (Donatti et al., 2011). In some cases, this glucocorticoid resistance can

result in an underproduction of cortisol (hypocortisolism) (Fries et al., 2005; Gustafsson et al., 2010).

There is great variability in the stress response, which can be mediated or exaggerated by social support networks and personality type (Avitsur et al., 2009). Many situations that are stressful for some individuals (or other animals) are not perceived as stressful for others (Dallman and Hellhammer, 2011; Dickerson and Kemeny, 2004). As a result, there is variation in when, how and for how long a biological stress response is activated, impacting on larger studies of stress. It will therefore be important to examine trends and individuals in analysis of cortisol concentrations, so that individuals at the extremes are not biasing or misrepresenting larger samples. Clinical studies have also suggested that beyond the immunosuppressive actions of cortisol, stress promotes increased risk of infection through behavioural changes (increased drinking, smoking, risk-taking) (Pedersen et al., 2011). These types of actions are largely invisible archaeologically, but remain important components of frailty, morbidity and mortality risk. Illnesses themselves, including bacterial or viral infections can elicit the biological stress response, activating the HPA axis (Jessop et al., 2004). Even if pathogen exposure or infection does not always result in illness, higher frequencies of exposure can tax and exhaust energetic resources and stress response pathways, with adverse consequences on long-term health (Tanner, 2014). In this way, cortisol concentrations are more responsive stress indicators than most skeletal lesions. Although this has the advantage of being more sensitive, it comes with the disadvantage of responding to different types of stimuli, many of which can be difficult to disentangle and interpret.

In addition to the skeletal stress markers reviewed in this research, chronic exposure to glucocorticoids can have other important effects on the body and behaviour. GCs play a crucial role in learning and memory. Under stress, higher levels of glucocorticoids disrupt synaptic plasticity and can disrupt memory formation in as little as a few days (Sapolsky et al., 2000). Over time, chronic exposure to glucocorticoids can result in hippocampus atrophy and neuron loss, which has significant implications for the effect of chronic exposure to stressors on cognitive abilities (Sapolsky et al., 2000). Exposure to high levels of GCs has also been associated with depression and psychosis (Chrousos, 2000; Dickerson and Kemeny, 2004; McKay and Cidlowski, 2003). Other effects of a chronically activated stress response include peptic ulcers, diseases of the eye muscles, cardiovascular disease and infertility (Charmandari et al., 2005; Sharpley et al., 2012). Wound healing is slowed because high levels of cortisol prevent the proper breakdown of collagen (an inflammatory action) and prevention of fibroblast proliferation. This creates further opportunities

for infectious agents to take hold. In adults, excessive exposure to glucocorticoids can result in osteoporosis and osteopenia, resulting in higher rates of fractures in bones with high trabecular content (ex. ribs, spine) (Cruess, 1983; Fraser et al., 2010; Mazziotti et al., 2006). Recently, variation throughout the life course, differences between the sexes and epigenetic effects in glucocorticoid production and response have also been explored (Rodney and Mulligan, 2014; Stirrat and Reynolds, 2016; Wilson and Thayer, 2017).

5. Conclusion

Cortisol, as the primary chemical messenger of the HPA axis, may play a role in the regulatory, metabolic and immunosuppressive actions that result in the manifestation of skeletal stress lesions. The relationship between cortisol, several commonly utilised skeletal stress indicators (mortality, growth disruption, DEH, CO, NBF) and carious lesions was reviewed, exploring implications for assessing frailty and stress in human skeletal remains. Preliminary examinations between obtained dental cortisol concentrations and pathological lesions did not reveal clear associations, frustrating attempts to use them as a straightforward frailty indicator or signal of early life stress. Although too early for conclusive interpretations, this research illustrates how cortisol could be functioning within the formation of skeletal stress indicators, highlighting the complexity of cortisol's many functions within the body. Because cortisol is an important and burgeoning topic in modern research, this analysis links palaeopathological research on stress, living conditions and environments in the past with modern trends and themes in clinical research. Future analyses should continue to consider how external stressors become embedded biologically and explore cortisol's potential to reveal hidden heterogeneity in frailty.

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Sex, Gender and Mortality in Roman and Late Antique Gaul

Anticipated Submission: Studies of Late Antiquity

Abstract:

Late Antiquity in Gaul (300-700 CE) is a period defined by cultural and socio-political transition. The impact of this transition on health and well-being is not yet well-understood, nor has the potential for differential effects on women and children been considered. This research examines how transitions occurring during Late Antiquity affected mortality in males and females by assessing age-at-death distributions in 13 skeletal collections (410 individuals) from Gaul dated to the Roman and Late Antique periods through Kaplan-Meier survival analysis. Results demonstrate significant differences in age-at-death distributions and survivorship over time between Roman and Late Antique burial populations, with female mortality notably affected during the latter. Female survivorship in Late Antiquity significantly decreased both in comparison to Roman females and males from both periods. Environmental shifts, trade localisation, and cultural changes in Late Antiquity could have placed new pressures on existing systems of structural inequalities, resulting in increased female mortality in early adulthood (18-35 years). This study suggests that gender-based inequities increased in Late Antiquity, resulting in greater resource restriction for women, and increased risk during reproductive years when metabolic and energetic needs would have been the greatest. Late Antique samples from southern Gaul had the largest degree of gender disparity in mortality, potentially supporting hypotheses of a more gradual transition, where female health and mortality was sacrificed to retain established cultural and social norms.

Keywords: Post-Roman, Women, Human skeletal remains, Structural inequities, Diet

Late Antiquity (300-700 CE) is a period defined by cultural and socio-political transition from the Roman Empire to Medieval Kingdoms (Brown, 1971; James, 2008). Major political, military and migration events along with changes in settlement structures, religious practices, trade networks, grave and burial rituals, all attest to significant change during Late Antiquity. Although large-scale transformations are illustrated through textual and archaeological evidence, many aspects of life during the transition remain poorly understood and hotly debated (Brown, 1971; Christie and Loseby, 1996; Durliat, 1988; Goffart, 1980; Mathisen, 2019; Pirenne, 1922; Van Dam, 1985; Ward-Perkins, 2006, 1996). Human health and well-being can be profoundly affected by cultural and socio-political transitions, where access to resources is often reoriented on the basis of new social structures. Age and gender roles are important axes along which power was re-conceived and distributed in Late Antiquity (Smith, 2009), suggesting that differential patterns in health and mortality between the sexes could be present. For example, previous research by Redfern (Redfern, 2006, 2003; Redfern and DeWitte, 2011a) demonstrated the differential effects of the Roman occupation of Britain on male and female health and mortality. The human body is affected by differential cultural practices that prioritise one sex over another, such as preferential resource allocation or care practices (Geller, 2016; Sofaer, 2006; Stone, 2020, 2016). This study examines how the Late Antique transformation impacted male and female health as indexed through mortality, considering how changing environments and cultural practices could have contributed. Further, very little is known about the lived experience of non-elite women. Therefore, analyses of skeletal data are an important and potentially more representative dataset for investigation than literary sources.

1. Late Antique Transformation in Gaul

Historical, archaeological and mortuary sources demonstrate shifts in political, social and cultural structures in Late Antique Gaul (modern-day France, Belgium, parts of Italy and Germany). Gaul had been an important part of the Roman Empire from as early as the late 2nd century BCE (Woolf, 1998). After weathering the military, financial and political crisis of the 3rd century, Gaul re-emerged as an integral part of a recovering and prospering Roman Empire in the early 4th century (Wickham, 2005). However, by the late 4th century, military defeats, civil wars and usurpations quickly undermined Roman political control and authority (Sarti, 2013). In the 5th century, migrations of 'barbarians' crossed the Rhine frontier, most notably in 406-7, complicating an already tenuous Roman hold on authority (Wickham, 2005; Wood, 1997). Power struggles between

Rome and the various barbarian kingdoms (within and between) resulted in increased violence throughout the 5th and 6th centuries (Sarti, 2013). Systems of long-distance trade that had been established in the early empire were disrupted and ultimately greatly retracted in Late Antiquity (Humphries, 2009; McCormick, 2001; Ward-Perkins, 2006). The 'Roman climate optimum', which purportedly generated advantageous conditions for agriculture, shifted to the Late Antique Little Ice Age. This was characterised by a period of pronounced cooling in the 6th and 7th centuries, following the extreme weather events of 535–536 (Büntgen et al., 2017, 2016; Büntgen and Hellmann, 2013; Harper, 2017, 2016; Helama et al., 2017, 2017), although see Haldon and colleagues (2018a, 2018b, 2018c). The reduced trade network, less favourable agricultural conditions, and the spread of Justinianic plague (*Yersinia pestis*) are thought to have substantially impacted the population, leading to pronounced population declines throughout the 5th and 6th centuries (Bitel, 2002; Feldman et al., 2016; Harper, 2017; Laes and Vuolanto, 2016). Gallo-Roman structures and practices changed, demonstrating increasing regional variability and the shifting needs of smaller communities, resulting in a tangible shift in culture (Christie and Loseby, 1996; Ward-Perkins, 1996). Urban areas contracted in size, traditional Roman construction methods and layouts were abandoned, and new defensive walls were built (Harrison, 2008; Sarti, 2013). Many villas or large rural estates appear to have been abandoned or were used in different ways through a reduced form of occupation and agricultural production (Theuvs, 2009; Van Ossel, 1992). Systems of production (metalwork, ceramics, tile-making, stone quarrying), communication and trade deteriorated across the western Roman Empire, reorienting what had been a large imperial network back to more local forms of production and politics (Härke, 2001; Mathisen, 1992; Uhalde, 2001; Ward-Perkins, 1996; Wickham, 2005; Wilkinson, 2015; Yoon, 2016). Whether this transition was a catastrophic collapse, or a more gradual transformation, involving the reorientation and evolution of existing structures has been debated (Brown, 1971; Cameron, 1998; James, 2008; Liebeschuetz, 2001). Transformation during Late Antiquity was complex, comprising many diverse factors with considerable regional variability across the Western Roman Empire.

1.1 Northern and Southern Gaul

Transformation in Gaul largely follows a geographic divide, where territories north of the Loire River experienced a more rapid and earlier transition than in southern, Mediterranean Gaul. Northern Gaul, as a frontier region, was always less wealthy than southern Gaul, and therefore elites were more dependent upon Roman patronage and government involvement to retain and

reproduce Roman social structures, hierarchies and cultural value systems (Halsall, 2005, 2004). As a result, the deteriorating influence (or rapid retreat) of Roman control and investment had a more profound impact in northern Gaul, and the region is often compared with Britain in terms of political and economic reduction and fragmentation during Late Antiquity (Halsall, 2007, 2004; Ward-Perkins, 1996). Many cities of this period within northern Gaul show evidence of defensive re-structuring, contraction and abandonment, although this was not universal (notable exceptions - Paris, Cologne) (Halsall, 2007; Wickham, 2005). Burial rituals also changed dramatically in the northeast of Gaul beginning in the late 4th century, with graves dug in regular rows (Reihengräberfeld) and with greater and more varied selections of grave goods than Gallo-Roman customs (Böhme, 1974; Effros, 2003; Halsall, 1992; James, 1979; Werner, 1950).

Southern Gaul remained more directly connected with established Gallo-Roman pathways, through greater continuity of Gallo-Roman funerary practices, maintenance of fine, skilled art and craftsmanship (sculptures and mosaics), and continued trade with the Mediterranean and other regions (Greece, Turkey, Egypt, Palestine) until the 6th and 7th centuries (Bonifay et al., 1998; Démians d'Archimbaud, 1994; Laes and Vuolanto, 2016; Wickham, 2005). Throughout southern Gaul, cities remained centres for cultural and economic activity, with Arles, Marseille and Bordeaux providing evidence of a flourishing political and cultural life during the 5th century (Drinkwater and Elton, 2002; Laes and Vuolanto, 2016; Sivan, 1992; Yoon, 2016). Not only was southern Gaul closer in geographic proximity to sources of Roman power, but established systems and elites were in a better position to absorb new influences and threats to Roman authority and cultural pathways. Elites from southern Gaul were wealthier, with greater security and resources that were not reliant on Roman imperial patronage or position (Halsall, 2007, 2004). Although seemingly more gradual than northern Gaul, wealth and displays of power and prestige in southern Gaul nonetheless declined from the 4th to the 5th centuries (Harries, 1994; Wilkinson, 2015). From as early as the 410s, Roman authority was challenged in southern Gaul, with Aquitaine under Visigothic control, and other southern territories controlled by the Alans and Burgundians (Laes and Vuolanto, 2016). In the early 6th century, the Franks (Merovingians) annexed southern Gaul, consolidating control of the entirety of Gaul until 751 (Laes and Vuolanto, 2016; Yoon, 2016). In comparison with the Roman period, all of Gaul displayed markedly reduced wealth, social complexity and long-distance connectivity by 700 CE (Harries, 1994; Wilkinson, 2015). Because of the different pace and experience of transition between the two regions, northern and southern Gaul are considered separately for the purposes of comparison in this analysis.

1.2 Gender

The decline of Roman authority in Gaul meant that new power structures were needed and could be based on different or evolving conceptions of value and authority, shifting focus away from Roman political hierarchy. Gender identities can be critical within social, economic and political manoeuvring and gender was an important axis along which power was re-conceived and distributed in Late Antiquity (Halsall, 2004; Pearce, 2011; Smith, 2009). Much of Roman and Late Antique worlds were structured around correct behaviour of men and women within their gender-specific roles (Allason-Jones, 1989; Halsall, 2004; Smith, 2009). Because gender is a cultural construction of sexual difference, it is culturally and historically contingent (Gilchrist, 2012) and therefore would have been an element of socio-political and cultural transformations (Allason-Jones, 1989; Garnsey, 1999; Halsall, 2004; Smith, 2009). Gender has been previously discussed in relation to Roman and Late Antique transformation (Bitel, 2002; Clark, 1993; Dickinson, 2002; Halsall, 2004; Pearce, 2011; Redfern, 2006; Rémy and Mathieu, 2009; Smith, 2000), where gender is deeply intertwined with politics and may even have played a part in producing transformation (Halsall, 2007). Northern and southern Gaul likely differed in the need for the performance of gender identities because of differences in elite stability, power and Roman authority (Halsall, 2004; Smith, 2009). In northern regions, where power bases were more directly tied to Roman investment and government, 'new' elaborate female burial rituals and gendered grave goods appeared (Halsall, 2004, 2001). These practices are rarely evidenced in southern Gaul, suggesting that gender hierarchies may not have taken on the same social significance, were organised differently, or were not reflected in archaeologically visible mortuary display.

It has been argued that within antiquity, conceptions of gender were based on a 'one-sex' theory, where females were understood as 'lesser males' (Gilchrist, 2012; Laqueur, 1992). As such, there is an explicit and implicit hierarchy (a greater and a lesser) with implications beyond mere distribution of work and societal roles. When a society is built on *unequal* gender roles, this framework of cultural thought is pervasive throughout the society and may result in structural inequalities, or practices that disenfranchise a segment of the population through the socio-political and economic ordering of the world (Farmer, 2004; Montesanti and Thurston, 2015; Shannon et al., 2017). Thus, sex and gender become incorporated into the body as part of the lived experience, where gender inequities can manifest physically through practices of structural violence (Farmer, 2004; Geller, 2005; Gowland, 2017; Joyce, 2017; Sofaer, 2006; Wesp, 2017). Human skeletal remains can therefore come to embody aspects of gendered cultural identity and

lived experiences (Gowland, 2017; Gowland and Knüsel, 2006; Sofaer, 2006; Walrath et al., 2017; Wesp, 2017).

1.3 Health and Mortality patterns

Previous analyses have identified changes in patterns of health and mortality from Roman to Late Antique periods, where stature and skeletal stress indicators have largely suggested reduced height and health in the Roman period across the Western Roman Empire (Giannecchini and Moggi-Cecchi, 2008; Gowland and Walther, 2019; Koepke, 2016; Koepke and Baten, 2008; Roberts and Cox, 2003). Gendered differences have been observed in trauma (Gilmour et al., 2015), skeletal indicators of health stress (Redfern, 2003) and mortality (Redfern and DeWitte, 2011a, 2011b). Sex/gender differences in frailty (susceptibility to disease) and mortality can be the result of genetic (XX or XY linked diseases), biological (hormonally driven), environmental (behavioural, living conditions) or cultural differences (DeWitte, 2014; Lukacs, 2017; Redfern and DeWitte, 2011b; Walrath et al., 2017; Wood et al., 1992). Within modern populations, males outnumber females at birth (107 boys to 100 girls) but have a higher infant and child mortality than females (Stinson, 1985). Females are thought to have greater 'buffering' from environmental stressors through more effective immune response, resulting in a better capacity to withstand infectious disease and nutritional stressors (Ortner, 1998; Stinson, 1985). This greater and more effective immune response in females is likely an evolutionary adaptation to the increased risk of infection during pregnancy and childbirth (Ornter, 1999). However, some sex-based biological differences in immune response only develop after puberty, during reproductive years (Klein and Flanagan, 2016; Zuckerman and Crandall, 2019). Within most populations across the world, females tend to have longer life expectancy than males, resulting from comparatively reduced frailty or susceptibility to disease (Cabeza de Baca et al., 2016; DeWitte, 2014; Redfern and DeWitte, 2011b; Stinson, 1985). Despite genetic and biological factors in mortality, even relatively small deviations from a balance between the sexes can reflect gendered cultural practices (Bardsley, 2014; Russell, 1948). Thus, differences in mortality patterns between Roman and Late Antique periods could demonstrate the effects of Late Antique transitions on the populace, contributing new data to the narrative of Late Antique transformation.

Environmental, economic, socio-political and cultural changes occurred in tandem during the Late Antique period, complicating specific interpretations of causal relationships with respect to shifts

in health and mortality. Although environmental changes (temperature, climate), with consequences for agricultural practices, would have impacted the entirety of the population, these effects are often layered with cultural and social priorities, potentially creating an unequal or biased distribution of harm. This study investigates diachronic and geographic differences in male and female mortality between Roman and Late Antique periods to investigate how Late Antique transitions were affecting the population. If cultural priorities (and gender roles) shifted dramatically as seems to be evidenced in northern Gaul during Late Antiquity, we would expect to see a change in mortality pattern, possibly as a result of a redistribution of resources in line with new cultural values (new or different pattern of structural inequities).

2. Materials and Methods

To examine the effects of the Late Antique transition on mortality, age-at-death distributions were examined in 13 skeletal populations dated to Roman and Late Antique Gaul. Skeletal collections were grouped into ‘Gallo-Roman South’ (GRS), ‘Late Antique South’ (LAS) and ‘Late Antique North’ (LAN) for comparisons (Table 1, Fig. 1). Preservation biases prevented the inclusion of a ‘Gallo-Roman North’ group and there are notable differences in sample sizes of each group, limiting the scope of this analysis. Additionally, as has been noted for Roman Britain (Pearce, 2011), the Roman sample in this study derives from urban contexts, which undoubtedly impacts comparisons and their interpretation.

Table 1. Sites included in the present research (F=female; M=male)

Group	N	Site	Context	Date	F	M	Site Reference
Gallo-Roman South (GRS)	74	Cirque Romain, Arles	Urban	2-4 th c	16	17	(Sintès, 1989)
		Saintes, Rue Jacques Brel	Urban/ Artisan Community	1-2 nd c	14	27	(Baigl et al., 1997)
					30	44	
Late Antique South (LAS)	121	La Grande Bastide de Cadarache	Rural	4-7 th c	24	15	(Pouyé et al., 1994)
		Colombier Vaison-la-Romain	Urban	5-6 th c	29	27	(Carru, 1991)
		Les Clavelles	Rural	6-7 th c	1	2	(Boiron, 1993)
		Rues de Toulon	-	4-7 th c	5	4	(Pouget et al., 2002; Salicetti, 1998)
		Saint-Martin (La Brillane)	Rural	4-5 th c	3	3	(Boiron, 1993)
		La Granède	Rural	4-7 th c	4	6	(Saint-Pierre, 2010)
					66	55	
Late Antique North (LAN)	215	Le Clos des Cordeliers	Rural	5-6 th c	16	11	(Castex, 2008; Guignier, 1997)
		St Martin de Fontenay	Rural	4-7 th c	61	36	(Pilet et al., 1994)
		Fontoy	Rural	4-7 th c	37	32	(Seilly, 1995)
		Rue du Tombois	Urban	4 th c	5	11	(De Filippo et al., 2000)
		Cutry	Rural/Villa	5-7 th c	3	3	(Godot, 2014; Liéger and Cussenot, 1997)
					122	93	
Total	410				218	192	

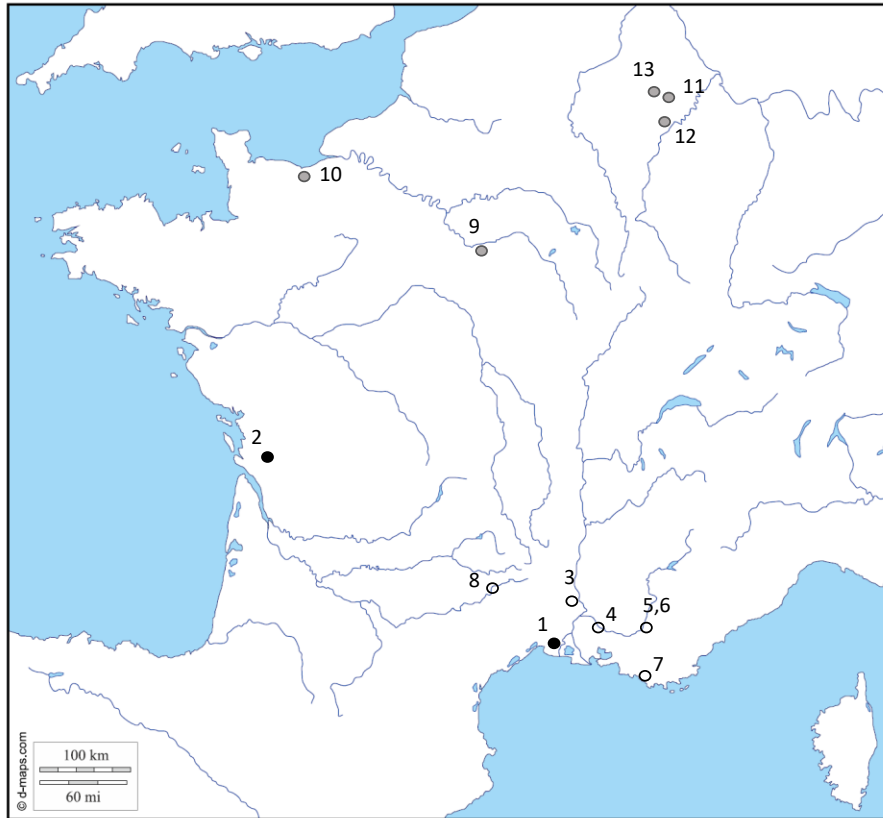


Fig. 1. Map of sites assessed in this analysis. Black dots indicate Gallo-Roman South, white dots indicate Late Antique South and gray dots indicate Late Antique North. 1= Cirque Romain, Arles, 2= Saintes, Rue Jacques Brel, 3= La Grande Bastide de Cadarache, 4= Colombier Vaison-la-Romain 5= Les Clavelles, 6= Saint-Martin (La Brillane), 7= Rues de Toulon, 8= La Granède, 9= Le Clos des Cordeliers, 10= St Martin de Fontenay, 11= Fontoy, 12= Rue du Tombois, 13= Cutry

Sex was estimated from morphological features of the skull and pelvis (Brothwell, 1981; Bruzek, 2002; Phenice, 1969). Where possible, features of the pelvis were preferentially used in assessment of sex. Age-at-death estimation was performed through analysis of degenerative changes in the auricular surface (Lovejoy et al., 1985; Schmitt et al., 2002) and pubic symphysis of the pelvis (Brooks and Suchey, 1990) and patterns of dental wear (Brothwell, 1981). Age estimates were pooled into standard age categories (18-25; 26-35; 36-45, 45+, and 20+ years) (O'connell, 2004). The mid-points of these age categories were used in survival analyses (21.5, 30.5, 40.5 years), in keeping with previous mortality studies (e.g. DeWitte et al., 2016). Forty-five was used for the 45+ age category, which likely underestimates differences in mortality (DeWitte et al., 2016). However, more detailed age estimates for older age categories remain a challenge for macroscopic analysis of age from skeletal remains (Saunders et al., 1992). Only adult individuals (18+ years) were included in this analysis, as sex cannot yet reliably be estimated from non-adult remains (Lewis, 2007, p. 13). Individuals whose age could only be estimated as 'adult' (20+ years) or for whom sex estimation was not possible or were found to be indeterminate, were not included in this analysis.

