University of Reading

Lepro-C: Defining the Macroscopic Assessment of Leprosy Using the Evidence of Child and Adult Skeletal Remains

PhD Archaeology

School of Archaeology

Thomas Mills

April 2024

Front Matter

Declaration

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

Thomas Mills, April 2024

Acknowledgements

I must first thank my supervisors, Prof Mary Lewis and Prof Anne Lawrence-Mathers. I literally would not have got to this point without their sound guidance and being so rigorously and helpfully held to account at all times of the journey. They are both so busy with all manner of different projects, yet I never felt like an afterthought, and for that I am eternally grateful and very much hope to stay in touch in some capacity in the future. I would also like to thank Prof Aleks Pluskowski for taking the time to chair all of my Advisory Panel meetings.

Secondly, I need to thank those that facilitated my access to Chichester and Winchester. So, many thanks to Prof Jo Buckberry for kindly facilitating my access to the University of Bradford. Many thanks also to Dr Heidi Dawson-Hobbis and Mr David Ashby for facilitating my access to the University of Winchester. These thanks are particularly pertinent given the covid disruption over the course of 2020 and 2021 that severely affected my data collection plans, and the difficulties that arose in navigating that and arranging visits.

Thirdly, I need to thank my family; Mum and Dad for always being proud and supportive, my sister Kerstine for the grim chats about pathology and my niece Maimie, who will probably take over the world.

I also need to thank Fran Roach and Louise Taylor, whose friendship and camaraderie were essential. The Triangle of Snark™ is alive and well, and long may it continue.

Finally, thanks go to my partner Nikoleta. She above all has carried me through this and is very much the sunshine that shines through the spectrumy clouds (although I was obviously the picture of grace and decorum at all times during this research). Обичам те и нямам търпение да се впуснем в следващата стъпка от нашето пътуване заедно.

And to Luke – I am your father.

Abstract

This project explored the nuance and variability of macroscopic skeletal manifestations of leprosy in 252 individuals from two leprosarium cemeteries from late medieval England. Modern clinical literature and translated medieval Latin medical texts were used to assess how leprosy was being diagnosed at the time, and how that compares with modern-day leprosy.

The aims of this research were to develop a new method to assess leprosy in skeletal remains, called Lepro-C, to increase diagnostic rigour in palaeopathology; assess the nuance and variability of leprosy in skeletal remains with reference to recent clinical research, including identifying previously unexplored lesions in skeletal individuals of adult ages. It also aimed to reassess the diagnostic capabilities of medieval physicians by directly engaging with the medieval medical texts of Constantine the African and John de Gaddesden.

The main conclusions from this research are that Lepro-C shows promise as a replicable and rigorous approach to assessing leprosy in skeletal remains; previously unexplored lesions for leprosy in bioarchaeology show encouraging links to leprosy; adults aged 26-35 years were most likely to die displaying the most distinctive signs of leprosy; and absorptive rhinomaxillary lesions are morphologically variable. It also showed that distinctive macroscopic combinations of leprosy lesions occur in non-adults older than 10 years, but other criteria are required for individuals younger than this in future research. This research also showed that Medieval physicians had a solid grasp on the variable manifestation of leprosy in affected individuals, noting symptoms comparable to that of modern clinical leprosy.

Lepro-C provides a way forward to improve our knowledge of the variable expression of leprosy in skeletal material, to increase the soundness of the contribution that palaeopathology can make to the wider discussion of leprosy, past and present, via consistent and replicable assessment. The medieval Latin texts also demonstrate the value of actively implementing a multidisciplinary approach to research by using primary historical resources to inform discussions.

Covid-19 Impact Statement

The data collection phase of this research, which was scheduled to take place over the course of 2020 and 2021, was severely impacted by the Covid-19 pandemic. The pandemic and ensuing lockdowns struck just as I had finalised data collection plans with Winchester for 2020. My planned trips to Winchester in the summer of 2020 had to be cancelled, as they were not allowing external researchers to come in that time (save for 1 week in September where I was able to arrange access). The visits I rescheduled around Christmas in 2020 were then also cancelled due to the lockdowns announced at short notice at that time, as Winchester did not allow external researchers to come due to these lockdowns and the ongoing regulatory uncertainty between lockdowns. This meant that by the end of 2020 I had only been able to complete a single week of data collection, which had a knock-on effect for the remainder of my data collection in 2021. I was only able to complete my Winchester data collection in August 2021, which left until the end of 2021 to complete my remaining data collection, as I had to progress to writing-up in 2022. This meant that I had to complete my Chichester data collection at Bradford in a compressed timeframe in October and November in 2021, and then had no time left to look at the Timberhill assemblage.