Age-at-death distributions were statistically analysed using Kruskal Wallis non-parametric tests. This test allows for the comparison of non-normally distributed data. Kaplan-Meier survival analysis with a log-rank test and using pooled data on age were used to assess potential differences in survival between the three groups as a whole and the sexes (both within and between groups). Kaplan-Meier survival analysis is used to examine differences between groups in the 'time' it takes an event to occur (Stel et al., 2011). Within this analysis, the 'event' was death and the 'time' was age.

3. Results

Adult mortality profiles are shown in Figures 2 and 3, results of Kaplan-Meier survival analysis in Table 2 and an example of a survival curve in Figure 4. Overall age-at-death distribution between Roman and Late Antique samples was significantly different ($p=0.001$). Gallo-Roman samples demonstrated higher survivorship (higher average age-at-death: mean age-at-death =38.11) than Late Antique South and North samples (34.63, 34.27) ($p= 0.001$) (Table 2). Significant differences were also found in survivorship between Gallo-Roman (38.43) and Late Antique females (32.05; 31.84) (Mantel-Cox $p=0.004$) (Table 2). In both Late Antique samples, the proportion of female mortality in early adulthood (18-35 years) is notably elevated in comparison with Roman females and young adult males (Fig. 3). Mean age-at-death was significantly different between Late Antique males and females in both northern and southern Gaul (Mantel-Cox $p= 0.002$ and 0.011). These results demonstrate significant differences in age-at-death distributions and survivorship over time between Roman and Late Antique burial populations, with female mortality notably negatively affected in Late Antiquity.

Fig. 2 Age-at-death distribution

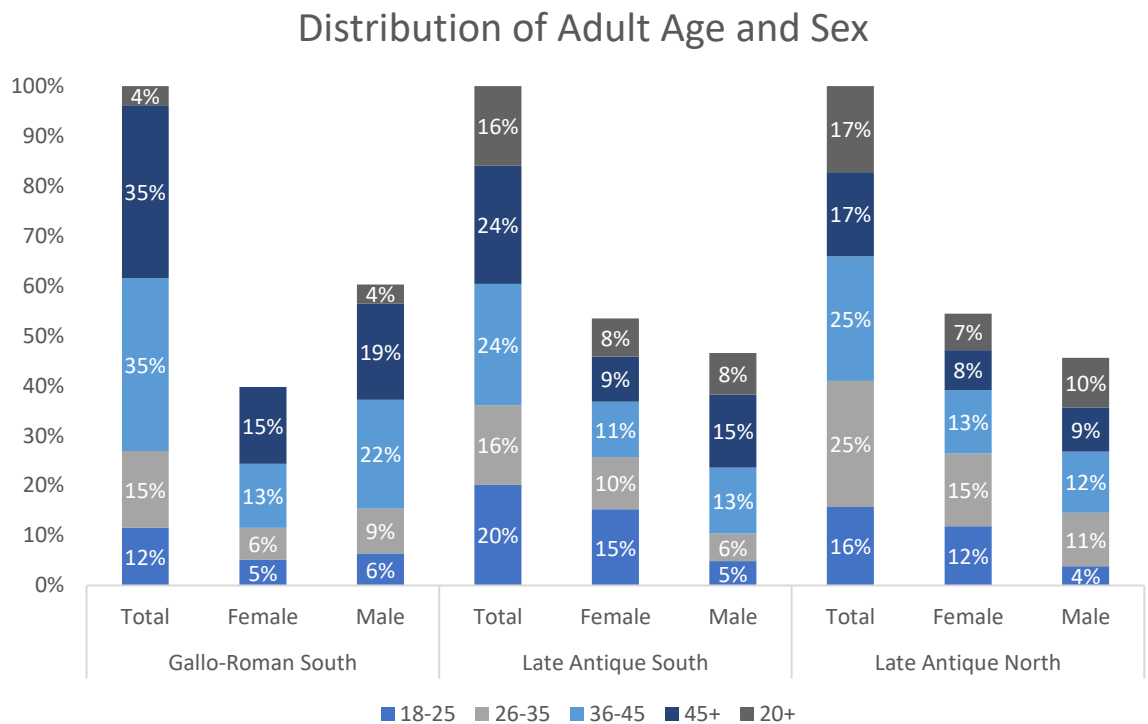


Table 2 Comparison using Kaplan-Meier Survival Analysis

	Total		Males		Female		P-Value
	Mean Age-at-death	95% CI	Mean Age-at-death	95% CI	Mean Age-at-death	95% CI	
Gallo-Roman	38.11	36.53-39.69	38.28	35.99-40.58	38.43	35.49-41.37	0.701
Late Antique South	34.63	33.20-36.06	37.95	35.72-40.18	32.05	29.73-34.37	0.002*
Late Antique North	34.27	33.27-35.27	35.51	33.78-37.24	31.84	30.18-33.49	0.011*
P-Value	0.001*		0.067		0.004*		

* Indicates significant results

Fig. 3 Proportion of burial sample comprising young adults (18-35 years)

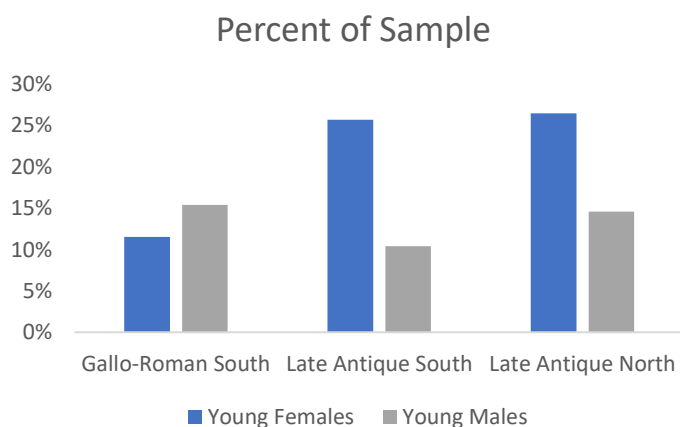
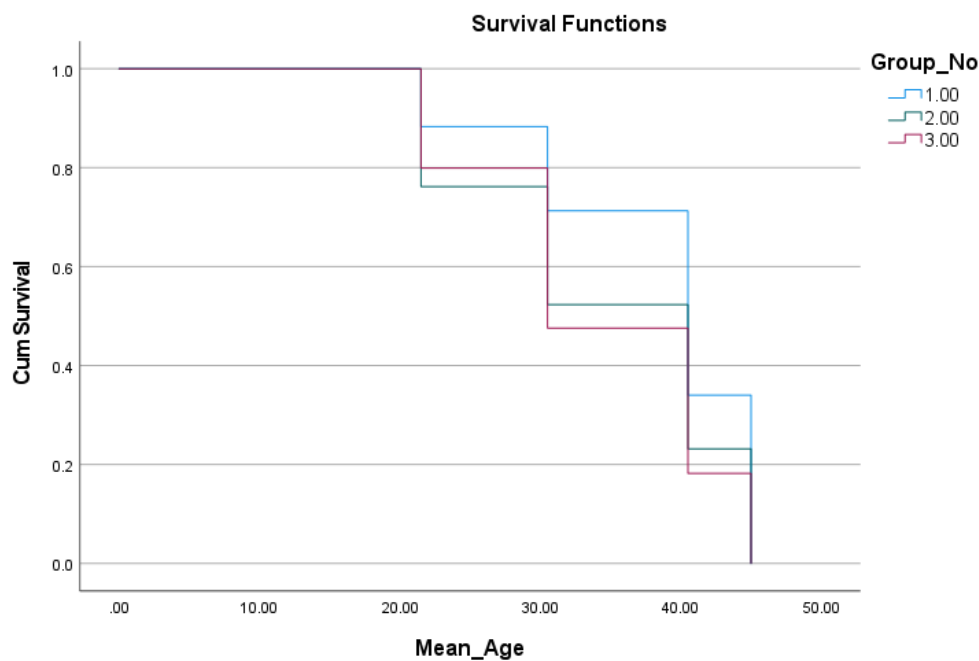


Fig 4 Example of a survival curve- Survival between groups (1= GRS, 2= LAS, 3= LAN)



4. Discussion

Age-at-death distributions and survival analysis reveal significant differences between Gallo-Roman and Late Antique samples, with a notable increase in female mortality in early adulthood (18-35 years) in Late Antiquity. In the Gallo-Roman sample, survivorship was comparatively high (mean age-at-death= 38.11) with relative equality between males (38.28) and females (38.43) ($p=0.701$). This pattern changes for both Late Antique South (34.63) and Late Antique North (34.27) samples, where overall survivorship declines and differences between the sexes become more pronounced (Table 2). These results demonstrate that transitions during Late Antiquity negatively influenced mortality, with differential impacts on males and females. Geographic region and thereby pace of transition had a comparatively small influence on male and female mortality. Instead, differences in male and female mortality patterns were more distinct between Gallo-Roman and Late Antique populations. Gender inequalities could have become more pronounced in Late Antiquity, resulting in earlier/premature female mortality. Because both shifts in cultural priorities and resource scarcity due to environmental declines or localisation of trade networks likely contributed to increased structural inequities, causal relationships cannot be determined.

However, it can still be useful to discuss these factors in relation to the patterns of mortality observed in this study.

4.1 Diachronic and Geographic Mortality Patterns

The comparatively small mortality differences between geographic regions could suggest that cultural, resource or environmental factors rooted in Roman or Late Antique living conditions are having a larger effect on mortality than the speed or severity of transition. However, a detailed look at the data reveals some notable results regarding the nature of transition as a contributing factor to survivorship. Differences between groups in male age-at-death were not significant ($p=0.067$) and LAS males show only a slight decrease in mean age-at-death (37.95 years) from Gallo-Roman estimates (38.28). This suggests that factors affecting male mortality did not greatly change and supports the hypothesis of a more continuous transition in southern Gaul during Late Antiquity. The decline in male age-at-death in northern Gaul is more severe (35.51 years) (although not significant), potentially indicating a more challenging transition experience. Interestingly, this pattern is not repeated in female mortality/survivorship. Female mean age-at-death in the Late Antique South sample (32.05) decreased dramatically from Gallo-Roman estimates (38.43). This represents a significant difference in the transition experience between LAS males and females ($p=0.002$), resulting in the largest degree of gender disparity in mortality. Although many factors, including environmental conditions, would have affected the entirety of the population, females were disproportionately affected, suggesting the additional influence of cultural or social factors. In modern societies, shifts in cultural values and/or resource scarcity (both of which are evidenced in Late Antiquity) have been shown to result in increased gender inequities and structural violence, with consequences for health and mortality (Mukherjee et al., 2011; Osmani and Sen, 2003). If transition was occurring more gradually in southern Gaul, attempts and efforts to retain Roman modes and ways of life, in addition to cultural shifts and restrictions in resource access, could have intensified societal pressures. This raises the question if male survival could have been maintained at the expense of female mortality?

In the LAN sample, although gender inequities are present, both male and female mean age-at-death decreased from Gallo-Roman estimates. Female mean age-at-death in northern Gaul (31.84) resembles values from LAS females (32.05). However, differences in mean age-at-death between males (35.51 years) and females are not as severe as in the south. This could be interpreted as a result of a more challenging or chaotic transition experience in northern regions, which prevented

the buffering of subgroups of the population. It has been hypothesized that in northern Gaul, transition marked by insecurity and competition placed increased pressure on age and gender as hierarchies to preserve or obtain power (Halsall, 2007). The emphasis on marriage in these interactions could increase status for young females as the connecting point in these important relationships (Halsall, 2007; Smith, 2009). This would seem to be reflected in the appearance of highly gendered grave goods, with emphasis on lavish female adolescent and young adult burials (Carroll, 2013; Effros, 2003; Halsall, 2004; Herlihy, 1972; Speith, 2012). (Although gender related grave goods are not always buried with their respective sex, as has been identified in Anglo-Saxon Britain – Stoodley, 1999; Lucy, 2000; 2011). The extravagant burials of adolescent and young adult women seem to stop for individuals who died after the age of 40 and decreased in general as aristocracies became more established and stable (Gowland, 2006; Halsall, 1996; Stoodley, 1999). This potentially highlights the perceived importance of young women in Late Antique society. However, these burial practices are largely absent from southern Gaul, perhaps suggesting that new power relations did not extend to this region or are not visible in the archaeological record. Burial trends could, therefore, support this interpretation of the data but it remains largely speculative.

4.2 Male Mortality

Roman society was highly patrilineal (Dixon, 2001). However, previous studies have reported negative health outcomes and mortality for males during the Roman period in Britain (Redfern and DeWitte, 2011a). Within this analysis, Gallo-Roman males and females displayed similar mean age-at-death, which was significantly higher than both Late Antique samples. This would suggest that Roman practices were not having a differential effect on the sexes, despite the supposed cultural and social advantages of being male. Late Antiquity, especially in northern Gaul was thought to be defined by militarisation, violence and political turmoil, in comparison with the Gallo-Roman period. Accordingly, concepts of men and masculinity changed and were renegotiated during Late Antiquity (Smith, 2000). Within southern Gaul, written evidence suggests that elites were aware of the social tensions between managing a Gallo-Roman lifestyle in the face of the ever-strengthening Germanic kingdoms (e.g. Sidonius Apollinaris) (Harries, 1994). Male mortality profiles in this analysis demonstrate a relative uniformity across Gallo-Roman and Late Antique periods, especially in the south. In the Gallo-Roman sample, the proportion of males who died between the ages of 18 and 35 years (15%) is remarkably consistent with both Late Antique samples (10% and 15%).

This finding would suggest that the degree of military recruitment pressure or activity between the Roman and Late Antique periods were broadly similar or resulted in similar proportions of young males in attritional cemeteries. Notably, there is a much higher proportion of older male individuals (36-45+ years) in the Gallo-Roman sample (41%) than Late Antique samples (28%, 21%). Perhaps males were struggling to survive to older ages in Late Antiquity (especially in the north) because of less effective immune responses, resulting in increased occurrence and severity of infectious disease (Ortner, 1998; Stinson, 1985). This could explain previous findings of poor male health and mortality in comparison with contemporary females (Redfern and DeWitte, 2011a, 2011b). Alternatively, it is possible that males were not returning from military or other migratory activities. Migration is an important topic in research of Gaul in Late Antiquity, as the roles of invading or migrating barbarians have been extensively debated (Goffart, 1980; Halsall, 1999; Mathisen, 2019; Périn and Kazanski, 2011; Wood, 1997). Migration impacts health and mortality through the introduction and spread of novel pathogens in local populations, and also migrants' increased vulnerability to pathogens endemic to the region (Redfern et al., 2018). Although this study does not seek to gloss over the potential importance of migration on the present results, there is insufficient evidence to discuss it adequately. Isotopic analyses could identify local and non-local individuals. As such, this type of analysis would be a particularly beneficial avenue for future research, providing a better understanding of the presence of migrants within burial communities and the influence of migration on health and mortality.

4.3 Female Mortality in Late Antiquity

The most striking finding of this study is the young female (18-35) mortality rate in Late Antiquity. Late Antique females have a lower mean age-at-death (make up a larger portion of the burial assemblages) both in comparison to Roman females and males from both periods. Despite the 'stability' in young adult male mortality, the percentage of females who died during young adulthood more than doubles in both Late Antique samples (26% and 26% from 12%) (Fig. 3). These results support archaeological and textual evidence from a range of geographic regions and similar time periods, which suggest that females who survived into adulthood, died younger than male counterparts, especially during reproductive years (Arnold, 1984; Barbiera et al., 2017; Bardsley, 2014; Bullough and Campbell, 1980; Fuller et al., 2006; Pearson, 1997; Wemple, 1985; Wilson, 2014). According to a survey from the Church of St Victor in Marseilles in the 9th century, females outnumbered males in childhood until about the age of 15, when male serfs outnumbered female

serfs and few females reached an advanced age (Guerard, 1957 cited in Bullough and Campbell, 1980). This survey included the name, rough age category, sex and marital status of individuals from approximately 128 households (Herlihy, 2009, p. 78). Ancient authors, including Aristotle (c. 384–322 BCE), Pliny the Elder (c. 23 – 79 CE) and Galen (c. 129 – 200/216 CE) commented that women did not seem to live as long as men (cited in Bullough and Campbell, 1980). However, these writers do not explain why women are dying young or what the larger cultural implications are (Pearce et al., 2000). Cultural and structural violence can underlie chronic stressors (Shannon et al., 2017; Stone, 2020) and may explain the patterns in early mortality observed in this study. Because females are thought to be more buffered from environmental stressors than males (Ortner, 1998; Stinson, 1985), these findings suggest that social or cultural factors likely contributed to patterns in mortality. Environmental, trade, and cultural changes in constructions of female social and political roles during Late Antiquity could have placed new pressures on already established systems of structural inequality, resulting in increased female mortality. This could manifest as early life adverse experience, changes in social roles, treatment or resource access that would alter vulnerability or exposure to illness or death.

4.3.1 Developmental Origins of Health and Disease

Although gender inequities existed in Roman and Late Antique societies, gender hierarchies could have become more pronounced in Late Antiquity, as reflected in greater resource restriction or treatment of females from early life, resulting in premature female mortality. The Developmental Origins of Health and Disease (DOHaD) hypothesis posits that early life adversity or events can result in negative health outcomes later in life (Barker, 2012; Barker et al., 2002). If gender inequality increased in Late Antiquity, it could have been reflected in the treatment of females from birth, potentially exposing females to greater early life risk than male counterparts, and resulting in later life history trade-offs (i.e. earlier mortality). Early life adversity includes restricted access to necessary dietary, hygiene or care resources, but discrimination or stressful living conditions have also been shown to have significant negative health consequences in later life (Anachebe, 2006; Barker, 2012; Fiscella, 2004; Ibison et al., 1996; Ronsmans and Graham, 2006). Not only does poor health or treatment in childhood affect the lifetime health of an individual, but it can also lead to difficulty in childbirth, with negative consequences for maternal mortality (dying in or around childbirth), in addition to infant health and mortality (Gilmour et al., 2015; Martorell, 1989; Scalone, 2014; Singh et al., 2015; Walrath, 2006). Poor nutrition in childhood can result in short stature and small pelvis size, also increasing the risk of complications in childbirth (Martorell,

1989; Scalone, 2014; Singh et al., 2015; Walrath, 2006) (although see Christian, 2018). Previous studies have suggested that early female mortality in Roman and Late Antique cemeteries was likely the result of differential treatment stemming from early life (Barbiera et al., 2017; Fuller et al., 2006; Molleson, 1989). For this skeletal sample, however, female femur lengths did not significantly change from Roman to Late Antique time periods (Fig. 5) (Manuscript 2). Although not conclusive, this finding does not support DOHaD hypotheses, as femoral lengths represent relative health and well-being from foetal life to approximately 20 years of age. As there is no direct evidence that the reduction in female life expectancy results from early life stressors, deleterious conditions later in the life course may be leading to premature mortality.

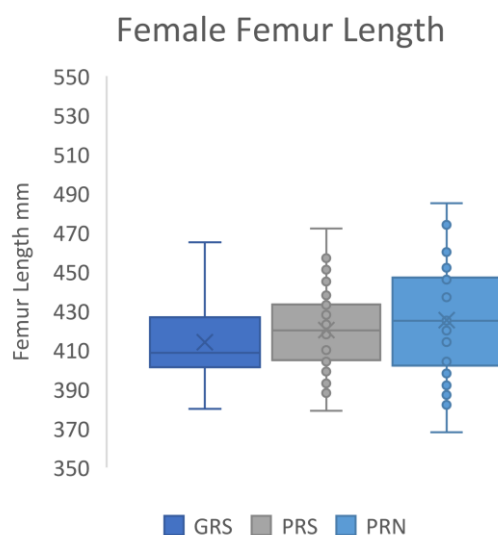


Fig. 5 Box and whisker plot of maximum femoral lengths. The line equals the median, X is the mean, the box is quartiles 2 and 3 and whiskers are the maximum and minimum values (Manuscript 2)

4.3.2 Marriage and social roles

Some scholars have argued that women's lives did not undergo significant change from 300 to 800 CE: roles continued to be centred around marriage and motherhood, and women were subordinate to fathers and husbands, irrespective of political events, changes in climate, or the rise of Christianity (Bitel, 2002; Smith, 2000). However, changes in Late Antiquity resulted in shifts in the ways families and women's roles within society were structured, in addition to expectations for marriage, inheritance of property, and changes in living standards (Alberici and Harlow, 2007; Pearce, 2011; Smith, 2000). Marriage was a foundational aspect of Roman society, where wives had important roles that contributed to the distributions of power, overall organisation and

successful running of the state (Harlow and Laurence, 2002a; Smith, 2000). Marriage acted as a contract for creating families; a foundational social unit and the 'testing ground for male authority' (Cooper, 2009; Harlow and Laurence, 2002b; Laes and Vuolanto, 2016). This arrangement meant that women acted as an important link between families, which generated them a form of power (Cooper, 2007). The degree to which marriage changed for the average person during Late Antiquity is not clear, and there is evidence of substantial continuity (Arjava, 1998; Cooper, 2007; Evans-Grubbs, 2009; Harper, 2012; Kuefler, 2007; Laes and Vuolanto, 2016). Scholars of Roman and Late Antique law have found that Roman women had a wide range and variety of legal protections and options available to them in terms of property ownership and protection in marriage relations (Arjava, 1998; Clark, 1993; Cooper, 2009; Kuefler, 2007; Smith, 2000). Roman wives were under the protection of their fathers and family (*patria potestas*), granting them sources of 'power' outside of (and potentially over) their husbands. Some suggest that the *patria potestas* was conserved throughout Late Antiquity (Arjava, 1998; Laes and Vuolanto, 2016). However, from as early as the 4th century, female dependence was shifted away from fathers to husbands, impacting women's control over and ability to inherit property (Barbiera et al., 2017; Clark, 1993; Cooper, 2007; Smith, 2000). In this way, there was a greater 'detachment' of women from their family of origin and subjugation to their husbands (Barbiera et al., 2017; Cooper, 2007). In comparison with Roman legal traditions, 'barbarian' customs and laws were preferential to men in terms of inheriting land (Smith, 2000). Marriage also changed in its larger focus on permanence, and divorce became more challenging to obtain (Cooper, 2009, 2007; Evans-Grubbs, 2009; Kuefler, 2007).

Although Late Antique women may have 'lost' some of the protections previously afforded to them under Roman regimes, the new construction of marriage also granted them a larger importance within their new families (Barbiera et al., 2017). During Late Antiquity, Christianity provided roles alternative to marriage, where men and women could live as ascetics, providing women with new routes to power (Cooper, 2009, 2007; Evans-Grubbs, 2009; Mathisen, 2008). However, asceticism was not necessarily straightforward or common, as marriage remained an important strategic tactic for families to retain or gain wealth, power and prestige. Many women were likely only able to follow asceticism after marriage and reproductive years had passed (Halsall, 2004; Jones, 2009). Christianity further altered dynamics within marriage, renegotiating the role of the traditional Roman 'domina', and women were increasingly tasked with ensuring the moral behaviour and Christian conduct for the entire household (Cooper, 2007; Smith, 2000). It would be difficult to directly relate patterns in mortality with changing conceptions of marriage and female social value

during Late Antiquity. However, social roles, within or outside of marriage reflect cultural constructions of value and power, which can influence health through access to resources or stress experience. If increased pressures on marriage or decreased support networks (in the form of patria potestas or separation from natal family) resulted in resource deprivation and/or greater stress experience, then this could result in increased frailty, or susceptibility to death.

4.3.3 Maternal mortality

One of the most prominent aspects of late adolescence and early adulthood for most women would have been motherhood. Motherhood could bring status, economic and social power to women and their families in Roman and Late Antique worlds (Garver, 2012; Gowland, 2017; Harlow, 2013). Children were a key part of the Roman family, permitting the transmission and control of property and status (Carroll, 2018). Bearing children was encouraged through legislation that incentivised freeborn couples who had three or more children (*ius trium liberorum*) (Scarfo, 2020). Although motherhood itself may not have changed in Late Antiquity, the practices and priorities of ‘social expression’ surrounding motherhood did (Smith, 2000). Within Frankish Salic law, the *wergeld* of a fertile woman was comparatively costly (600 *solidi* instead of 200 *solidi*), indicating the high value placed on young women (Garver, 2012; Halsall, 1996). Given the importance and potential dangers of childbearing, it is worth considering how practices surrounding motherhood might have changed in Late Antique communities with consequences for female mortality, especially through the lens of possible changes in cultural or structural inequities.

Although the pathologizing of pregnancy and childbirth should be avoided (Walrath, 2006; Walrath et al., 2017), childbirth was considered to be dangerous for mother and baby in both Roman and Late Antique periods, with specifically allocated gods, rituals and prayers (*Mater Matuta* and *Juno Lucina*) (Carroll, 2018, 2014, 2011; Garver, 2012; Todman, 2007). Women were likely fertile from approximately their mid- to late-teens to their 40’s or menopause (Arthur et al., 2016; Harlow and Lawrence, 2002; Pilkington, 2013). Ancient maternal mortality has been estimated at 25 maternal deaths per 1000 births (based on rural England in the 18th century), suggesting that difficulty in childbirth was a significant factor in high female early mortality rate (Harper, 2012; Todman, 2007). Age of the mother (especially the very young) and increasing number of births can render childbirth particularly perilous, especially with limited medical care or hygiene practices (Carroll, 2018). In modern society, the global lifetime risk of maternal mortality (which includes cumulative mortality

risk from complications of multiple pregnancies and childbirths) is one in 74 women, one in 16 in sub-Saharan Africa and one in six for Afghanistan and Sierra Leone (Ronsmans and Graham, 2006). Although challenging to estimate for past populations, it seems likely that Gallo-Roman and Late Antique maternal mortality would have been on the higher end. It has been suggested that fertility declined in Late Antiquity (in Italy), resulting from later age of marriage (Barbiera et al., 2017). If also true for Gaul, later marriage might have increased age at first birth and reduced the number of pregnancies and childbirths, with positive effects for maternal mortality. However, within this study there is a notably high proportion of reproductively aged females in both Late Antique samples. Following previous studies (Bardsley, 2014; Fuller et al., 2006; Garver, 2012; Hopkins, 1966; Molleson, 1989; Skinner, 1997; Todman, 2007), it is suggested that the high young female mortality rate and difference between Gallo-Roman and Late Antique female mortality cannot be explained by childbirth complications alone.

Maternal health and mortality involve a much wider framework than conditions immediately surrounding childbirth. Although most maternal deaths occur between the last trimester of pregnancy and the week after birth, women remain at an increased risk of death for approximately 6 weeks after birth (and this could be for up to a year afterwards) (Ronsmans and Graham, 2006). During this time, women are more susceptible to infections (Scalone, 2014). Countries with the highest degrees of gender inequality also show high maternal mortality (Chirowa et al., 2013; Chukuezi, 2010; Mukherjee et al., 2011; Singh et al., 2015). Significantly, disparities in maternal mortality between the developed and developing world are more extreme than child or neonatal mortality (Ronsmans and Graham, 2006), signalling the importance of this metric of societal health and equality (Stone, 2016). Problems with childbirth and delivery can be understood as a form of structural violence (Chukuezi, 2010; Morgan et al., 2017; Stone, 2016), and acts as a reflection of 'the complex interaction between reproductive biology and the cultural position of women' (Walrath, 2006, p. 70). In modern Nigeria, a society with pronounced gender inequality, women have less access to food and medical attention than men, which is then exacerbated by physical work demands and childbearing, resulting in a 'cycle of ill-health' (Chukuezi, 2010). This highlights that other factors could be combining with reproductive stressors, or repeated pregnancies, births or lactation periods to result in high mortality in young adulthood for women. Social pressures or discrimination also impact maternal mortality, as evidenced through higher rates of maternal mortality in Black and Hispanic women in the United States and immigrant women in the United Kingdom (Anachebe, 2006; Fiscella, 2004; Ibison et al., 1996; Ronsmans and Graham, 2006). The results of this study therefore suggest that structural gender inequities increased in Late Antiquity,

with greatest harm occurring during reproductive years when metabolic, energetic and medical needs would have been the greatest and risk of morbidity and mortality the highest. It is argued that stressors and gender inequities synergistically culminated to affect female mortality during reproductive years. However, it is worth reiterating that this interpretation is based on the results of the studied samples and therefore may not be representative of wider experiences in Late Antiquity.

4.4 Diet

Although the gender biased nature of Roman and Late Antique society is well established, it is not clear how this inequity was distributed in terms of resource allocation, health, stress and mortality outcomes (Allason-Jones, 1989; Fuller et al., 2006; Garnsey, 1999). Evidence of increasing gender inequality during Late Antiquity through differential access to resources and in particular during reproductive years would support the present interpretation of mortality patterns observed in this study.

Diets need to be of an adequate quantity, but also quality, including proteins, vitamins and minerals to avoid metabolic deficiencies, stunted growth, illness and death. Changes in diet from the Roman to Late Antique periods have already been evidenced and discussed, with implications for different patterns in growth and skeletal stress markers (Keenleyside et al., 2009; Koepke, 2014; Koepke and Baten, 2008; Lightfoot et al., 2012; López-Costas and Müldner, 2016; Scheidel, 2012). In Late Antiquity, isotopic studies from across the Western Empire have revealed that diets were largely based on cereals (wheat or oats), with an increased consumption of millet (a C4 plant) in comparison with Roman diets (Hakenbeck et al., 2010; Jordana et al., 2019; Lightfoot et al., 2012; López-Costas and Müldner, 2016; Maxwell, 2019; Mion, 2019; Mion et al., 2016; Riccomi et al., 2020). It has been suggested that during the Roman period, millet was considered to be a 'lesser' or 'poverty crop', reserved for animal fodder and acting as a security against crop failure and famine (Killgrove and Tykot, 2017; Murphy, 2016). As such, a shift to a diet with large quantities of millet could indicate important agricultural or cultural changes in crop production or dietary preferences (Keenleyside et al., 2009; Mion et al., 2016; Prowse, 2011). However, millet may have been an important crop in Gaul from as early as the Iron Age and carpological studies (studies of seeds and fruits) have not always shown consistent results for changes in the production or consumption of millet (Murphy, 2016; Zech-Matterne et al., 2017). Proteins comprised legumes

(lentils, peas, beans), dairy products, meat and fish (Jordana et al., 2019; López-Costas and Müldner, 2016; Mion et al., 2016). It is likely that there were geographic differences in food consumption between Late Antique northern and southern populations, as alimentary practices are shaped by many factors, including location, cultural and social status and availability (Pearson, 1997). Archaeobotanical research has suggested that diets were more diverse during the Roman period because of expanded trade routes and access to a wider variety of food and food production techniques than had been previously available (Bakels and Jacomet, 2003; Harper, 2016; Pearson, 1997; Redfern et al., 2010). Disruption and reductions in the extent of trade networks in the Post-Roman period meant that the variety of foods that the Romans had introduced disappeared, with some items not returning until the 18th or 19th centuries (Kron, 2019, 2012). Poor harvests in Gaul during Late Antiquity in the 5th and 6th centuries led to famine, the effects of which were compounded by breakdowns in road and waterway systems, preventing the transport of available food (Van Dam, 1985).

Constraints on access to resources, whether from reduced trade networks or poor harvests, would have impacted the entirety of the population. However, within this study, females are disproportionately affected, suggesting the influence of cultural or social factors. As seen in modern societies with strong gender and age hierarchies, gender inequities become more pronounced in times of resource scarcity (Mukherjee et al., 2011). In modern and past societies, there is often differential access to adequate nutrition between males and females (Chirowa et al., 2013; Fuller et al., 2006; Garnsey, 1999). In times of scarcity, food distribution may be particularly biased toward the members of the family deemed to perform the most crucial labour (Mukherjee et al., 2011; Zuckerman and Crandall, 2019). When nutrition is inadequate it increases susceptibility to both the frequency and severity of infection, potentially compounding negative effects (Scalone, 2014). In the 8th and 9th centuries, Carolingian nuns were allocated less food than monks, due to their smaller size and thereby decreased need, but also to curb sexual inclinations (Pearson, 1997; Rouche, 1979). In Late Antiquity, the diets of young women and adolescents were also reportedly restricted to reduce sexual desire, especially the consumption of meat (Fuller et al., 2006; Garnsey, 1999). Isotopic studies of skeletons from Late Antiquity have identified both differences between male and female diets (Craig et al., 2009; Fuller et al., 2006; Hakenbeck et al., 2010; Knipper et al., 2013) and similarities (Hakenbeck et al., 2010; Keenleyside et al., 2009; Knipper et al., 2013; López-Costas and Müldner, 2016; Saragoça et al., 2016), depending on the population. Several studies have found that females demonstrated a lower trophic level than males, where females had less access to protein (Craig et al., 2009; Fuller et al., 2006; Knipper et al., 2013). All of these isotopic

analyses were performed on bone (reflecting diet from relatively close to time of death) rather than dental tissues (which can reflect dietary isotopic values from childhood), strongly suggesting that adult female diets were different from the males' in many populations. This supports the interpretation of differential access to resources contributing to early female mortality, especially when combined with increased metabolic requirements during reproductive years.

Previous studies have suggested that nutritional deficiencies and diseases of deficiency were important contributing factors to early female mortality in Late Antiquity (Bardsley, 2014; Bullough and Campbell, 1980; Pearson, 1997). Males and females have slightly different dietary requirements and these differences would be the most exaggerated during pregnancy and lactation. Dietary requirements are amplified (calories, proteins, vitamins A, D, C, folic acid, niacin, B12, calcium) for pregnant and nursing women with important consequences for infant and maternal mortality (Fuller et al., 2006; Garver, 2012; Osmani and Sen, 2003; West, 2004). In Late Antiquity, a typical diet would likely have provided just enough iron to meet the minimum requirement for males (Bullough, 1987). Females normally require twice as much iron as males and approximately three times the amount during pregnancy and lactation (Bullough and Campbell, 1980; Bullough, 1987). This suggests that women would have been at high risk for iron deficiency anaemia and severely so during pregnancy and lactation (Bullough and Campbell, 1980; Bullough, 1987). Further, there is a cumulative effect of multiple pregnancies on women, where stores of iron and folic acid can become depleted, also resulting in anaemia (Bullough and Campbell, 1980; Garver, 2012). In this way, anaemia can result from primary dietary deficiencies, but also the constant cycle of pregnancy, childbearing, nursing and potentially short interbirth intervals (Bullough and Campbell, 1980; Pearson, 1997). Continuing the potential detrimental effects, anaemic mothers are more susceptible to excessive bleeding and disease after or during childbirth with significant effects on maternal and infant mortality (Chukuezi, 2010; Garver, 2012; Zimicki, 1989). Although only one of many possible examples, the heightened risk of anaemia for females in general and during reproduction in particular illustrates how stressors and gender inequities could synergistically affect female mortality during reproductive years.

5. Conclusion

This research examined if transitions occurring during Late Antiquity had differential effects on mortality in males and females by assessing age-at-death distributions and survivorship in several

skeletal samples. Results indicate that female mean age-at-death decreased during Late Antiquity in comparison with Roman women and males from both time periods, resulting in higher mortality for women aged 18-35. Based on the evidence presented in this analysis, it is suggested that environmental changes, trade or resource reductions and cultural shifts resulted in increased pressure on Late Antique structures, strengthening gender inequities during Late Antiquity. This gender inequality may have manifested as greater resource restriction for women, particularly in southern Gaul, where young females may not have experienced the same elevation in status, as evidenced in burial customs of northern regions. Resources that might have been adequate for children and young women became inadequate for reproductive women, who had heightened nutritional needs and vulnerabilities to morbidity and mortality, which increased with successive pregnancies/ reproductive cycles. As previously discussed, and in common with all studies based on human skeletal remains from archaeological contexts, there are known and unknown biases within the burial samples, which cannot be controlled for.

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Chapter 7

Discussion

Despite centuries of research and public fascination with the Roman Empire and its transition into Medieval kingdoms (Late Antiquity), understandings of the lived experience during these periods are comparatively limited. Debate has long centred around the nature of transition; was this a dramatic and chaotic collapse or a slow transformation, punctuated by the continuation of key structures in different, yet recognisable forms? Although sources are limited and written works are largely biased to elite, male Roman points of view, scholars have found resourceful and ingenious ways to analyse and interpret the material and textual remnants available.

Over recent years there has been an increasing focus on the bioarchaeological evidence for health in Roman and Late Antique populations (e.g. Klinge, 2011; Redfern, 2008; Redfern et al., 2010; Riccomi, 2020). Health is affected by socio-political, cultural and lived environments and is therefore remarkably informative about societal transformations. The primary goal of this research was to contribute new information and perspectives to debates surrounding the Late Antique transition from a large-scale analysis of human skeletal remains. In this chapter, results are discussed within the framework of the overarching aims, objectives and questions of this doctoral research. It also addresses several aspects of the research that were beyond the scope of the preceding manuscripts.

It was hypothesized that consistent patterns of skeletal indicators of stress would suggest a gradual transition experience, whereas distinctive changes in the prevalence, or the age and sex of those affected, could demonstrate more extreme forms of transformation, possibly collapse. To accomplish these aims, the skeletal remains of 844 individuals dated to Roman and Late Antique periods in Gaul were assessed for a variety of skeletal stress markers (sex, age-at-death, femoral growth, DEH, CO, Tibia PR, carious lesions, trauma, dental cortisol concentrations). These indicators were examined in both non-adult and adult remains to understand how both survivors and non-survivors were affected, addressing problems associated with the osteological paradox. This choice also permits analysis of differences between the sexes and enables an examination of health over the life course.

7.1 Research Question 1: How was health and wellbeing impacted by the social, political and cultural transformations taking place during Late Antiquity in Gaul?

Despite the importance of Gaul in Roman and Post-Roman periods, bioarchaeological analyses have been limited in comparison with other regions, in particular Roman and Post-Roman Britain (Gowland and Redfern, 2010; Gowland and Walther, 2019; Lewis, 2010; Pitts and Griffin, 2012; Rohnbogner, 2015). Gaul encompasses areas that were tightly bound with Roman lifeways through the Mediterranean basin, but also includes more diverse frontier regions. Although many Gallo-Roman and Late Antique skeletal collections have been extensively and expertly studied in France, these analyses are often not embedded within larger discussions of Late Antique health or transitions. Survey studies of Roman and Post-Roman stature (Jongman et al., 2019; Ruff, 2017; Scheidel, 2012a; Steckel et al., 2018; Steckel and Rose, 2002) have included Gallo-Roman and (French) Late Antique collections, but data from France are often underrepresented in comparison with other regions. Published research has generally focused on case studies (Blondiaux et al., 2002; Blondiaux, 1991; Crubézy et al., 1998; Signoli et al., 2009; Vidal, 2000), which although useful, are limited in terms of understanding broad patterns in health. However, case studies can be pooled and included within larger population studies, making useful and important contributions in big data projects (e.g. (Roberts and Cox, 2003).

The data recorded and analysed for the purposes of this thesis represent a significant additional body of work that contributes to new understandings of health during Late Antiquity. This analysis includes burial populations that have not previously been studied and develops and applies innovative methods, never hitherto used to study skeletal collections (e.g. cortisol). Finally, the research interprets the evidence using novel theoretical approaches, including the Developmental Origins of Health and Disease and the 'Intermittent Stress of Low Lethality' hypotheses, as well as evaluating the data against more recent epidemiological models of societal collapse (i.e. Soviet Union).

7.1.1 Are differences in frequencies of skeletal stress indicators observed between Gallo-Roman and Late Antique skeletal collections?

This study identified differences in the prevalence of several skeletal stress indicators between Gallo-Roman and Late Antique samples (Fig 7.1, Tables 7.1-7.2; Manuscripts 1,2,5). The Gallo-Roman South sample demonstrated extensive growth stunting in non-adults, small adult femur lengths and heightened frequencies of DEH and Tibia PR in comparison with both Late Antique samples (Figs. 7.1, 7.6, 7.9). The Late Antique South sample had the lowest prevalence of DEH and Tibia PR. The Late Antique North demonstrated the highest frequencies of CO and caries and marked increases in adult male femoral lengths. Differences in the age and sex of those affected were also noted, as well as differences in patterns of growth faltering and mortality (Manuscripts 1,2,5). This demonstrates that factors surrounding health and physiological wellbeing differed between the two time periods, answering the first research question, and justifying more detailed analyses. Further information about the lived experience during Late Antiquity might be gleaned through examination of stress indicators in subgroups of the samples, such as non-adults and males and females. Geographic trends in health are also explored.

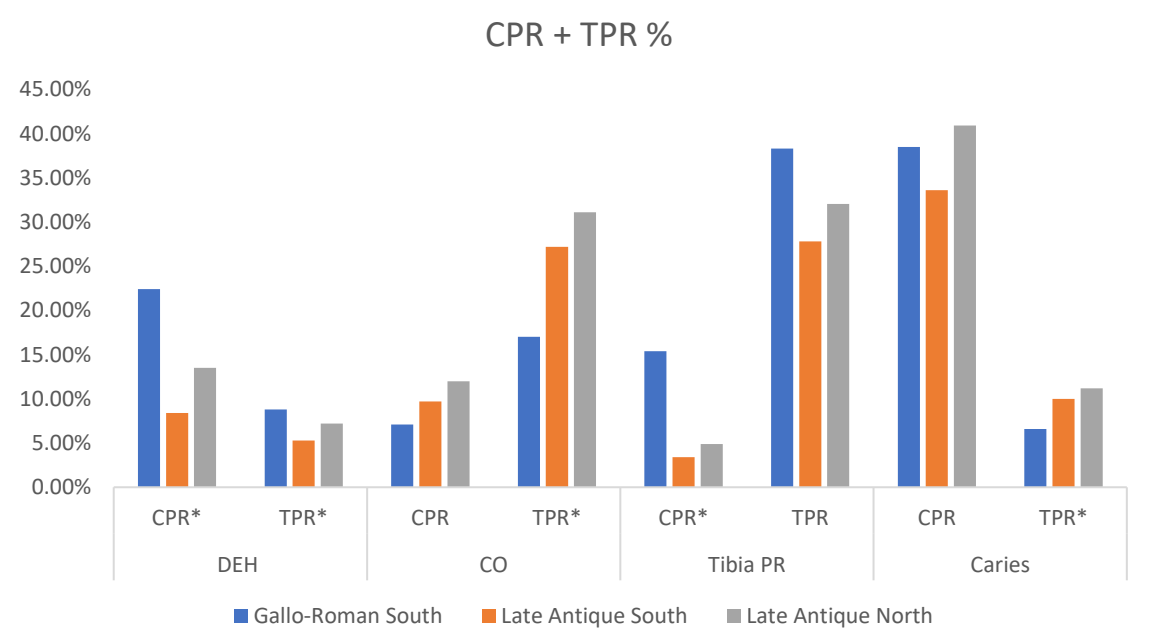


Fig. 7.1 Crude and True Prevalence rates of skeletal stress indicators, * indicates significant differences found between samples

Table 7.1 Key results of the present analysis

Group	Key Findings
Gallo-Roman South	Highest rates of DEH (CPR + TPR) and Tibia PR (CPR + TPR); High frequency of multiple DEH events; High growth stunting in non-adults; Small adult femur lengths
Late Antique South	Lowest rates of DEH (CPR + TPR) and Tibia PR (CPR + TPR); In-between the other samples in other parameters
Late Antique North	Highest frequency of CO (CPR + TPR) and Caries (CPR + TPR); Long adult femur lengths (in males)

Table 7.2 Crude and True Prevalence Rates of non-specific stress indicators

Group	Affected n (n/N)	DEH		CO		Tibia PR		Caries	
		CPR	TPR	CPR	TPR	CPR	TPR	CPR	TPR
Gallo-Roman South	Non-adults	13	79	5	4	7	16	4	10
	Females	4	27	2	3	6	18	17	36
	Males	13	63	1	1	8	26	26	72
	Total	35 (22.4%)	196 (9.0%)	11 (7.10%)	13 (7.1%)	24 (15.4%)	72 (38.3%)	60 (38.5%)	147 (6.6%)
	Total (N)	156	2223	156	174	156	188	156	2223
Late Antique South	Non-adults	5	30	12	23	3	8	4	6
	Females	6	30	7	13	3	7	30	110
	Males	7	57	2	3	1	11	28	93
	Total	20 (8.4%)	136 (5.3%)	23 (9.70%)	41 (13.3%)	8 (3.4%)	30 (27.8%)	80 (33.6%)	259 (10.1%)
	Total (N)	238	2573	238	308	238	108	238	2573
Late Antique North	Non-adults	10	83	22	33	6	20	9	24
	Females	26	166	12	18	3	12	77	273
	Males	15	97	15	21	10	32	68	218
	Total	61 (13.6%)	400 (7.2%)	54 (12.0%)	80 (16.6%)	22 (4.9%)	74 (32.0%)	184 (40.9%)	625 (11.2%)
	Total (N)	450	5558	450	483	450	231	450	5558
p-value		<0.001	<0.001	0.197	0.011	<0.001	0.153	0.175	<0.001

Non-adults are individuals estimated to be less than 18 years old; n= number affected individuals or bone elements; N=number of individuals or observable bone elements in group

7.1.2 Collapse or Continuity? Can observed health changes be attributed to societal transition- 'collapse' or a more gradual form of transformation?

Large-scale transitions in the past, such as from hunter-gathering to agriculture and industrialisation, have had profound effects on the frequency and type of skeletal lesions observed within burial populations (Gowland and Newman, 2017; Larsen, 2002; Roberts and Cox, 2003; Steckel and Rose, 2002). However, health data can be challenging to interpret in relation to societal transitions and skeletal indicators of poor health can be subtle and complex to interpret. Previous studies have had difficulties in connecting changes in skeletal lesion frequency with patterns of societal collapse (Jennings, 2010; Kurin, 2016, 2012; Schrader and Buzon, 2017; Wright, 1997a, 1997b; Wright and White, 1996). This may be because these authors did not consider modern or past parallels for understanding and conceptualising the health effects a societal collapse might generate. As a result, a critical aspect of this thesis has been to better understand the ways that societal collapse (as the most extreme and therefore visible form of societal transformation) can affect health and how these effects might manifest in the skeleton. Modern examples can provide a framework to better understand skeletal stress data and augment the interpretation of more subtle shifts in pathological conditions found in previous analyses. This was undertaken through an examination of health data and trends during the collapse of the Soviet Union in the early 1990s (Manuscript 1). While contextually far removed from the Roman Empire, the Soviet Union is the only example of a large-scale union of multiple countries with a predominantly centralized economy and government for which clinical data relating to its collapse is available. The characteristics of this transition in terms of mortality, morbidity and the demographic impacts were developed into a model against which to assess the late Antique data (Table 7.3). Such models can be helpful for constructing boundaries and thresholds that the data must meet to support or refute a hypothesis of collapse (though arguably only if the model is relevant).

Using this model, hypotheses of Late Antique societal collapse in Gaul were not supported. Femoral growth, HAZ scores and adult femoral length from Late Antique samples met several, but not all of the model's tenets (Table 7.3). In Late Antiquity, growth stunting was reduced, and adult femoral lengths increased, suggesting an improvement from Gallo-Roman conditions in both non-survivors and survivors. As a result, catastrophic hypotheses of Late Antique collapse are not supported. On the contrary, Gallo-Roman practices were having a negative effect on height and health, which appear to have been alleviated when Roman authority retreated in Gaul. The inability to detect collapse in post-Roman Gaul may stem from generalities built into the model to account for and combat issues when comparing modern and archaeological populations. As a result, the model was

found to lack sufficient specificity to identify societal collapse. When applied to the Gallo-Roman sample, all four of the model's tenets were met, identifying society level or cultural influences on health. Although failing in its initial intended purpose, the model still provides a valuable contribution. The ability to isolate culturally dictated determinants of health in skeletal remains in a hypothesis-driven manner has the potential to expand current analyses, while providing a falsifiable framework. When applied to the other data collected in this analysis, the model reveals the same pattern for DEH in the Gallo-Roman sample (Table 7.3). No other indicators met all four tenets in the studied groups.

Table 7.3 Tenets of collapse/cultural influences on health model

	Tenets	Sample	Femur Length	DEH	CO	Tibia PR	Caries	Mortality
1.	health is substantially and negatively impacted	GRS	X	X		X		
		LAS			X			X
		LAN			X		X	X
2.	child health and in particular early childhood health (conception to 1000 days) is affected	GRS	X	X		X		
		LAS						
		LAN	X					
3.	subgroups within the populations are affected differentially	GRS	X	X	X	X		
		LAS	X		X			X
		LAN	X		X		X	X
4.	subgroups do not necessarily conform to traditional expectations of who the most vulnerable within a society were	GRS	X	X	X			
		LAS	X		X			X
		LAN	X		X		X	X

X=tenet met in the sample; GRS- Gallo-Roman South, LAS- Late Antique South, LAN- Late Antique North

Despite being unsuccessful, research underpinning the Soviet collapse model highlighted the strong influence of stressors on health and their exaggerated role in health outcomes in times of instability. Brainerd and Cutler (2005) estimated that a quarter of the excess mortality in Russia during and immediately after the Soviet collapse resulted from 'stress of transition' and 'reduced social cohesion'. Several other studies of health outcomes during and as a result of the Soviet collapse reached similar conclusions (Brainerd, 1998; Leonard et al., 2008; Marmot, 1996; Stillman, 2006). Although dietary changes, healthcare system dilapidation and economic recession associated with collapse contributed to negative health outcomes, studies have shown that they were not the 'determinants' of increased morbidity and mortality (Brainerd and Cutler, 2005; Cockerham, 1997). For example, mortality from heart attacks increased during the Soviet collapse. Although this could have been the result of multiple factors, the increase in fatality did not result from a reduction in the quality of care or treatment. Instead, the *number* of heart attacks increased.

The cause for the upsurge in heart attack occurrence was determined to be stress induced (rather than dietary) (Brainerd and Cutler, 2005; Leon et al., 1997; Murphy, 2011). As such, high political events, cultural and environmental factors can affect health through instability and increased stressors (Thayer and Kuzawa, 2015, 2011). In animal and human studies, regular exposure to physical and social stressors are known to cause Hypothalamic-Pituitary-Adrenal (HPA) dysregulation (allostatic load), eliciting the highest or most extreme stress responses in situations where there is a lack of control or stability (Dickerson and Kemeny, 2004; Sapolsky, 1993; Sapolsky et al., 2000; Thayer and Kuzawa, 2015). In this way, instability in Late Antiquity could still have had pronounced effects on health and mortality through allostatic load. Although hypotheses of Late Antique collapse are not supported, this transition may still have impacted access to resources, stability of hierarchies in power and status and heightened environmental stressors, with consequences for HPA activation and ultimately health, wellbeing and mortality.

7.1.3 Are differences between northern and southern Late Antique samples observed?

Late Antiquity, especially in northern Gaul was thought to be defined by militarisation, violence and political turmoil (Kulikowski, 2013b; Sarti, 2013). There is evidence of increased fortification, weaponry increasingly became a part of burial rituals and textual sources describe ‘barbarian invasions’ and the subsequent abandonment of land (Geary, 1988; Sarti, 2013; Theuws, 2019; Theuws and Alkemade, 2000; Wickham, 2005). Although slight in comparison with diachronic changes, the Late Antique North sample demonstrates several skeletal signs of decreased health status in comparison with the Late Antique South (higher rates of DEH, CO, Tibia PR and Caries) (Fig. 7.2). Because heightened frequencies of skeletal stress indicators can reflect a physiological struggle to adapt to living environments, these results could be indicative of more tumultuous or challenging living conditions, as evidenced in historical and archaeological data (Effros, 2001; Elton, 1992; Halsall, 2006; Theuws, 2009; Van Ossel, 2006; Ward-Perkins, 2006). Potentially contributing to this interpretation of the data, the presence of new inhumation customs (including weaponry and gendered grave goods) in northern Gaul are thought to reflect the re-negotiation of unstable or unclear social hierarchies and local power conditions (Effros, 2003; Halsall, 2007, 1992; Härke, 2001; Speith, 2012; Theuws and Alkemade, 2000). It has been argued that unrest and heightened military activity in Gaul from the 4th to the 7th centuries increased the population’s exposure to violent interactions (Sarti, 2013). To explore this possibility, patterns of limb trauma were analysed. However, trauma prevalence does not suggest a more violent experience in northern regions (Fig.

7.2, Table 7.4). Young male mortality patterns also demonstrate a relative uniformity across northern and southern regions (and also the Gallo-Roman period), further suggesting that within these samples, military pressures may not have changed (Fig. 7.3). The Late Antique South sample has slightly lower crude and true prevalence rates of all examined skeletal stress indicators, which could reflect a more gradual transition process. There are some notable differences between males and females during the Late Antique period in both samples, especially in regard to femur length and mortality. These are discussed in more detail in a later section.

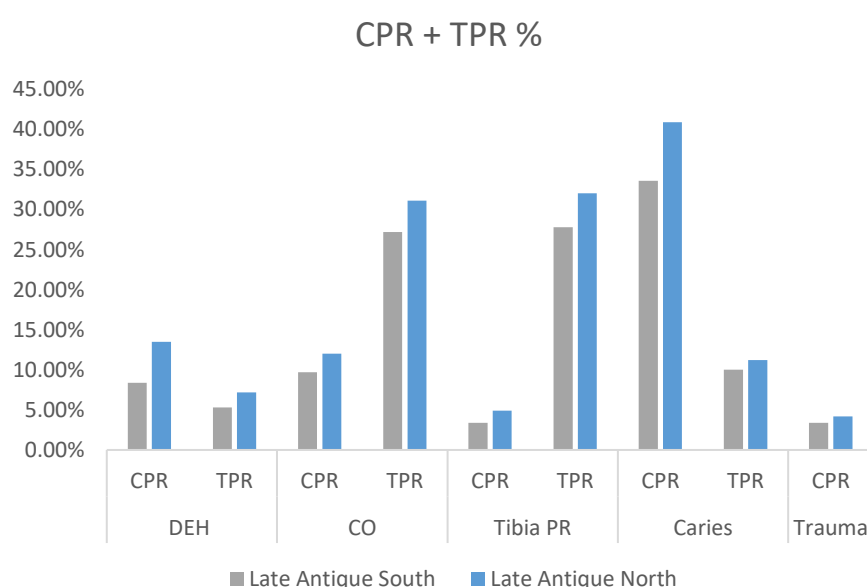


Fig. 7.2 Crude and true prevalence rates of skeletal stress indicators in Late Antique samples

Table 7.4 Trauma Adults

	Total		Males	Females	p-value
GRS	16 (108) 14.8%		6 (47) 12.8%	6 (31) 19.4%	0.268
LAS	7 (201) 3.4%%		2 (66) 3.0%	3 (77) 3.9%	0.821
LAN	16 (377) 4.2%		7 (119) 5.9%	5 (142) 3.5%	0.487
p-value	<0.001*		0.100	<0.001*	

* indicates significant differences found between samples

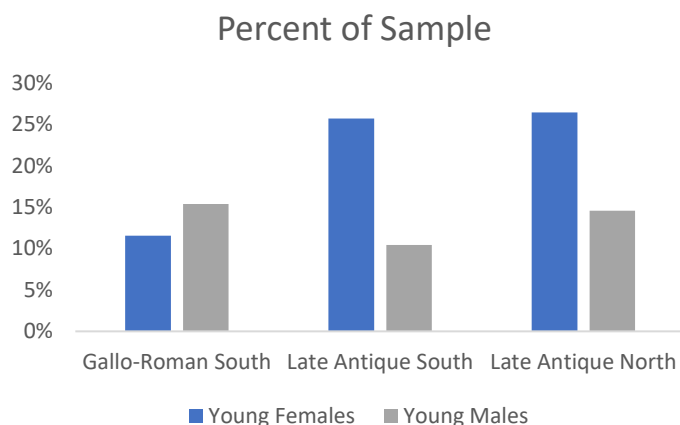


Fig. 7.3 Proportion of burial sample comprising young adults (18-35 years)

Slight differences in skeletal stress indicators are evidenced between northern and southern Gaul in Late Antiquity, potentially supporting hypotheses of a differential transition experience. However, the two regions show more similarity between each other and greater differences from Gallo-Roman data in frequencies and distribution of skeletal health indicators. This suggests that important factors were rooted in Gallo-Roman or Late Antique practices or conditions, rather than geographic differences or experience of transition. The inclusion of a Gallo-Roman North group would have been important to identifying and clarifying these patterns. However, preservation and practical difficulties prevented their incorporation in this analysis. As a result, the influence of Gallo-Roman practices on health needs to be interpreted with caution. Although hypotheses of societal collapse were not supported, this study has shown evidence for diachronic change in population stress indicators, with implications for the lived experience during Gallo-Roman and Late Antique periods. Based on these initial results, it is useful to slightly re-orient the focus of this analysis to features or trends in Late Antiquity that would have led to health *improvements* as well as detriments. Even if different than originally hypothesized, the research questions remain important and contribute to understandings of Late Antiquity and the Gallo-Roman period.

7.2 Research Question 2: Do stress indicators suggest changing cultural or social priorities during Gallo-Roman and Late Antique periods, as reflected in the age and sex of those affected?

This research utilises a biocultural approach (Goodman and Leatherman, 1998; Larsen and Milner, 1994), examining health status over the life course to understand changing cultural or social

priorities during Gallo-Roman and Late Antique periods. High political events or trends can affect the populace by influencing or re-arranging value systems and resource accessibility (Thayer and Kuzawa, 2015). In this way, changes in the health of population subgroups can provide information about transition in Late Antiquity. The application of the model to growth and other stress indicators in this analysis highlighted that subgroups were affected differentially during Gallo-Roman and Late Antique periods. Health during childhood and development is the most sensitive to environmental conditions and stressors (Gowland, 2015; Lewis, 2007), making it a significant focus of this research. As evidenced in the Soviet Collapse model, differences in health between males and females could suggest a differentially gendered experience of Late Antique transition or possible shifts in cultural roles or ideologies.

7.2.1 Childhood Health

Changing conditions in Late Antiquity would likely be reflected in patterns of health during childhood (as indexed through growth stunting/HAZ scores, DEH and CO). This research has identified differences between Roman and Late Antique periods in skeletal indicators of childhood stress and health. Growth stunting was more frequent and of greater severity during the Gallo-Roman period, as was the frequency of DEH (CPR and TPR) and number of DEH events than either Late Antique group (Figs. 7.4-7.6). This pattern of physiological stress in childhood is further demonstrated through evidence of shorter adult height in the Gallo-Roman sample. As assessed in the second manuscript, DEH presence was correlated with earlier mortality in the Gallo-Roman context. Late Antique samples also experienced early life adverse environments. Rates of CO were significantly higher in Late Antique samples and were associated with earlier mortality (Fig. 7.4). This analysis demonstrates that both Gallo-Roman and Late Antique samples experienced notable physiological stress in childhood, with implications for adult health.

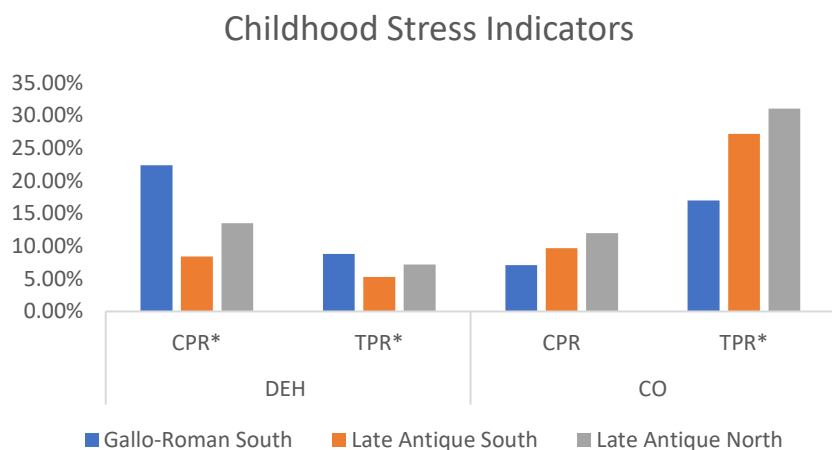


Fig. 7.4 Childhood stress indicators (non-adult and adult individuals)

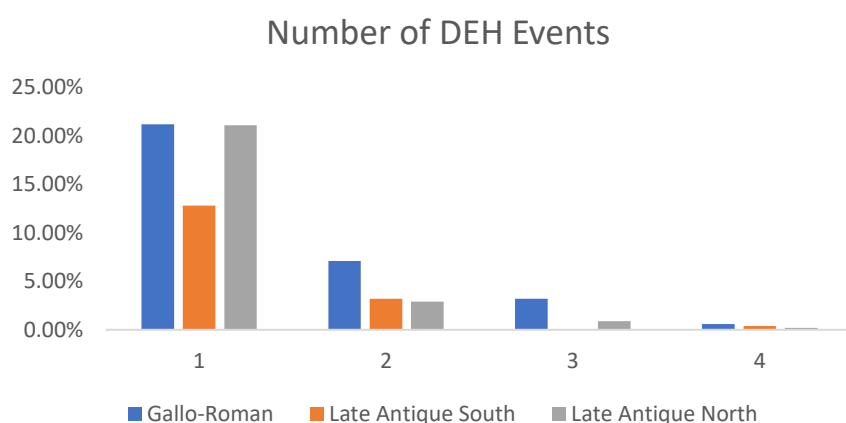


Fig. 7.5 Percent of samples with 1,2,3 or 4+ DEH events

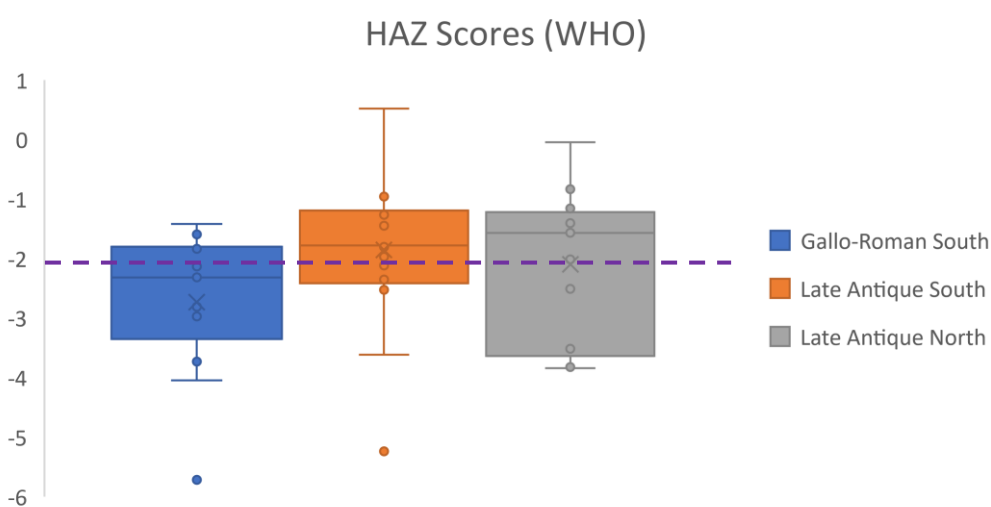


Fig. 7.6 HAZ scores derived from the WHO modern reference sample femoral lengths, including individuals from 3 to 18 years of age. The line equals the median, the X is the mean, the box is quartiles 2 and 3 and whiskers are the maximum and minimum values, not including outliers. Additional dots are outliers. The purple line represents the threshold for growth stunting.

Although both Gallo-Roman and Late Antique groups displayed evidence of early life adversity, the samples differed in the skeletal manifestations of stressors, complicating interpretation. The relationship between growth disruption and poor health is well established in modern and past contexts. Adult stature reflects overall well-being during development and is positively correlated with life expectancy (Barker, 2012a). Short stature or stunted growth has been associated with a reduction in immune system functioning and reduced life span (Martorell, 1989; McDade, 2012; Pelletier et al., 1995). The Gallo-Roman sample demonstrates pronounced growth stunting and multiple DEH events (another form of growth disruption) in several age categories, whereas Late Antique growth (in stunting and DEH) appears to be less affected (Manuscripts 1,2). As a result, it is likely that Gallo-Roman communities were also more deeply affected by illness than their Late Antique counterparts. Limited evidence for growth disruption could indicate a less adverse early life environment in Late Antiquity or suggest that conditions improved for individuals who survived vulnerable early childhood years. If environmental or nutritional stressors subside, 'catch-up' or compensatory growth can occur, masking some signs of early life adversity (Bogin, 1999a; Eveleth and Tanner, 1990b). Because Late Antique samples demonstrate signs of early childhood stressors (heightened prevalence of CO), in addition to longer adult femoral lengths and less growth stunting in older children and adolescents, hypotheses of 'catch-up growth', or improved conditions in later development seem promising.

Contextual data may help to explain these results and suggest potential changes in cultural priorities and environments from Gallo-Roman to Late Antique periods. Roman settlement structures were more urbanised than in Late Antiquity. Urbanisation is associated with heightened population density, overcrowding and high pathogen loads (Gowland, 2017; Griffin et al., 2011; Griffin, 2017; Jongman et al., 2019; Morley, 2004; Redfern and DeWitte, 2011a; Scheidel, 2012a,b). Vast road and communication networks would have connected cities across the empire, facilitating trade, travel and also the transmission of pathogens (Harper, 2016; Porter, 1999). Further, waste management and disposal in Roman cities was likely inadequate and could have led to food and water contamination and subsequent illness (Morley, 2004; Scobie, 1986). Housing within urban environments could also have contributed to negative health consequences, as overcrowding and poor ventilation would have been common, especially for people low socio-economic status (Scobie, 1986). The Gallo-Roman sample in this analysis derives from cemeteries located in Arles and Saintes, major Gallo-Roman cities.¹ Therefore, Gallo-Roman individuals in this study may have been more regularly exposed to infectious pathogens in urban environments throughout

¹ See appendix for a small summary of the data used in this analysis divided by 'urban' and rural contexts

childhood, maintaining a negative living environment and inhibiting opportunities for catch-up growth (intermittent stress of low lethality hypothesis) (Pezo-Lanfranco et al., 2020) (Manuscript 2). Several Gallo-Roman individuals show multiple DEH events, further suggesting repeated exposure to (and survival of) stressors. Also supporting this interpretation of the data, individuals from multiple age-at-death cohorts in the Gallo-Roman South context show heightened frequency of Tibia PR. Although multifactorial in their origins, both DEH and Tibia PR can result from infection (Resnick and Nakamura, 1995; Roberts, 2019). This could indicate that negative environmental conditions were present throughout the life course, as might be expected for individuals living in urban environments.

Because urban settlement structures and expansive trade networks are thought to have decreased in Late Antiquity, this interpretation is consistent with observed health or stress patterns in Late Antique samples. There is evidence of early childhood stressors in the Late Antique samples through the heightened prevalence of CO and notable frequencies of DEH. Although multiple and varied aetiologies are possible, CO typically develops in early childhood. Post-natal and weaning periods are known to be particularly dangerous (greater biological vulnerability due to immune incompetence etc) (Brothwell and Sandison, 1967). Therefore, the heightened prevalence of CO in Late Antique samples could reflect stressors during this vulnerable period of life, while longer femoral lengths demonstrate adequate environmental conditions in later developmental stages. Further, DEHs are more concentrated in individuals who died in adulthood, suggesting the survival of early life stressors. Perhaps for those that survived precarious early life periods, rural settlement structures in Late Antiquity meant that risk of pathogen exposure and subsequent infection was decreased, permitting catch-up growth in some individuals. Similar observations have been made for Roman Britain (Rohnbogner and Lewis, 2016, 2017).

Some research has suggested that social stressors associated with Roman lifeways may have contributed to negative health outcomes (Gowland, 2017, 2015; Griffin et al., 2011; Pitts and Griffin, 2012; Redfern, 2008, 2003; Redfern and DeWitte, 2011a; Roberts and Cox, 2003; Scheidel, 2012 a,b). Roman society was thought to be rigidly hierarchical, with pronounced social inequalities and accompanying psycho-social stressors (Gowland, 2015; Scheidel, 2012b). During Late Antiquity, there is also evidence of social stress, through increased security needs, less consistency in power forms and the breakdown of roads and aqueducts (Halsall, 2006; Sarti, 2013; Sessa, 2018; Ward-Perkins, 2006). Additionally, there was the development of the 'colonate', a 'new' social class of tenant farmers who were bound to the agricultural land they worked on (Carrié, 1983, 1982;

Jones, 1958; Wickham, 1984). Although the nature of the colonate has been extensively debated, it has been suggested that free peasants would only adopt this 'binding to the land' out of absolute necessity (Jones, 1958; Sessa, 2018; Whittaker, 1987; Wickham, 1984). Not only does this make the colonate the beginnings of serfdom and the feudal system, but also a potential source of and response to stress in the Late Antique world.

In addition to its impact on adult health and mortality, 'stress' is a critical pathway that erodes child health and through which, the environment impacts and dictates later health trajectories (Anda et al., 2010; Nyberg et al., 2012; Rodney and Mulligan, 2014; Tarullo et al., 2017). Maternal and early life stress affects HPA axis development and cortisol secretion, with negative effects manifesting throughout the life course, influencing morbidity and mortality (Edes and Crews, 2017; McEwen, 2008, 2006; Solís et al., 2016; Tarullo et al., 2017). Through the HPA axis, psychosocial and environmental stressors affect growth, where elevated basal cortisol levels and cortisol response have been recorded in children with stunted growth (Kelly et al., 2012; Mason and Narad, 2005; Nyberg et al., 2012; Rodney and Mulligan, 2014). In this analysis, dental cortisol concentrations were assessed in a subsample of teeth to identify 'stress' on a biochemical level (Manuscripts 3,4). Dental cortisol concentrations were not significantly different between groups in either dentine or enamel (Fig. 7.7, Table 7.5). Due to small sample sizes, this finding neither refutes nor supports social stress hypotheses for reduced growth or health status in the Gallo-Roman or Late Antique samples. Further, correlations between cortisol concentrations and growth stunting or CO could not be performed due to preservation constraints. Comparisons of dental cortisol concentrations with age-at-death and DEH also did not reveal observable patterns or results. However, the two individuals with the highest enamel cortisol concentrations did display enamel hypoplasia (along with several other notable pathological lesions) (Manuscript 4). Cortisol data has thus far not elucidated patterns in early childhood health but may make considerable contributions in the future.

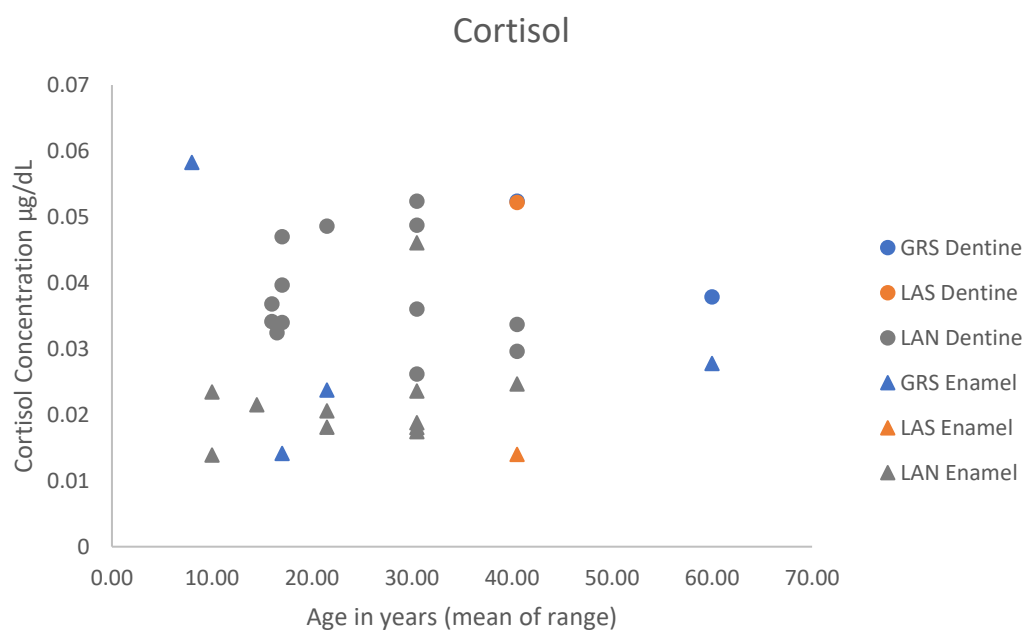


Fig. 7.7 Cortisol concentration in Gallo-Roman and Late Antique groups

Table 7.5 Cortisol concentrations

Group	Mean Dentine	Mean Enamel
Gallo-Roman South	0.038	0.031
Late Antique South	0.052	0.014
Late Antique North	0.038	0.022
p-value	0.333	0.194

7.2.2 Adult Health

Although childhood and adult health can be differentially affected in response to cultural and societal transitions (Klaus and Tam, 2009; Leonard et al., 2008, 2002), it can be challenging to isolate adult health outcomes from childhood origins; adult health, frailty and survival are influenced by childhood stressors and experiences (DOHaD). Adult health outcomes can also derive from negative conditions into adulthood, or the introduction of novel conditions (Steckel, 2005). Given the challenges and impracticalities in attempting to artificially separate adult health from childhood origins, the data are examined through divisions based on sex.

7.2.2.1 Males and Females

Differences between males and females in health outcomes can help to reveal changing cultural and social priorities in response to societal transitions. Many of the health effects stemming from

the collapse of the Soviet Union varied by sex (Brainerd and Cutler, 2005; Leonard et al., 2002; Stillman, 2006). Critical health consequences, such as the substantial increase in young adult male mortality during the Soviet Collapse would have gone unidentified if the population had only been considered as a whole, demonstrating the importance of this line of inquiry. Social and societal roles were built around sex and gender in Roman and Late Antique periods, meaning that sex and gender were linked and likely represented an inescapable embodied experience (Allason-Jones, 1989; Halsall, 2004; Smith, 2009). Because females were regarded as lesser males, gender inequity was built into cultural and societal systems (Allason-Jones, 2004; Dixon, 2001; Evans-Grubbs, 2009; Gilchrist, 2012). In this way, gender can become embodied, mapped onto sex and the skeleton, with implications for stress experience, health and wellbeing.

One of the most striking findings in this study was the difference in mortality patterns between males and females in the Roman and Late Antique periods (Manuscript 5). Because data on life expectancy at birth is more strongly affected by fertility than mortality (Sattenspiel and Harpending, 1983; Wood et al., 1992), fertility rates were generated to contextualise the observed results. Following similar studies, fertility rates were produced by dividing the number of individuals over 30 years of age by the number of individuals over five years of age and accompanying 95% confidence intervals (Table 7.6) (Buikstra et al., 1986; Larsen, 2002). Fertility rates show no difference between the samples and substantial overlap in confidence intervals. Therefore, the observed patterns in mortality are not explained through changes in fertility.

Table 7.6 Fertility rate D30+/D5+ values and their 95% confidence intervals

	D30+/D5+	95% CI
GRS	0.6748	0.59–0.75
LAS	0.6010	0.53–0.67
LAN	0.6196	0.57–0.67

The female mortality pattern in Late Antiquity is distinct both from the Gallo-Roman patterns and trends in male mortality across both periods, signalling a profound change during Late Antiquity that is not equally distributed across the sexes (Fig. 7.3, Table 7.7). Late Antique females have a lower mean age-at-death and despite the ‘stability’ in young adult male mortality, the percentage of females who died during young adulthood more than doubled in both Late Antique samples (25.7% and 26.4% from 11.5%). This represents a marked difference in male and female experience of Late Antique transition. Although there are biological differences between the sexes that affect mortality, many of these differences are thought to have a positive or ‘buffering’ effect for females.

For example, females have lower metabolic rates and higher proportions of body fat than males, which can buffer them from nutritional deprivation and mortality in comparison with males (Steckel et al., 2018). Further, sex-based differences in disease susceptibility, progression, predisposition and response tend to result in higher male mortality (male sensitivity hypothesis) (Lukacs, 2017; Ortner, 1998; Stinson, 1985). However, female immunity is reduced during conception to prevent rejection of the foetus (Ortner, 1998). Importantly, biological differences between the sexes do not explain the diachronic shift observed in female mortality. Although settlement structures, population density and pathogen load are important components in health and disease states, it is unlikely that they would have differentially impacted females in Late Antiquity, especially as urbanisation declined in Late Antiquity. Therefore, while this hypothesis is still a legitimate explanation for early life stressors and health outcomes, it does not explain patterns of female mortality in Late Antiquity. Similarly, plague hypotheses (specifically the Justinianic plague known to be present in Gaul in the 6th century and potentially even within one of the studied sites - Clos des Cordeliers²) are not supported. Instead, other factors are more likely to have led to differential mortality outcomes in Late Antiquity.

Table 7.7 Comparison using Kaplan-Meier Survival Analysis (Adults only)

	Mean Age-at-death			P-Value
	Gallo-Roman	Late Antique South	Late Antique North	
All Adults (Males and Females)	38.11	34.63	34.27	0.001*
Males	38.28	37.95	35.51	0.067
Females	38.43	32.05	31.84	0.004*
P-Value	0.701	0.002*	0.011*	

* Indicates significant results

Both Roman and Late Antique societies are thought to have had substantial gender inequality. Could environmental pressures, reduced trade networks or access to resources in Late Antiquity have strengthened inequities, leading to differential health outcomes? Gender or sex-biased differences in treatment and resource access could begin from as early as birth and therefore might be reflected in early life stress indicators. Although both samples demonstrate early female mortality, Late Antique south females display similar frequencies of DEH to males and Gallo-Roman females, while Late Antique North females show a marked increase (Fig. 7.8, Table 7.8). These results are challenging to interpret as they highlight heterogeneity in living conditions during development. CO results are broadly similar for females across all groups. Adult male and females

² See appendix for a brief examination of the health data from Clos des Cordeliers in comparison with the rest of the Late Antique North sample

demonstrated differences in how femoral length was affected during Late Antiquity, where female femoral lengths underwent minimal change ($p=0.352$) and male femoral lengths increased in northern regions ($p= 0.004$) (Fig. 7.9). Although sex-based differences in absolute femoral length are expected (Humphrey, 1998), differences in growth patterns suggests males and females were not exposed to or experiencing the same environmental factors affecting growth during development.

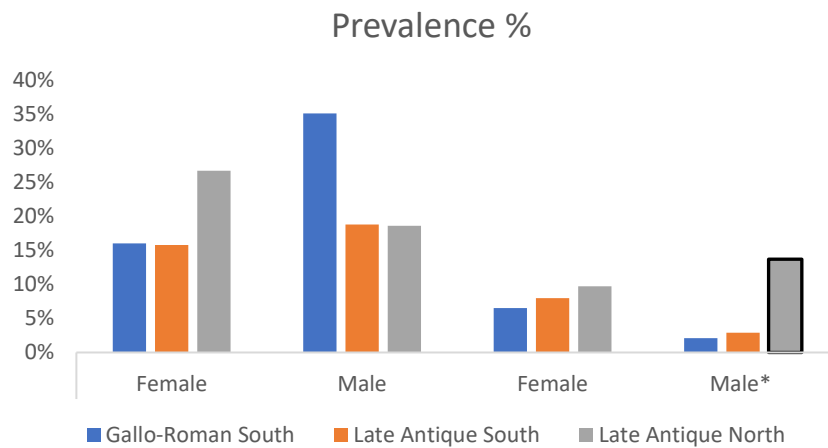


Fig. 7.8 Crude prevalence rate of skeletal stress indicators in adult males and females

Table 7.8 P-values from chi-squared tests of skeletal stress markers between groups

Sex	p-value	
	DEH	CO
Female	0.207	0.801
Male	0.110	0.007

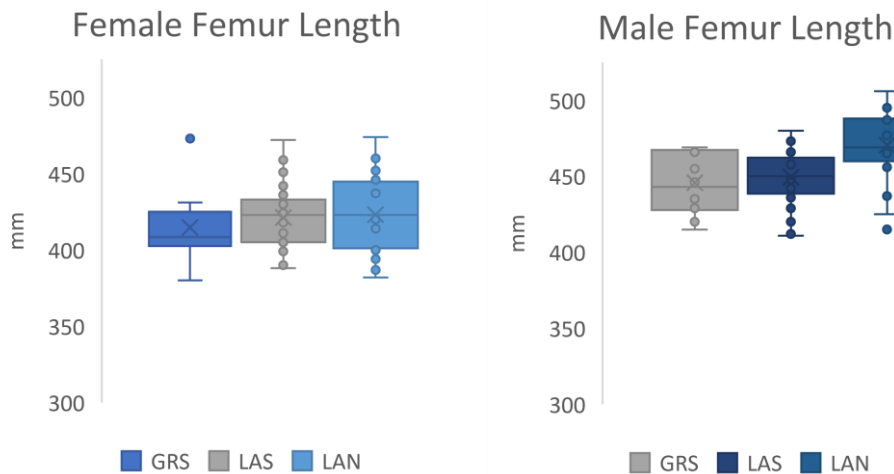


Fig. 7.9 Box and whisker plot of maximum femoral lengths. The line equals the median, the X is the mean, the box is quartiles 2 and 3 and whiskers are the maximum and minimum values, not including outliers. Additional dots are outliers

In addition to growth, sexual dimorphism can be ‘an indicator of environmental quality’ and can contextualise height data (Bogin, 1999b; Nikitovic and Bogin, 2014; Stinson, 1985). Linear growth in males is thought to be more sensitive to changes in the environment than in females (Guntupalli and Baten, 2009; Nyberg et al., 2012; Stinson, 1985). Because males grow over a longer period of time, there is greater opportunity for male growth to be affected by adverse environments or inadequate nutrition (Bogin et al., 2017). In this way, not only are male growth and height negatively affected in adverse environments, but sexual dimorphism is also reduced (because males are more negatively affected for longer) (Bogin et al., 2017; Guntupalli and Baten, 2009; Moradi and Guntupalli, 2009). When environmental and nutritional conditions are positive, sexual dimorphism increases, as males have a longer opportunity to either catch-up in their growth or to maximize growth potential (Bogin et al., 2017; Guntupalli and Baten, 2009). Within this analysis, sexual dimorphism in femoral length is similar between the Gallo-Roman south and Late Antique south contexts (Table 7.9). In the Late Antique North group, sexual dimorphism is markedly higher. This observation coupled with overall increased femoral lengths and decreased frequency of DEH suggests that LAN individuals had more advantageous living conditions during growth and development. Sexual dimorphism can also be informative about gender discrimination in modern and past populations (Bogin et al., 2017; Guntupalli and Baten, 2009; Mark, 2014; Moradi and Guntupalli, 2009; Steckel et al., 2018). ‘Gender dimorphism’ (or sexual dimorphism resulting from cultural constructs) increases with increasing gender discrimination, as distribution and access to resources, and discrimination experience can all contribute to obtained height and body size

(Guntupalli and Baten, 2009; Moradi and Guntupalli, 2009). Therefore, the increased sexual dimorphism in LAN could also be reflective of increased gender discrimination.

Table 7.9 Average maximum femur length and sexual dimorphism

Group	Male Femur Average	Female Femur Average	Sexual Dimorphism Average cm
Gallo-Roman South	44.6	41.9	2.7
Late Antique South	44.6	42.0	2.6
Late Antique North	46.4	42.7	3.7

Examination of childhood stress indicators does not seem to clarify if gender inequities stemming from early life experience were contributing to early female mortality in Late Antiquity. However, sex could not be determined for non-adult individuals, masking a potentially important set of data. Cortisol data were also inconclusive, revealing no differences between males and females in either dentine or enamel (Fig. 7.10). Differential cultural practices relating to males and females might not have become significant until puberty or adolescence. Isotopic studies of populations from the Medieval period have identified that differences between the sexes in diet only appear in adults (Reitsema et al., 2010; Reitsema and Vercellotti, 2012). Some differences in immune responses also develop after puberty (Klein and Flanagan, 2016; Roberts and Steckel, 2018).

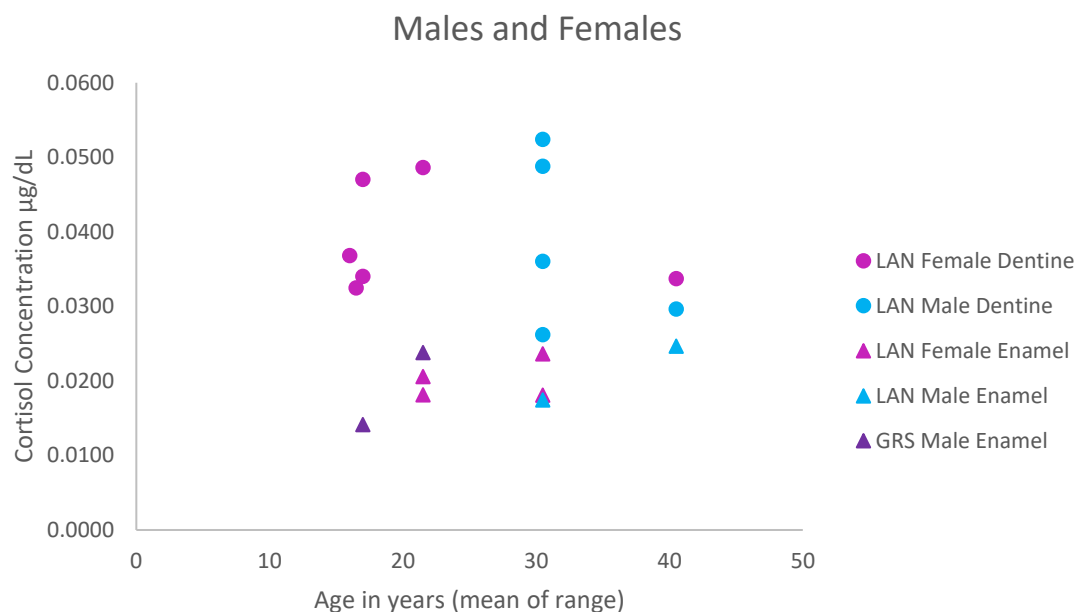


Fig. 7.10 Dentine and enamel cortisol concentrations in males and females

Following previous studies (Gilmour et al., 2015; Novak and Šlaus, 2010; Redfern, 2003), patterns of limb fractures were examined in regard to potential gendered patterns or inequities. Although cultural and structural signs of violence likely contributed to patterns of health, morbidity and mortality, trauma evidence is likely to be more visible archaeologically (Stone, 2020). Fractures can result from accidents (slips, trips, falls), work or activity related actions, as well as interpersonal violence (Davies et al., 2003; Judd and Roberts, 1999; Lovell, 1997; Manning, 1983). Both men and women would have encountered everyday hazards related to living and working conditions. However, gendered work and social roles could have resulted in an unequal distribution of injury risk (Gilmour et al., 2015). Male roles and positions included military action and potentially strenuous manual labour from agricultural or construction work (Redfern and DeWitte, 2011b). Female work also likely included strenuous activities, such as agricultural, trade or commerce related jobs.

The majority of fractures observed in this study were well-healed and, in most cases, were likely the result of accidents and everyday hazards (Table 7.4). Interestingly, the rates of trauma observed in Gallo-Roman (14.8%) and Late Antique samples (3.8%; 4.2%) were markedly higher and lower than those reported in Roman Aquincum (modern-day Hungary) (9.5% total; 10.4% males; 8.4% females) (Gilmour et al., 2015). However, Roman Aquincum was a border province of the Roman Empire and the authors have suggested that their results indicate a less hazardous experience than has been observed in other Roman provincial sites (Booth et al., 2010; Wells, 1982). It is worth noting that the Saintes, Rue Jacques Brel necropolis is thought to have been associated with an artisan community, based on its location and unusual grave goods (nails and shoes in great quantities) (Baigl et al., 1997). People engaged with industry, whether male or female, would likely have been exposed on a daily level to increased hazards associated with working with tools, animals and equipment (Gilmour et al., 2015). A more detailed analysis of the trauma patterns would be necessary to explore this explanation of results. Other studies of trauma have found higher rates of fractures in urban communities (Novak and Šlaus, 2010), possibly associated with accidents or interpersonal violence related to overcrowding. This might also have contributed to the higher frequencies of limb fractures seen in the Gallo-Roman sample. Because there were no pronounced differences in limb fracture prevalence between the sexes in Gallo-Roman and Late Antique samples, trauma patterns do not support theories of gender inequities increasing in Late Antiquity (Table 7.4). However, trauma was only assessed systematically on long bones. The thorax and skull were not systematically analysed for evidence of trauma.



Fig. 7.11 Ulnae and radii from individual 1612, Cirque Romain, Arles. Right radius and ulna display well-healed antemortem fractures at approximately midshaft.

7.2.3 Osteological Paradox

The osteological paradox suggests that the most frail individuals in a population would succumb to illness before the development of skeletal stress markers (Wood et al., 1992). Interpreted paradoxically, skeletal assemblages with tall stature and limited evidence of skeletal stress markers can reflect a population under stronger selective pressures or stress experience. Skeletal assemblages with higher frequencies of stress indicators and short stature can reflect a more robust population, who had sufficient health resilience to sustain and survive stress events (Wood et al., 1992). Importantly, the osteological paradox is *one* framework to interpret skeletal stress data (DeWitte and Stojanowski, 2015). Skeletal stress indicators can be interpreted as negative consequences of physiological stress (conventional) and/or as evidence of robusticity (paradoxical) in the face of adversity (Vercellotti et al., 2014; Wood et al., 1992). This thesis has incorporated several strategies to aid in understanding whether paradoxical or conventional interpretations are appropriate. This includes the analysis of multiple skeletal stress indicators (Cohen et al., 1994; DeWitte and Stojanowski, 2015; Wilkinson, 1992), the analysis of skeletal stress indicators in relation to age (Temple and Goodman, 2014; Wood et al., 1992; Wright and Yoder, 2003), the inclusion of non-adults (Bennike et al., 2005; DeWitte and Stojanowski, 2015; Holland, 2013) and the analysis of subgroups (based on sex) (Wright and Yoder, 2003).

Although alternative interpretations are possible, when skeletal stress indicators, growth and mortality patterns are considered together, a conventional framework best suits this study. Increased prevalence of DEH, number of DEH events, growth stunting, shorter adult femoral length and periosteal reaction of the tibia in the Gallo-Roman sample and overall mortality patterns contradict paradoxical thinking. For example, DEH is correlated with earlier mortality in the Gallo-Roman sample. However, it is interesting to note that adult and older age categories do still have comparatively high levels of DEH, suggesting that a substantial proportion of individuals were also able to survive. Based on these findings, it is proposed that Gallo-Roman populations experienced or were exposed to more physiological stressors during development than Late Antique individuals. Gallo-Romans were able to survive these stressors long enough to develop skeletal lesions, resulting in a higher frequency of skeletal stress indicators, but often at the expense of life expectancy. The Gallo-Roman sample has a higher mean-age-at-death because those who survived not just the stress episode, but also into adulthood were more robust. This highlights that survival can exist in multiple layers or levels; one can be a survivor and a non-survivor. Cortisol analyses, if/when refined enough to contribute data on frailty might be helpful (Manuscript 4).

Late Antique samples show a decreased prevalence of physiological stress during childhood, as indexed through low DEH prevalence, growth stunting and increased adult femoral lengths. The increased femoral lengths coupled with a higher DEH prevalence in older age categories in Late Antique samples (especially LAN males) could be indicative of high selection pressure, suggesting that paradoxical interpretations of these data are more appropriate (DeWitte and Stojanowski, 2015; Vercellotti et al., 2014). However, if this were a suitable explanation, we would expect to see higher mean age-at-death in the Late Antique samples, indicating a more robust surviving group. Late Antique samples have significantly lower mean age-at-death, especially females. In contrast with studies that have found higher skeletal stress marker frequency with taller stature (Giecz) (Vercellotti et al., 2014), this study finds the opposite. There is no correlation between age-at-death and DEH in the Late Antique samples, which suggests that the marker cannot be interpreted as a sign of high or low frailty, supporting conventional interpretation of the data. It is therefore suggested that Late Antique samples were not under high selective pressures/stressor exposure during development. This resulted in a group of individuals with more heterogeneous frailty surviving into adulthood (hardy and weak), as has been suggested for other populations (DeWitte et al., 2016). Several Late Antique individuals demonstrate growth stunting, short adult stature and DEH development, demonstrating that Late Antique samples did not entirely escape physiological stressors during childhood. What is perhaps most important is that there is a difference between

Gallo-Roman and Late Antique samples in skeletal stress indicators and how early childhood stressors impacted mortality.

Different factors created conditions with divergent impacts on health during Gallo-Roman and Late Antique periods. As pointed out in the original publication, the presence of skeletal stress indicators is more straightforward to interpret than their absence (Wood et al., 1992). Textual and archaeological contextual data have provided several intriguing and plausible possibilities as to why Gallo-Roman populations might have been more exposed to physiological stressors during childhood than their Late Antique counterparts. Roman Gaul was more urbanized, with a higher population density and therefore pathogen load than Late Antique Gaul. The decline in these features evidenced in textual and archaeological sources was perhaps better for health during development than the protections and integration Rome supposedly provided. However, this created a situation where in adulthood, other factors or heterogeneous frailty created a population more likely to succumb to illness and death in early age cohorts in Late Antiquity.

7.3 Research Question 3: Can understandings of stress through skeletal markers be augmented through biochemical methods?

Evidence from the Soviet collapse demonstrated that psychosocial stressors were a primary driver for increases in morbidity and mortality. Although skeletal stress markers revealed some differences in physiological stress experienced between Gallo-Roman and Late Antique samples, stressors could have been impacting Gallo-Roman and Late Antique populations in ways that were not being captured through traditional skeletal stress markers. The presence of stressors could have been masked by unknown thresholds for skeletal lesion development. Foregrounded and popularised by Hans Selye in the 1930s, the general adaptation syndrome identified that the body's stress response is non-specific, attempting to restore homeostasis in the face of challenges, either physiological or psychological, 'real' or perceived (Selye, 1950). Allostatic load (hyperactivation or overloading of the HPA Axis) is a primary way in which external environments and psychosocial stressors become internalised throughout the life course (Edes and Crews, 2017; Klaus, 2014; Mason and Narad, 2005; McEwen, 2012; Reitsema and McIlvaine, 2014). Therefore, an important component of this research was to consider potential biochemical methods for assessing stress in skeletal remains. This was achieved through an exploration of and expansion upon existing cortisol

extraction methods (Nejad et al., 2016; Webb et al., 2015a, 2015b, 2010) to obtain cortisol concentrations from archaeological tooth structures (Manuscripts 3,4).

7.3.1 Can detectable cortisol concentrations be obtained from archaeological tooth structures?

Cortisol has been previously examined in archaeological hair but has never before been extracted from archaeological tooth dentine and enamel. Only performed once on modern teeth (Nejad et al., 2016), the cortisol analysis method required some adaptation and development to be applied to archaeological remains. Two ELISAs were performed, one for dentine and the other for enamel. Of the 96 tooth samples tested for cortisol concentrations, 32 (16 dentine and 16 enamel samples) yielded results detectable through ELISA (Fig. 7.12) and the remaining 64 samples produced values below the 0.007 ug/dL concentration sensitivity threshold. Obtained concentrations were very low (0.02 µg/dL – 0.04 µg/dL). In only two of the 29 teeth tested for both dentine and enamel cortisol, did both tissues yield detectable concentrations. In both cases, the dentine values were higher than enamel values, suggesting different uptake mechanisms or timing between the tissues (Fig. 7.12). These results suggest that cortisol is incorporated within tooth structures and merits further investigation in both modern and archaeological contexts. The ability to access cortisol concentrations from teeth has important implications for future research as archaeological hair is relatively rarely preserved, while teeth represent some of the best-preserved elements of the body.

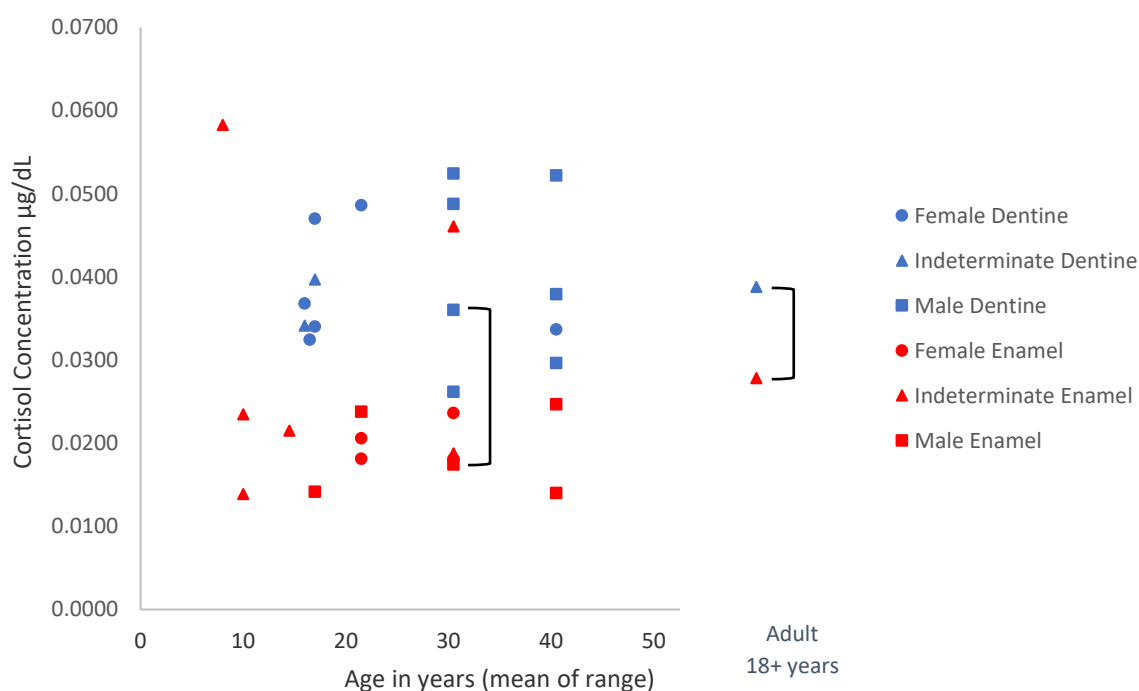


Fig. 7.12 Tooth cortisol concentration ($\mu\text{g/dL}$) per 300 mg tissue sample, plotted against age-at-death mean of range. Red symbols denote enamel and blue symbols are dentine values. Circles are female, triangles are indeterminate sex, and squares are male individuals. Brackets indicate representative cortisol concentrations from the same tooth.

7.3.2 Do cortisol concentrations vary based on sex?

Based on modern analyses of cortisol and HPA axis development, concentrations were hypothesized to vary by sex. Teeth from 25 females and 21 males were selected and tested for cortisol concentrations (Fig. 7.12). Differences in cortisol concentrations between males and females were not significant in either dentine ($p = 0.751$) or enamel ($p = 0.663$) (Student T-Test) (Table 7.10). This could be a result of the small sample size or the overall low values obtained in this analysis. Sex based differences in HPA axis and cortisol concentrations are thought to develop at puberty, but reported results are not consistent (Kirschbaum et al., 1992; Raven and Taylor, 1996). Nejad et al. (2016) also did not find differences between male and female cortisol concentrations in their analysis of modern tooth dentine. If cortisol is deposited within the dental tissues during mineralization, the results are reflecting cortisol exposure before puberty and might explain the lack of difference between male and female cortisol concentrations in this analysis and in modern dentine. Future analyses should continue to examine potential differences in cortisol concentration based on sex, as current results require further investigation.

Table 7.10 Detectable cortisol concentrations (mean) (µg/dL)

	Female	Male	p-Value
Dentine	0.0387503	0.404359	0.751
Enamel	0.200946	0.01879750	0.663

7.3.3 Are there correlations between cortisol concentrations and skeletal stress indicators?

Dental cortisol analyses were undertaken to provide more information about stress during Gallo-Roman and Late Antique periods. Although initial analyses of cortisol concentrations from dental structures were successful, many teeth did not yield concentrations detectable through ELISA. This resulted in there not being enough ‘valid’ concentrations for comparisons of cortisol and pathological conditions between groups. However, because initial cortisol analyses revealed promising results, the pathophysiology of cortisol in commonly examined skeletal stress indicators (mortality, growth disruption, DEH, CO, periosteal reaction, carious lesions) was examined in the fourth manuscript. Interestingly, the two individuals with notably high enamel cortisol displayed DEH. Examinations of cortisol concentrations in conjunction with pathological lesions or growth disruption associated with stress may help to further current understandings of macroscopic methods, in addition to providing a more quantitative metric of stress. Future analyses should continue to consider how external stressors become embedded biologically and explore cortisol’s potential to reveal hidden heterogeneity in frailty. It is hoped that with further work on this method, not only will relationships between atypical cortisol concentrations (i.e. elevated stress levels) and pathology be elucidated within the context of this research, but also the potential to address questions related to cortisol in bone and stress in the past might be broached.

7.4 Limitations

The present research has a number of important limitations. Access to skeletal collections was restricted by the time available for study and the location, storage and preservation of the remains. As a result, certain collections that would have been beneficial to include (such as burial populations from the Gallo-Roman North) could not be incorporated in this study. Further, the Gallo-Roman South group is composed of individuals from two large and important urban areas, heightening the potential influence of urban living within this group. Additionally, the skeletal

collections included in this analysis do not derive from as wide a geographic range as would have been preferable for responding to the large-scale questions proposed in this study. The southern sites are primarily from the Rhône delta, with Saintes, Rue Jacques Brel and La Granède as outliers. Northern sites are dominated by one large cemetery in the West (Saint-Martin de Fontenay) and several smaller sites in the East (Ancienne Chambre des Métiers, Rue de Tombois, Fontoy and Cutry). This limits the reach and scope of the interpretations and conclusions drawn from the present research. The skeletal collections that were included in this analysis are 'samples of samples', introducing additional levels of bias and challenges to interpretation of these data (Roberts and Manchester, 2005, p. 9). In common with other large-scale bioarchaeological research projects (Cohen and Armelagos, 1984; Roberts and Cox, 2003; Steckel et al., 2019; Steckel and Rose, 2002), the broad scale of analysis necessitated the inclusion and comparison of skeletal collections from varying contexts and which were subject to differing methods of dating and excavation. This inevitably impacts the relative comparability of the skeletal collections finally included in this research. This is because the adoption and application of general and broad characterisations can mask 'local' cultural influences (Beauchesne, 2012; Dressler, 1995). On a more positive note, all the data were collected by a single individual (the author), using a consistent set of methods that are accepted in bioarchaeology. However, due to preservation of individual skeletons and time constraints, as well as differential curation practices, it was not always possible to record or analyse all the skeletal elements from each individual included within this analysis. This also acts as a potential source of error or bias in the present study.

Further limitations stem from the complex interaction between social organisation, cultural practices, human behaviours and health. Health and stress states are influenced by multiple factors, including differing social status between individuals and groups, migration and the influence of specific practices or pathogens. Although this research tried to adopt a holistic approach, not all of these important determinants of health could be adequately considered. Reconstruction of social status from grave goods or funerary practices was not attempted but could add important nuance to the results of this research. In particular during the Roman period, many studies have highlighted the influence of lead (food and wine additives and piping) on health (Le Roux et al., 2005; Moore, 2019; Scobie, 1986). Migration has also been found to be a primary driver for patterns of disease in Roman Britain (Redfern et al., 2018; Redfern and DeWitte, 2011b) and the presence of migrants within the site of Saintes, Rue Jacques Brel has been previously identified (Stark, 2017). Migrants expose local populations to new types of pathogens, but also experience heightened susceptibility to endemic diseases, potentially affecting mortality profiles (DeWitte et

al., 2016; DeWitte and Stojanowski, 2015; Gowland and Redfern, 2010; McNeill, 1998). Migration was an important component of society in both Roman and Late Antique periods in Gaul. Despite the clear significance of migration on health status in Roman and Post-Roman periods, it was not possible to adequately address this topic in this study.

The application of recent scientific methods to Late Antiquity have yielded important new results and debates surrounding the period. Recent work with aDNA has proven invaluable in identifying the presence of specific pathogens in past populations from Late Antiquity and particularly those that do not manifest skeletally, such as *Yersinia pestis* (Castex and Drancourt, 2005; Drancourt et al., 2004; Feldman et al., 2016; Harbeck et al., 2013). As such, the role of the Justinianic Plague in the decline of the Roman Empire or experience of Late Antiquity is a current topic of intense debate (Haldon et al., 2018a, 2018b, 2018c; Harper, 2017; Mordechai et al., 2019; Mordechai and Eisenberg, 2019). Recent research has also engaged with environmental and climatic data and changes in Roman and Late Antique periods (Büntgen et al., 2017; Harper, 2017, 2016; McConnell et al., 2018). Time and resource constraints prevented a deep engagement with these important topics. However, this study has contributed systematic data analysis, providing some broad characterisations about health and stress in Roman and Late Antique Gaul. In this way, the present research could act as a starting point for future analyses to pose more specific questions and apply detailed methods to address new areas of inquiry.

Other important limitations derive from the development of a comparatively new method. Although off to a promising start, the cortisol method requires further development. There are problems interpreting the cortisol data, as there are no comparable datasets. Despite these risks, it remains important to pursue ambitious studies that do not have guarantees or known outcomes (Roberts, 2017). One of the challenges when working with cortisol is the sheer vastness of the current research and existing literature. These include studies on different types of methodology, psychology, public health, clinical, pharmacology, social wellbeing, animal and human contributions³. Few aspects of cortisol are neat, defined and concrete, making it challenging to properly contextualise findings with a robust understanding and presentation of the relevant publications and wider research context. In this way, the temptation and perhaps necessity of cherry-picking studies that support a certain outcome or viewpoint becomes problematic. Even though the HPA response pathway is supposedly a simple one, much about cortisol remains poorly

³ A google scholar search of 'cortisol' yields 1,390,000 results in 0.03 seconds compared to 18,300 results (0.07 sec) for bioarchaeology and 7,300 results (0.04 sec) for palaeopathology, 88,400 results (0.05 sec) for scurvy

or not at all understood. Conflicting results reveal deeper complexities in how cortisol methods and data need to be interpreted. This highlights the complexity of the interplay of embodiment of stress from external to internal stimuli, behaviours, genetics, social behaviours and networks evolution and adaptation.

The chosen theoretical framework and even terminology utilised in this analysis also imports bias. Scholars debate the appropriateness of concepts of 'decline and fall' or 'adaptation and resiliency' (Ando, 2008; Faulseit, 2016; Jongman, 2007; Liebeschuetz, 2001; McAnany and Yoffee, 2010). These different approaches frame the questions that are asked, and methods selected. Additionally, different terminology and periodisation pose a particular problem within the studied time period. Late Antiquity (chosen here) can also be Late Roman, Post-Roman or Early Medieval. Translations or considerations with French periodisation adds an additional layer of complication. *Antiquité Tardive* does not really equate to Late Antiquity, which might actually be better associated with *Haut Moyen-Age*. This makes the finding, isolating and comparison of relevant data and literature problematic.

7.5 Summary

Differences in health status (as indexed through skeletal stress markers) were identified in skeletal samples from Gallo-Roman and Late Antique periods. These differences could not be attributed to societal collapse in northern or southern regions of Gaul. Results instead have indicated that Roman practices had a stronger influence on health than geographic differences in transition. Roman and Late Antique samples were affected by physiological stress during childhood with significant impacts on frailty and adult mortality. However, stressors manifested in different skeletal signs, with possible implications for the factors affecting their health, especially when considered within the different historical and archaeological contexts. Within Late Antique samples, female mortality was dramatically affected. Modern examples of societal collapse highlighted that cultural and socio-political transitions can impact health through stress, leading to the development of methods for exploring stress biochemically. Biochemical analyses of stress (cortisol) may represent new ways to consider frailty and stress in skeletal remains in relation to Roman and Late Antique Gaul.

Table 7.11 Summary of research questions and responses

	Research Question	Response?
1	How was health and wellbeing impacted by the social, political and cultural transformations taking place during Late Antiquity in Gaul?	Health, or stress states, were impacted. However, these changes resulted in a decrease of observable skeletal stress indicators in Late Antique populations.
1a	Are differences in frequencies of skeletal stress indicators observed between Gallo-Roman and Late Antique skeletal collections?	Yes
1b	Can observed health changes be attributed to societal transition- 'collapse' or a more gradual form of transformation?	No
1c	Are differences between northern and southern samples observed? Do differences in health, as evidenced through skeletal stress indicators, follow regional trends suggested by archaeological and textual data	Yes, but slight
2	Do frequencies of stress indicators suggest changing cultural or social priorities during Gallo-Roman and Late Antique periods, as distributed by sex or age-at-death categories?	Yes
2a	Are particular stages of development more affected by environmental stressors?	Yes
2b	Are differences in health between males and females detectable, suggesting possible shifts in cultural roles or ideologies?	Yes
3	Can understandings of stress through skeletal markers be augmented through biochemical methods?	Yes
3a	Can detectable cortisol concentrations be obtained from archaeological tooth structures?	Yes
3b	Do cortisol concentrations vary based on sex?	No
3c	Are there correlations between cortisol concentrations and skeletal stress indicators?	Not sufficiently evidenced

Chapter 8

Conclusion

“A great many things keep happening, some of them good, some of them bad”
-Gregory of Tours (538-594)

In the present research, the skeletal remains of 844 individuals from Gaul dated to the Gallo-Roman period and Late Antiquity were examined for several indicators of systemic stress or health status. There was a focus on stress indicators occurring during childhood and development, when health is most sensitive to environmental conditions. To better understand ‘stress’ in the past, a new methodology accessing glucocorticoid hormone concentrations (indicative of stress) from dental tissues was adapted and developed (Nejad et al., 2016). This research demonstrates the utility of examining stress, health and wellbeing during Late Antiquity as a barometer of the socio-political environment and concentrates on often overlooked subdivisions of the population, including women and children. Research contributions are summarized, and some future directions are also discussed.

8.1 Research Contributions

The fall of the Roman Empire and rise of Medieval Kingdoms have long conjured a grim image of a destabilization of society, regression of enlightened progress and deterioration of living conditions across Europe. This conception of a bleak destruction of civilization – the ‘Dark Ages’ – has remained cemented in the popular imagination. However, Late Antiquity has proven to be a challenging time period to study, with conflicting interpretations of historical and archaeological sources. This has resulted in often muddled and sometimes contentious understandings of even basic concepts of how life in Late Antiquity was experienced. A specific objective of this research was to contribute new data and interpretations to current understandings of the lived experience of the end of the Roman Empire and the rise of Medieval Kingdoms. Health is a sensitive gauge of living conditions and is remarkably informative about large scale changes taking place in society, as well as within its about subgroups. Past communities cannot be fully understood, unless health is considered (Redfern, 2003). An initial goal of this dissertation was to contribute to the Late Antique debate through the addition of health data from skeletal remains. Because health data can be challenging

to interpret in relation to societal changes, it was important to (1) conceptualise how health is impacted by societal transitions (2) examine extremes, as subtle changes in health may be difficult to identify in skeletal remains (3) make the most out of the data that were available by applying creative and modern theoretical frameworks and using cutting edge techniques.

This research makes several original contributions to knowledge within archaeological and methodological domains. The present study contributes not only new data to debates over Late Antiquity, but also incorporates a biocultural approach looking at health status over the life course. Although this approach has been applied to populations in Roman and Post-Roman Britain, it has yet to be utilized in studies of populations coming from Gaul during Late Antiquity. Although there is always room for future inquiry, this dissertation has met the original research aims and addressed many aspects of the research questions. It has contributed new data to debates of Late Antiquity and its transitions, examining different skeletal populations with new and different methodologies than have been previously applied. It investigated regional variability in transition experience in Gaul, between northern and southern regions. This research has likewise tackled trends in health data between subgroups of the population (childhood health in survivors and non-survivors; males and females) to better characterise transition. Within this study, the relationship between cultural and socio-political transitions and health have been explored in modern and past populations, identifying the critical mechanism of stress and leading to the development of methods for exploring stress biochemically.

This research has made several original contributions to knowledge:

1. Provided a standardised and systematic analysis of skeletal health indicators during Roman and Late Antique periods from France
2. Developed of 'model' for culturally mediated changes to health based on modern examples
3. Identified a change in the distribution of vulnerability between Roman and Late Antique periods, where young adult females became more vulnerable during Late Antique period
4. Developed and applied a cortisol method for assessing stress from archaeological skeletal remains

Key Findings:

1. Gallo-Roman samples demonstrated more skeletal signs of stress (growth faltering, small adult femoral length, DEH, number of DEH, Tibia PR) than either Late Antique sample. This suggests that social and cultural factors rooted in Roman lifeways were more deleterious to health than the process of transformation.
2. Early childhood stressors impacted both Gallo-Roman and Late Antique samples with negative effects on mortality. However, the skeletal manifestations of both early life stressors and later health indicators were different between diachronic periods.
3. Gallo-Roman individuals may have been more regularly exposed to stressors throughout the life course ('intermittent stress of low lethality'). This could be the result of overcrowding and insalubrity in urban settlement structures.
4. Although slight in comparison with diachronic changes, the Late Antique North sample demonstrates several skeletal signs of a decline in health status in comparison with the Late Antique South (higher rates of DEH, CO, Tibia PR and Caries). Heightened frequencies of skeletal stress indicators could be indicative of more tumultuous or challenging living conditions.
5. Female mortality was notably negatively affected in Late Antiquity, especially for reproductively aged females (18-35 years). Late Antique samples from southern Gaul had the largest degree of gender disparity in mortality, potentially supporting hypotheses of a more gradual transition, where female health and mortality was sacrificed to retain established cultural and social norms.
6. Cortisol concentrations can be detected from within archaeological tooth dentine and enamel.
7. Differences in cortisol concentrations have not yet been associated with sex or specific skeletal stress indicators, but this remains a promising avenue for future research.

8.2 Future Directions

Having established a large-scale pattern in skeletal health data from the Roman and Late Antique periods, it becomes relevant to pursue more detailed questions, looking at differences between smaller regions of France or to isolate out more localised cultures (Merovingian, Frankish). In this way, specific distributions of lesions and/or trends might be more directly related to cultural

practices within these groups residing in Gaul. Smaller geographic areas might be easier to understand in relation to a more isolated or specific transition experience than this broad synthesis, and efforts could focus on particular areas where there is extensive contextual evidence. Another important future direction will be to examine the present data in more detail, namely through an examination of relative status through grave goods and/or funeral practices and pathology or health status. Breaking down this study into a diachronic analysis (century by century) within a single cemetery site, such as Saint Martin de Fontenay, could also yield interesting results related to Late Antique transitions. This would help to isolate the effects that such a large and broad analysis was unable to achieve, provided that sample sizes remained large enough for analysis.

This research has found similar patterns to the rest of Europe and Britain in the skeletal indicators analysed (growth, DEH, CO, Caries, tibiae periosteal lesions). This suggests that other research, specifically research targeting more specific signs of disease, including infection, would be important next steps. In future analyses, it would also be beneficial to examine signs of non-specific infectious disease (rib lesions, sinusitis), respiratory disease and lesions linked with specific infections (tuberculosis, leprosy) and diseases of deficiency (scurvy, rickets) in a systematic manner. Many of these conditions were recorded anecdotally within this analysis. However, systematic analysis with a pre-set methodology would be crucial to using the data more efficiently and drawing larger comparisons and interpretations. Some of these diseases would also be better considered in combination with advanced testing (DNA, isotopic, plaque inclusions) in addition to macroscopic analyses. More detailed analysis of trauma occurrence, patterns and healing would also be beneficial.

The cortisol method requires further research and development. In addition to validation through other methodologies, there needs to be testing for possible degradation of cortisol over time or under certain conditions. Much of this research might be better achieved through more extensive analyses of cortisol in modern teeth, before being reapplied to archaeological material. Ultimately, more cortisol data is required for comparisons and for understanding patterns or relationships in tooth cortisol concentrations. Once the method is more established and there are more data to examine, the relationships between cortisol concentrations and other skeletal stress indicators might be elucidated. Examining cortisol in relation to isotopic analyses of carbon and nitrogen, as well as epigenetics and palaeoepigenetics, may also have particular promise.

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Appendix 1

Timelines

Some of the historical information about the complex period known as Late Antiquity was deemed too detailed for inclusion in the body of this dissertation. A brief summary of some of this detail along with several thematic timelines are included here for reference. The purpose is not be exhaustive, but as thorough as was possible.

A.1.1 Problems with Succession

As previously mentioned, the imperial succession greatly affected the Gallic political atmosphere and was often heavily influenced by people and events in Gaul. Some additional details on imperial succession and usurpers is provided here and summarised in a timeline (Fig. A1). In 395, Honorius became full emperor in the west at the age of 10. The youth and inexperience of Honorius coupled with barbarian incursions (re-) instigated political upheaval in Gaul. In 407, Constantine III, a Roman general, proclaimed himself the Western Emperor in Britain and invaded Gaul, ultimately settling his capital in Arles in 409. Constantine III took advantage of the turmoil caused by the invasion of the Rhine frontier by the Vandals, Alans and Suevi (or Suebi) and the frustration of the Gallic aristocracy with ineffective imperial rule (Drinkwater, 1998). He held control of Gaul until 411, when facing internal rebellions in the north and betrayals by key generals in the south, Constantine III was deposed and executed by Honorius and his army (Drinkwater, 1998). Far from regaining imperial stability, in 411 yet another usurper, a Gallo-Roman senator named Jovinus took control of Gaul with the support of the Alans, Burgundians and the Gallic aristocracy, indicating both the power of Gallic society in establishing emperors, but also their displeasure in being ruled from Ravenna (Drinkwater, 1998). Jovinus maintained control until he was captured and executed by fellow Gauls with the support of the Goths in 413 (Drinkwater, 1998). Honorius was then again in power until his death in 423. Honorius died without a male heir, leaving a complicated political situation. Sensing the power vacuum, several ambitious individuals attempted to seize control, essentially forcing the Eastern Emperor Theodosius II to reassert Roman authority by promoting the son of Galla Placidia (the half-sister to Emperor Honorius and descendant of Theodosius I) to emperor at the age of six. Galla Placidia acted as regent for her son, Valentinian III until 437, when he came of age.

The second half of the 5th century was politically chaotic in Gaul, with the promotion and deposition of several Roman and non-Roman emperors. In 455 Valentinian III was murdered and his successor/murderer Petronius Maximus was murdered in turn (Fanning, 1992). Avitus, a Gallo-Roman aristocrat and general under Petronus Maximus, claimed control of the Western Empire in 456 with much support from the Gallic aristocracy, as well as several barbarian peoples (Heather, 2001). Avitus promoted several Gallo-Roman senators to high ranking positions, frustrating the Italian aristocracy and ultimately leading to his deposition by Majorian in 457 (Heather, 2001). Majorian then became emperor and made serious attempts to regain control of Gaul (and Spain) from various barbarian groups, but was deposed and assassinated in 461 (Elton, 1992). Ricimer, a powerful Gothic general based in Italy was instrumental in the deposition of both Avitus and Majorian, after whom he placed his own puppet emperor, Libius Severus, on the throne (Elton, 1992). Severus's authority was not recognised in Gaul and a revolt led by Aegidius, (Majorian's general) confined Roman control of Gaul to its southern regions, where Aegidius held the northern region (Elton, 1992). From this point onwards, Rome could only claim a tentative security in southern Gaul and none at all in the North (Elton, 1992). When Aegidius died in 464/5, his son Syagrius continued an entirely separate reign from the Roman Empire in Northern Gaul. Severus was the official Western Roman Emperor for only 4 years, dying in 465. The Eastern Emperor Leo I then placed Anthemius on the throne in 467, but he was assassinated in 472, again by Ricimer (Heather, 2001). In 475 Romulus Augustulus was appointed western Emperor, only to be deposed by Odoacer (who was supposedly of non-Roman origins and leader of a *foederati* group in Italy) in 476 (Geary, 1988). From this point on there was no Western Roman Emperor.

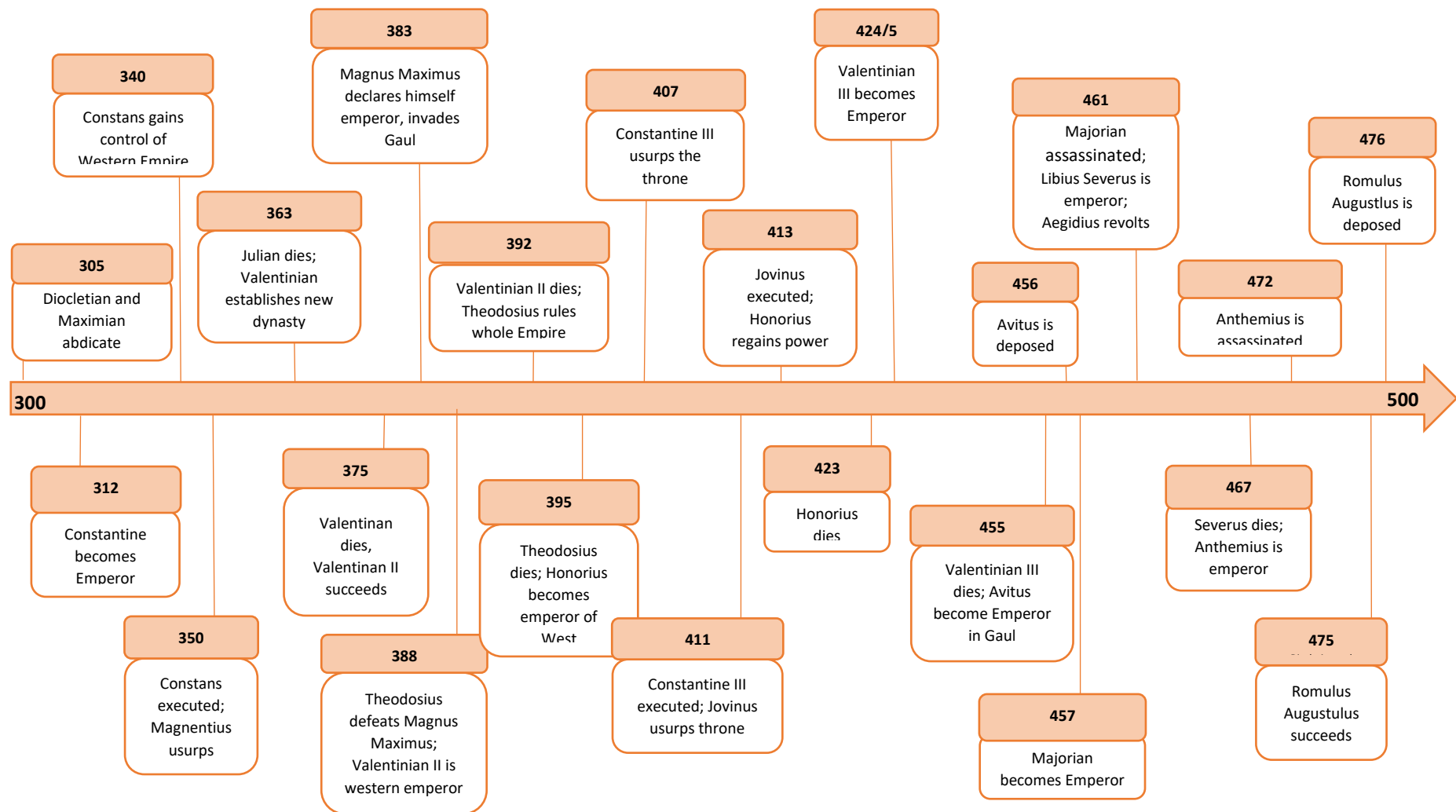


Fig. A1 Timeline of Western imperial succession with a focus on Gaul

A.1.2 Military Activity Timeline

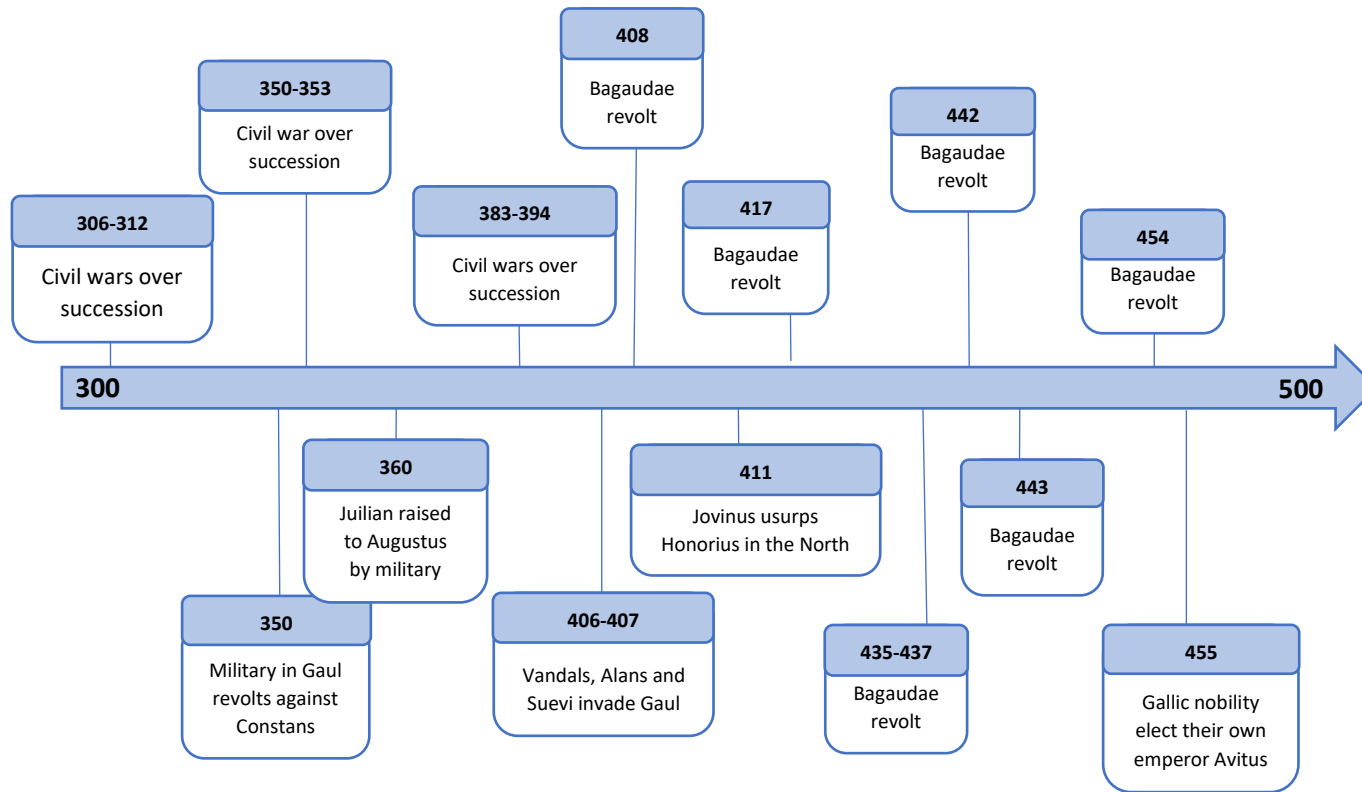


Fig. A.2 Timeline of Western imperial succession with a focus on Gaul

A.1.3 Economic History Timeline

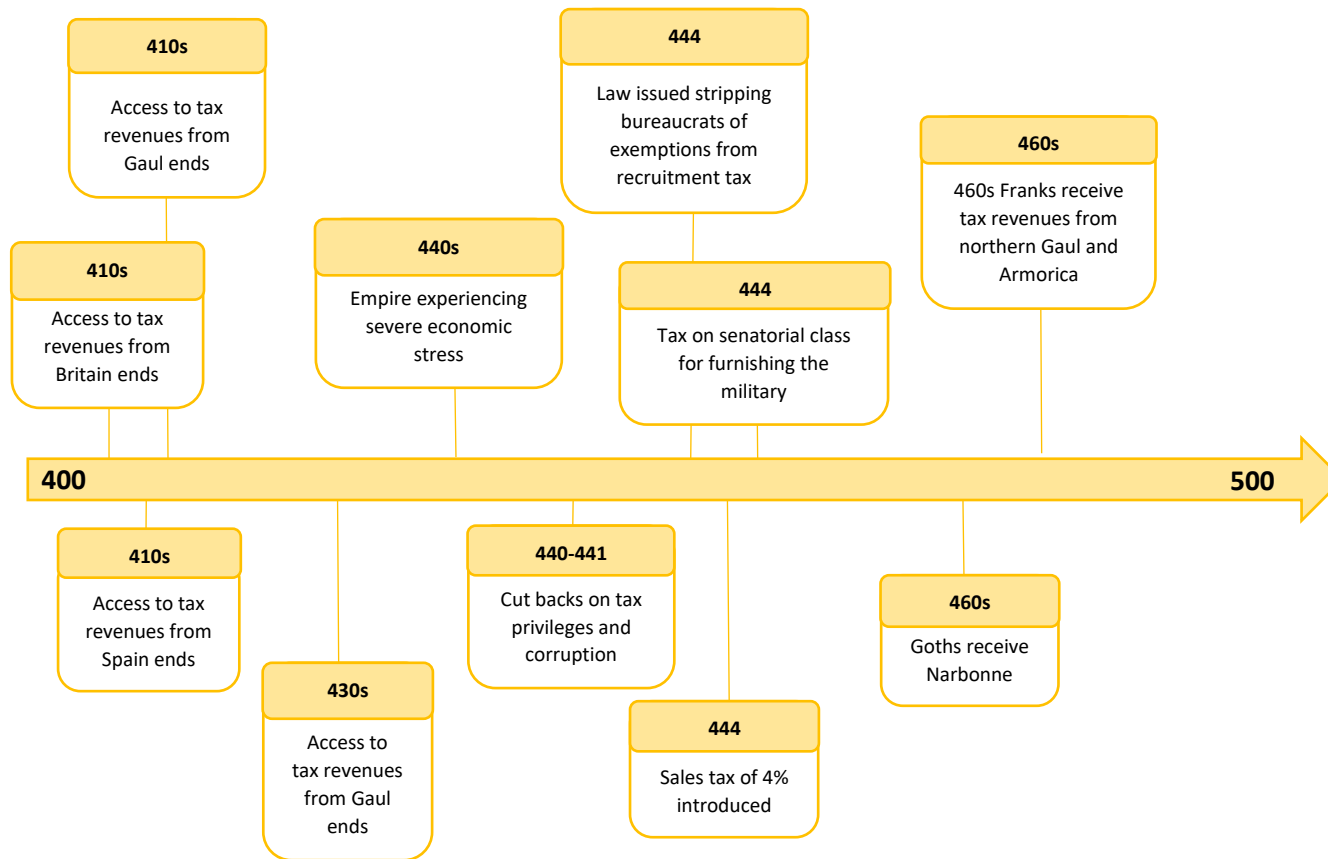


Fig. A.3 Timeline of Economic events in Gaul (Modified from VortigernStudies © Robert Vermaat 1999-2010)

A.1.4 Barbarian Interactions Timeline

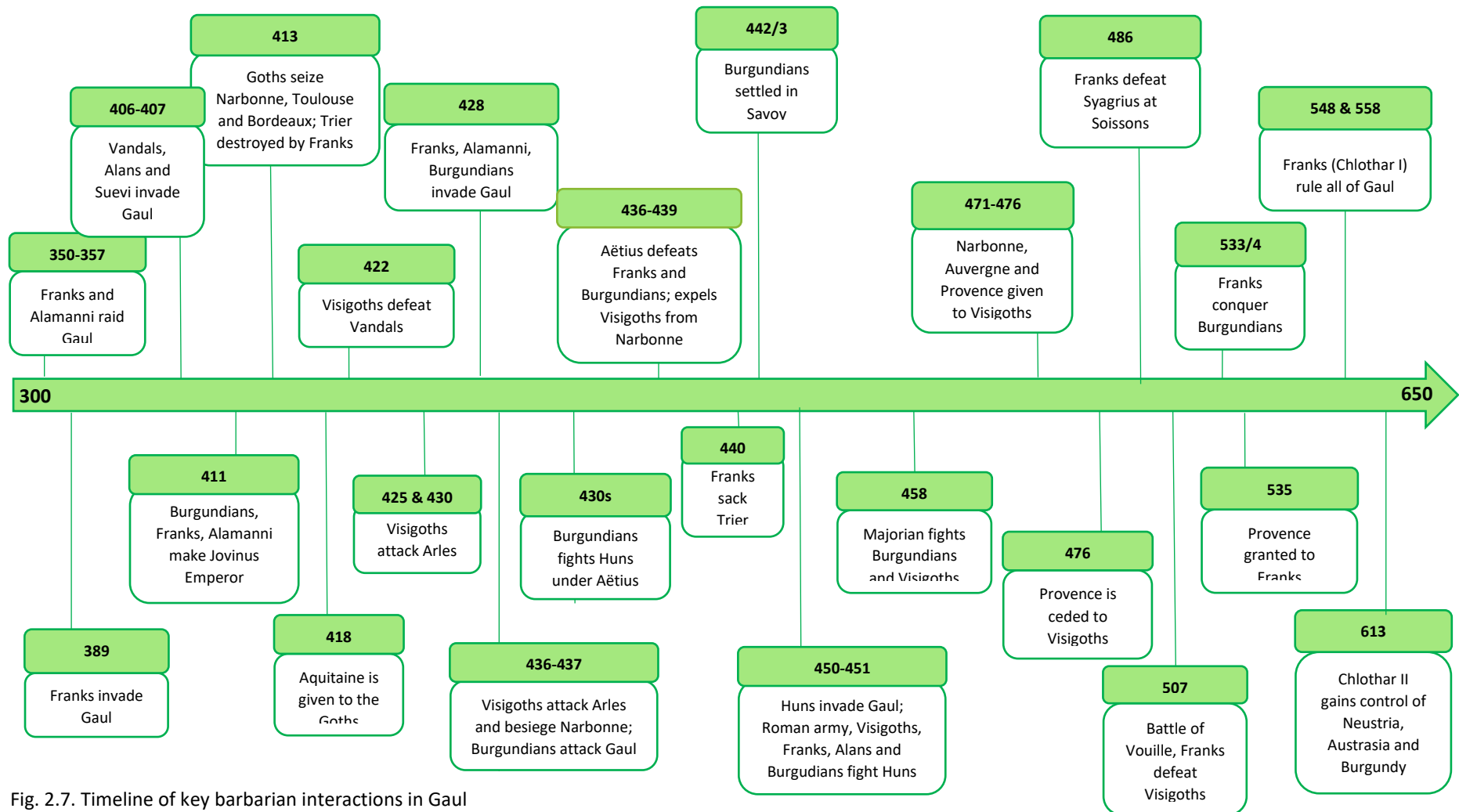


Fig. 2.7. Timeline of key barbarian interactions in Gaul

Appendix 2

Data and Methods

A.2.1 Bone Preservation

The degree of preservation of each skeleton was assessed following McKinley (2004), including analysis of bone surface preservation, degree of fragmentation and completeness. The results of these analyses are in Tables A.2.1-A.2.3.

A.2.1 Surface Preservation of all analysed individuals

Grades	Description	Gallo-Roman South	Late Antique South	Late Antique North
0	Surface morphology clearly visible with fresh appearance to bone and no modifications	1	0	0
1	Slight and patchy surface erosion	17	17	34
2	More extensive surface erosion	41	58	57
3	Most of bone surface affected by some degree of erosion; general morphology maintained but detail of parts of surface masked by erosive action	54	67	97
4	All of bone surface effected by erosive action; general profile maintained and depth of modification not uniform across surface	33	81	102
5	Heavy erosion across whole surface, completely masking normal surface morphology with some modification of profile	8	19	133
6	Extensive modification, completely obscuring the cortical surface of the bone and affecting bone profile	0	0	26

A.2.2 Degree of fragmentation of all analysed individuals

Degree of fragmentation	Gallo-Roman South	Late Antique South	Late Antique North
Minimal	11	30	11
Slight	47	107	113
Moderate	65	87	202
Severe	24	15	106
Extreme	4	0	15
Not scored	13	5	15

A.2.3 Completeness in all analysed individuals

Completeness	Gallo-Roman South	Late Antique South	Late Antique North
1-20%	26	39	126
21-40%	30	54	130
41-60%	19	56	89
61-80%	44	62	77
81-100%	35	26	30
Not scored	10	7	9

A.2.2 Tibial Periosteal Reaction

In analyses of tibia periosteal reaction, the type of new bone formation and degree of healing was recorded. However, these data were not explicitly included or discussed in the main body of the dissertation. The results of these analyses are presented in Tables A.2.4-A.2.5.

A.2.4 Right Tibia New Bone Formation Type

	Gallo-Roman South	Late Antique South	Late Antique North
Tibia PR Present	35	15	32
Woven	5	2	1
Mixed	3	2	9
Lamellar	27	11	22
Active	9	3	10
Healing	22	9	16
Healed	4	2	6

A.2.5 Left Tibia New Bone Formation Type

	Gallo-Roman South	Late Antique South	Late Antique North
Tibia PR Present	37	15	42
Woven	4	1	2
Mixed	7	6	6
Lamellar	26	8	34
Active	11	2	19
Healing	20	12	57
Healed	6	1	16

A.2.3 Intra-observer Error

Sixty individuals included in this research were analysed for a second time to test for intra-observer error using Cohen's Kappa value and the technical error of measurement (TEM) with coefficient of reliability (R) (Goto and Mascie-Taylor, 2007; Perini et al., 2005). Cohen's Kappa is used to assess intra-observer reliability in data collected on a binary basis (presence or absence) (CO, DEH, Tibia PR, Trauma presence, Caries). Because there is a large chance of randomly assigning presence or absence, Kappa value corrects for chance agreement. Kappa values range from 0.01 (poor agreement) to 1.0 (perfect agreement), where kappa values above 0.6 are considered reliable (Cicchetti and Sparrow, 1981; Landis and Koch, 1977). Overall, there was a high level of agreement for most skeletal stress indicators in this analysis (Table A.2.6). The lower kappa value for DEH likely stems from the more complicated nature of the recording system. Although this value still indicates an acceptable level of agreement.

A.2.6 Cohen's Kappa for Crude Prevalence Rate of studied stress indicators

	DEH	CO	Tibia	Caries	Trauma
Kappa Value	0.658	1.0	1.00	1.0	0.843

The technical error of measurement (TEM) with coefficient of reliability (R) is also understood on a 0-1 scale, where 0 is not reliable and 1 is completely reliable (Goto and Mascie-Taylor, 2007; Perini et al., 2005). In this analysis the calculation of TEM and the accompanying R value revealed a very high reliability in measurements of femoral length (Table A.2.7). This could result from the relatively large standard deviation in femur length measurements, as both adult and non-adult femurs were included in the analysis. Separating adult and non-adult femur length measurements did not change R, suggesting that the results are reliable.

A.2.7 Technical Error of Measurement

	Femur length
TEM	0.70
R	0.999

A.2.4 False Discovery Rate

Although divided across five separate manuscripts and the discussion chapter, multiple statistical tests were used to assess differences between samples in this analysis. To decrease the false discovery rate created by multiple statistical tests, Benjamini-Hochberg post-hoc analysis was applied to these data, reducing the probability of Type 1 errors (false positives) (Benjamini and Hochberg, 1995) (Table A.2.8). In this procedure, ranks are determined for all existing p-values as a function of the total number of statistical tests performed (50 tests). A Benjamini-Hochberg critical value is generated $[(i/m)Q]$. In this equation, i is the rank, m is the total number of tests, and Q is the false discovery rate (10%) (Benjamini and Hochberg, 1995). The Benjamini-Hochberg critical value is then compared to the original p-value and rank to determine significance. This analysis did not change significant results.

A.2.8 Benjamini-Hochberg analyses

Rank i	Manuscript/Chapter	Description of Test	Original p-value	Benjamini-Hochberg (i/m)Q
1	Manuscript 2. Health in Roman and Post-Roman Gaul	DEH CPR all individuals between groups	<0.001	0.002
2	Manuscript 2. Health in Roman and Post-Roman Gaul	DEH TPR all individuals between groups	<0.001	0.004
3	Manuscript 2. Health in Roman and Post-Roman Gaul	Tibia PR CPR all individuals between groups	<0.001	0.006
4	Manuscript 2. Health in Roman and Post-Roman Gaul	Caries TPR all individuals between groups	<0.001	0.008
5	Manuscript 2. Health in Roman and Post-Roman Gaul	Age-at-death and CO all individuals LAS	<0.001	0.01
6	Manuscript 3. Desperately Seeking Stress	Comparisons between valid dentine and enamel concentrations	<0.001	0.012
7	Chapter 7. Discussion	CPR Trauma Adults Females	<0.001	0.014
8	Manuscript 5. Gender, Sex and Mortality	Kaplan-Meier Survival Analysis between groups Females	0.004	0.016
9	Manuscript 2. Health in Roman and Post-Roman Gaul	Male Mean Adult Femur Length	0.001	0.018
10	Manuscript 2. Health in Roman and Post-Roman Gaul	multiple DEH (2, 3 and 4) 'lines' between groups	0.001	0.02
11	Manuscript 5. Gender, Sex and Mortality	Adult age-at-death distribution between groups	0.001	0.022
12	Manuscript 5. Gender, Sex and Mortality	Kaplan-Meier Survival Analysis between groups (Males and Females)	0.001	0.024
13	Chapter 7. Discussion	CPR Trauma Adults Between groups	0.001	0.026
14	Manuscript 5. Gender, Sex and Mortality	Kaplan-Meier Survival Analysis LAS Males and Females	0.002	0.028
15	Manuscript 1. Modelling Collapse	Male femur length between groups	0.004	0.03
16	Manuscript 2. Health in Roman and Post-Roman Gaul	Age-at-death and DEH all individuals GRS	0.007	0.032
17	Chapter 7. Discussion	CPR CO between groups adult males	0.007	0.034
18	Manuscript 2. Health in Roman and Post-Roman Gaul	CO TPR all individuals between groups	0.011	0.036
19	Manuscript 5. Gender, Sex and Mortality	Kaplan-Meier Survival Analysis LAN Males and Females	0.011	0.038
20	Manuscript 2. Health in Roman and Post-Roman Gaul	Age-at-death and CO all individuals LAN	0.013	0.04
21	Manuscript 1. Modelling Collapse	The distribution of HAZ scores between groups	0.053	0.042
22	Manuscript 2. Health in Roman and Post-Roman Gaul	Age-at-death and small femur length adults LAN	0.061	0.044
23	Manuscript 5. Gender, Sex and Mortality	Kaplan-Meier Survival Analysis between groups Males	0.067	0.046
24	Manuscript 1. Modelling Collapse	proportion of individuals with stunted growth in each group	0.07	0.048

25	Chapter 7. Discussion	CPR Trauma Adults Males	0.1	0.05
26	Chapter 7. Discussion	CPR DEH between groups adult males	0.11	0.052
27	Manuscript 2. Health in Roman and Post-Roman Gaul	Age-at-death and CO all individuals GRS	0.12	0.054
28	Manuscript 2. Health in Roman and Post-Roman Gaul	Tibia PR TPR all individuals between groups	0.153	0.056
29	Manuscript 2. Health in Roman and Post-Roman Gaul	Caries CPR all individuals between groups	0.175	0.058
30	Chapter 7. Discussion	Enamel cortisol concentrations between groups	0.194	0.06
31	Manuscript 2. Health in Roman and Post-Roman Gaul	CO CPR all individuals between groups	0.197	0.062
32	Chapter 7. Discussion	CPR DEH between groups adult females	0.207	0.064
33	Chapter 7. Discussion	CPR Trauma Adults Males and Females GRS	0.268	0.066
34	Manuscript 2. Health in Roman and Post-Roman Gaul	Female Mean Adult Femur Length	0.315	0.068
35	Chapter 7. Discussion	Dentine cortisol concentrations between groups	0.333	0.07
36	Manuscript 1. Modelling Collapse	Female femur length between groups	0.352	0.072
37	Manuscript 2. Health in Roman and Post-Roman Gaul	Age-at-death and small femur length adults LAS	0.373	0.074
38	Manuscript 3. Desperately Seeking Stress	Enamel differences in cortisol concentrations between males, females and indeterminate individuals	0.407	0.076
39	Chapter 7. Discussion	CPR Trauma Adults Males and Females LAN	0.487	0.078
40	Manuscript 2. Health in Roman and Post-Roman Gaul	Age-at-death and DEH all individuals LAN	0.572	0.08
41	Chapter 7. Discussion	Enamel cortisol concentrations Males and Females	0.663	0.082
42	Manuscript 5. Gender, Sex and Mortality	Kaplan-Meier Survival Analysis GRS Males and Females	0.701	0.084
43	Chapter 7. Discussion	Dentine cortisol concentrations Males and Females	0.751	0.086
44	Manuscript 1. Modelling Collapse	height-for-age differences between groups	0.791	0.088
45	Manuscript 2. Health in Roman and Post-Roman Gaul	Age-at-death and small femur length adults GRS	0.793	0.09
46	Chapter 7. Discussion	CPR CO between groups adult females	0.801	0.092
47	Manuscript 3. Desperately Seeking Stress	Dentine differences in cortisol concentrations between males, females and indeterminate individuals	0.808	0.094
48	Chapter 7. Discussion	CPR Trauma Adults Males and Females LAS	0.821	0.096

49	Manuscript 2. Health in Roman and Post-Roman Gaul	Non-adults- Differences between dental and femoral age	0.879	0.098
m 50	Manuscript 2. Health in Roman and Post-Roman Gaul	Age-at-death and DEH all individuals LAS	0.936	0.1

A.2.5 Clos de Cordeliers

It is possible that the Clos de Cordelier site (from the Late Antique North group) contained individuals who had and may have died from the Justinianic Plague. The site is composed of four mass graves (Castex and Drancourt, 2005) and previous analyses have isolated *Yersinia pestis* DNA from the teeth of several individuals buried within the graves (Drancourt et al., 2004). However, developments in the processing of ancient DNA and anti-contamination protocols have revealed that the initial results may have been contaminated (Gilbert et al., 2004). This finding does not preclude the possibility that Justinianic Plague was present at this site or in these individuals. However, without sufficient aDNA analyses, this determination becomes more speculative.

If the Clos de Cordeliers site is a series of mass graves related to the Justinianic Plague, it may have a mortality profile that is quite different from the rest of the Late Antique North sample. Frequencies of the studied skeletal stress indicators might also vary considerably. To account for this possibility, the individuals from the Clos de Cordeliers site were compared with the remainder of the individuals from the Late Antique North group (Table A.2.9). Although not identical, the proportion of individuals and bone elements with the various pathological conditions are broadly similar between the Clos de Cordeliers and other samples from the Late Antique North group. As stated before, this does not preclude the possibility that *Yersinia pestis* was present at Clos de Cordeliers. However, these results do suggest that it is appropriate to include the individuals from Clos de Cordeliers in larger analyses in this research.

Table A.2.9 Crude and True Prevalence Rates of non-specific stress indicators in Clos de Cordeliers and other Late Antique North individuals

Group		DEH		CO		Tibia PR		Caries		Mean Age-at-Death	
		CPR	TPR	CPR	TPR	CPR	TPR	CPR	TPR		95% CI
Clos de Cordeliers	Affected n (n/N)	8 (14.3%)	57 (10.8%)	4 (7.1%)	5 (10.6%)	3 (5.4%)	15 (34.1%)	20 (35.7%)	82 (15.5%)	27.17	22.67-31.7
	Total (N)	56	528	56	47	56	44	56	528		
LAN (non CDC)	Affected n (n/N)	53 (13.5%)	343 (7.0%)	50 (12.7%)	75 (17.2%)	19 (4.8%)	59 (31.6%)	164 (41.5%)	543 (11.1%)	28.25	26.9-29.6
	Total (N)	394	4912	394	436	394	187	394	4912		

A.2.6 Urban and Rural Differences

Sites from urban and rural contexts were included in the Late Antique groups in this analysis. Although time constraints and word limitations prevented an exhaustive study of differences in skeletal stress indicators between urban and rural contexts, preliminary results are presented below (Table A.2.10).

Table A.2.10 Crude Prevalence Rate of non-specific stress indicators in individuals from urban and rural contexts

Group	Gallo-Roman South	Post-Roman South			Post-Roman North		
	Urban	Urban	Rural	P-Value	Urban	Rural	P-Value
DEH	35 (22.4%)	9 (11.3%)	8 (5.8%)	0.143	7 (20.0%)	54 (13.0%)	0.246
CO	11 (7.1%)	8 (10.0%)	13 (9.4%)	0.875	9 (25.7%)	45 (10.8%)	0.009
Tibia PR	24 (15.4%)	3 (3.8%)	4 (2.9%)	0.724	4 (11.4%)	18 (4.3%)	0.062
Caries	60 (38.5%)	38 (47.5%)	36 (25.9%)	0.001	18 (51.4%)	166 (40.0%)	0.187
Total (N)	156	80	139		35	415	

Cortisol Samples

Table A.2.11. Teeth utilised for cortisol analyses

Sample #	Group	Site	Individual	Sex	Mean Age	Tooth	Valid	Kit #	Tissue	CC/Weight	DEH	CO	Caries	R Femur	L Femur
57a	Late Antique North	ACM (Tombois)	tom 26	5	30.5	LRM3	1	2	D	0.036014	1	0	1		482
58a	Late Antique North	Fontoy	F 26	2	17	LRM2	1	2	D	0.034005	1	0	1		
63a	Late Antique North	Fontoy	F 53	2	17	LRM2	1	2	D	0.046994	0	0	1		
71a	Late Antique North	Fontoy	F 96	3	17	LLM2	1	2	D	0.039668	0	0	0		
72a	Late Antique North	Fontoy	F 109	4	40.5	LRM2	1	2	D	0.029634	0	0	1		
73a	Late Antique North	St Martin de Fontenay	5	1	16.5	ULM1	1	2	D	0.032438	0	1	0		
77a	Late Antique North	St Martin de Fontenay	44	2	40.5	LLM1	1	2	D	0.033683	0	0	0		
79a	Late Antique North	St Martin de Fontenay	46	1	21.5	ULM2	1	2	D	0.048597	0	0	1		
80a	Late Antique North	St Martin de Fontenay	47	1	16	LLM2	1	2	D	0.036784	0	0	0		
84a	Late Antique North	St Martin de Fontenay	85	4	30.5	LRM2	1	2	D	0.026174	1	0	1		
91a	Late Antique North	St Martin de Fontenay	193	5	30.5	LRP2	1	2	D	0.048768	1	0	1		
95a	Late Antique North	St Martin de Fontenay	263b	3	16	LLM2	1	2	D	0.034111	1	0	0		
97a	Late Antique North	St Martin de Fontenay	278	4	30.5	LLM3	1	2	D	0.0524	0	0	1		
41a	Late Antique South	La Granede	Suj 52 Sep 61	5	40.5	LLM2	1	2	D	0.052168	0	0	1		
49a	Gallo-Roman South	Jacques Brel	S112	5	40.5	URM2	1	2	D	0.037893	0	0	1		
50a	Gallo-Roman South	Jacques Brel	S115	3	60	LRC	1	2	D	0.038776	0	0	1		
216	Late Antique North	ACM (Tombois)	Tom 19	3	14.5	LLM2	1	5	E	0.021505	0	0	0		

217	Late Antique North	ACM (Tombois)	tom 25	1	30.5	URM2	1	5	E	0.023612	1	0	1		394
218	Late Antique North	ACM (Tombois)	tom 26	5	30.5	LRM3	1	5	E	0.017441	1	0	1		482
219	Late Antique North	ACM (Tombois)	tom 28	2	21.5	LLM2	1	5	E	0.018126	0	0	1	482	485
220	Late Antique North	ACM (Tombois)	tom 31	3	30.5	LLM3	1	5	E	0.046054	1	0	1	465	453
225	Late Antique North	Fontoy	F 30	1	21.5	LRM3	1	5	E	0.020569	1	0	1	387	392
226	Late Antique North	Fontoy	F 50	5	40.5	URM2	1	5	E	0.02466	1	0	0	484	488
228	Late Antique North	Fontoy	F 55	3	30.5	LRM3	1	5	E	0.018781	0	0	1		
229	Late Antique North	Fontoy	F 63	1	30.5	LLM3	1	5	E	0.018073	0	0	1	437	
235	Late Antique North	Fontoy	F156	3	10	ULM1	1	5	E	0.013879	1	0	0		
236	Late Antique North	Fontoy	F163	3	10	LRM1	1	5	E	0.023455	1	0	0		
203	Late Antique South	La Granede	Suj 52 Sep 61	5	40.5	LLM2	1	5	E	0.013983	0	0	1		
204	Gallo-Roman South	Jacques Brel	S15	3	8	LLM1	1	5	E	0.058254	1	0	1		
207	Gallo-Roman South	Jacques Brel	S57	5	17	URM2	1	5	E	0.014138	0	0	1		
210	Gallo-Roman South	Jacques Brel	S109	5	21.5	LRM2	1	5	E	0.023766	0	0	0		
212	Gallo-Roman South	Jacques Brel	S115	3	60	LLM1	1	5	E	0.027799	0	0	1		
53a	Late Antique North	ACM (Tombois)	Tom 10	4	40.5	LLM2	0	2	D		0	0	1	480	493
54a	Late Antique North	ACM (Tombois)	Tom 11	3	18	LLM2	0	2	D		0	1	0		
55a	Late Antique North	ACM (Tombois)	Tom 19	3	14.5	LLM2	0	2	D		0	0	0		
56a	Late Antique North	ACM (Tombois)	tom 25	1	30.5	URM2	0	2	D		1	0	1		394
59a	Late Antique North	Fontoy	F 28	5	30.5	LRM3	0	2	D		0	0	1	486	488
60a	Late Antique North	Fontoy	F 30	1	21.5	LRM3	0	2	D		1	0	1	387	392
61a	Late Antique	Fontoy	F 40	4	30.5	LLM3	0	2	D		0	1	1		

	North														
62a	Late Antique North	Fontoy	F 50	5	40.5	URM2	0	2	D		1	0	0	484	488
64a	Late Antique North	Fontoy	F 55	3	30.5	LRM3	0	2	D		0	0	1		
65a	Late Antique North	Fontoy	F 63	1	30.5	LLM3	0	2	D		0	0	1	437	
66a	Late Antique North	Fontoy	F 72	5	40.5	LLM3	0	2	D		0	0	1	515	
67a	Late Antique North	Fontoy	F 78	4	45	LRM3	0	2	D		0	0	0		
68a	Late Antique North	Fontoy	F 90	1	21.5	ULM2	0	2	D		0	0	1	437	448
69a	Late Antique North	Fontoy	F 93	3	15	LRM2	0	2	D		1	1	1		
70a	Late Antique North	Fontoy	F 94	1	30.5	URM2	0	2	D		0	0	1		
74a	Late Antique North	St Martin de Fontenay	7	1	21.5	URM1	0	2	D		0	0	0		
75a	Late Antique North	St Martin de Fontenay	28a	3	30.5	LLM2	0	2	D		0	0	0		
76a	Late Antique North	St Martin de Fontenay	32b	5	30.5	URM2	0	2	D		0	0	0		
78a	Late Antique North	St Martin de Fontenay	45	3	21.5	LRM3	0	2	D		1	0	0		
81a	Late Antique North	St Martin de Fontenay	49	2	21.5	LRM1	0	2	D		1	0	0		
82a	Late Antique North	St Martin de Fontenay	49	2	21.5	ULC	0	2	D		1	0	0		
83a	Late Antique North	St Martin de Fontenay	72b	1	21.5	URM2	0	2	D		0	1	1		
85a	Late Antique North	St Martin de Fontenay	85	4	30.5	URM2	0	2	D		1	0	1		
86a	Late Antique North	St Martin de Fontenay	105	3	12	LLM1	0	2	D		0	1	0		
87a	Late Antique North	St Martin de Fontenay	148A	2	45	LRM3	0	2	D		1	1	1		
88a	Late Antique North	St Martin de Fontenay	148D	1	21.5	LRM2	0	2	D		0	0	0		
89a	Late Antique North	St Martin de Fontenay	189	2	21.5	LLM2	0	2	D		1	0	0		
90a	Late Antique North	St Martin de Fontenay	189	2	21.5	LRP1	0	2	D		1	0	0		

92a	Late Antique North	St Martin de Fontenay	196	1	16	URM1	0	2	D		1	0	1		
93a	Late Antique North	St Martin de Fontenay	213	1	45	URM2	0	2	D		0	0	1		
94a	Late Antique North	St Martin de Fontenay	219	1	21.5	URM1	0	2	D		0	0	1		
96a	Late Antique North	St Martin de Fontenay	273b	1	21.5	LLM2	0	2	D		1	0	0		
98a	Late Antique North	St Martin de Fontenay	293	1	30.5	ULM2	0	2	D		0	0	1		
99a	Late Antique North	St Martin de Fontenay	301	5	30.5	ULM2	0	2	D		0	1	1		
40a	Late Antique South	La Granede	subj 39 sep 48	1	21.5	LLM2	0	2	D		0	1	0		
42a	Gallo-Roman South	Jacques Brel	S15	3	8	LLM1	0	2	D		1	0	1		
43a	Gallo-Roman South	Jacques Brel	S23	5	40.5	LLM2	0	2	D		1	0	1		
44a	Gallo-Roman South	Jacques Brel	S26	3	8	LLM2	0	2	D		1	0	0		
45a	Gallo-Roman South	Jacques Brel	S82	5	30.5	URM2	0	2	D		0	0	1		
46a	Gallo-Roman South	Jacques Brel	S57	5	17	URM2	0	2	D		0	0	1		
47a	Gallo-Roman South	Jacques Brel	S98	1	30.5	ULM2	0	2	D		0	0	1		
48a	Gallo-Roman South	Jacques Brel	s109	5	21.5	LRM2	0	2	D		0	0	0		
51a	Gallo-Roman South	Jacques Brel	S115	3	60	LLM1	0	2	D		0	0	1		
52a	Gallo-Roman South	Jacques Brel	S119	3	12	ULM1	0	2	D		1	0	0		
214	Late Antique North	ACM (Tombois)	Tom 10	4	40	LLM2	0	5	E		0	0	1	480	493
215	Late Antique North	ACM (Tombois)	Tom 11	3	18	LLM2	0	5	E		0	1	0		
221	Late Antique North	ACM (Tombois)	tom 32	3	21.5	URM2	0	5	E		0	1	1		
222	Late Antique North	ACM (Tombois)	tom 35	5	16	LLM2	0	5	E		0	1	1	489	487
223	Late Antique North	Fontoy	F 26	2	17	LRM2	0	5	E		1	0	1		
224	Late Antique	Fontoy	F 28	5	30.5	LRM3	0	5	E		0	0	1	486	488

	North														
227	Late Antique North	Fontoy	F 53	2	17	LRM2	0	5	E		0	0	1		
230	Late Antique North	Fontoy	F 90	1	21.5	ULM2	0	5	E		0	0	1	437	448
231	Late Antique North	Fontoy	F 93	3	15	LRM2	0	5	E		1	1	1		
232	Late Antique North	Fontoy	F 94	1	30.5	URM2	0	5	E		0	0	1		
233	Late Antique North	Fontoy	F 96	3	17	LLM2	0	5	E		0	0	0		
234	Late Antique North	Fontoy	F 109	4	40.5	LRM2	0	5	E		0	0	1		
237	Late Antique North	Fontoy	F171	3	15	LLM2	0	5	E		0	0	0		
200	Late Antique South	La Granede	Suj 2 Sep 1	5	45	URM3	0	5	E		1	0	1		
201	Late Antique South	La Granede	Suj 8 Sep 10	3	8	LLM1	0	5	E		1	1	0		
202	Late Antique South	La Granede	Suj 39 Sep 48	1	30.5	LLM2	0	5	E		0	1	0		
205	Gallo-Roman South	Jacques Brel	S23	5	40.5	LLM2	0	5	E		1	0	1		
206	Gallo-Roman South	Jacques Brel	S26	3	8	LLM2	0	5	E		1	0	0		
208	Gallo-Roman South	Jacques Brel	S82	5	30.5	URM2	0	5	E		0	0	1		
209	Gallo-Roman South	Jacques Brel	S98	1	30.5	ULM2	0	5	E		0	0	1		
211	Gallo-Roman South	Jacques Brel	S112	5	40.5	URM2	0	5	E		0	0	1		
213	Gallo-Roman South	Jacques Brel	S119	3	12	ULM1	0	5	E		1	0	0		