This situation was complicated further as I am a part-time student that works full-time, so there was the additional complication of having to also arrange time away from work. The rearranged data collection had to take place at the times agreed with my work, as I'd had to repeatedly cancel visits for reasons outside my control, and I had no remaining leave or goodwill to spend by this point.

These factors mean that the amount of data collected is not as extensive as planned. There was also the intention to collect radiographic data, particularly from the non-adults at Winchester, but the ongoing delays and need to complete data collection in a compressed timeframe meant that the macroscopic data at Chichester and Winchester had to be prioritised, particularly as it was still unclear at that point how much longer the disruption would continue for. Therefore, if the thesis had not been impacted by this disruption there would have been more macroscopic data from a third site to consider, as well as radiographic evidence to further explore leprosy lesions in skeletal remains.

To mitigate for this as much as possible, the chapters where I directly translate and engage with medieval medical texts and where Lepro-C is applied to previous papers were introduced to broaden and diversify the scope of thesis into areas that inherently could not be impacted by the pandemic, to ensure that the thesis had as much opportunity as possible to make original contributions to the field in light of the covid disruption.

I ask the examiners to take these factors into account when considering the scope of the thesis as it turned out.

Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1 Background to Research

Leprosy is a complex disease, caused by the bacteria *Mycobacterium leprae* and *Mycobacterium lepromatosis*. This is reflected in its variable presentation in modern clinical and bioarchaeological contexts, and is driven by the variable immune status and response thereof of affected individuals. This has important implications for how leprosy may manifest on bone. Leprosy also has a complex social history, with recent revisionist historical research showing that people suffering from leprosy in late medieval England were not always viewed as social outcasts, and were in fact venerated in some cases (Rawcliffe, 2007).

The Danish medical historian and palaeopathologist, Vilhelm Møller-Christensen (1903-1988), was the first to catalogue the range of leprous changes in skeletons excavated from St George's leprosarium in Naestved, Denmark. Moller-Christensen published his observations over a period of 25 years (Moller-Christensen, 1953; 1961; 1967; 1978). Using knowledge of the clinical manifestations of the disease on the soft tissue, he described a series of lesions, many of which are still used today. These publications were the first to provide detailed descriptions, scoring schemes and illustrations that showed the variety of expression of the lesions associated with leprosy. This research was built upon by Johannes Andersen (1923-2005) and Keith Manchester (b. 1938) (with others), who developed the criteria for the *rhinomaxillary syndrome* in leprosy, distinguishing it from the *facies leprosa* developed by Møller-Christensen. This was to adequately distinguish the bony changes caused by leprosy from the soft tissue lesions and to account for the different underlying causes and progression of these lesions (Andersen and Manchester, 1992: 122). Andersen and Manchester also added other lesions to the criteria for assessing leprosy in skeletal remains, including palmar grooving, dorsal tarsal exostoses, as well as septic changes related to leprosy. This research was built upon with further lesions described by Lewis et al. (1995).

Leprosy continues to be identified and reported in individuals in an archaeological context, with the majority of papers focussed on individual 'first' cases or on chemical analyses. However, the introduction of new lesions for use in appraising leprosy has been scant in recent years. Concern regarding diagnostic rigour in palaeopathology generally was highlighted as a widespread issue by Zuckerman et al. (2016). The variable consistency and rigour noted there is present when reviewing

recent studies concerning leprosy (Blau and Yagodin, 2005; Rubini and Zaio, 2009; Roffey and Tucker, 2012; Antunes-Ferriera, 2013; Crespo et al., 2017), these papers routinely cite the pioneering research into the macroscopic assessment of leprosy in skeletal remains without full consideration of the source material or how terminology and descriptions should be applied to provide consistency. This has resulted in the macroscopic diagnosis of leprosy in skeletal individuals amounting to something of a 'box-ticking' exercise, which belies the macroscopic complexity and variability of the expression of the disease from one individual to the next. Where lesions have been introduced, there is no evident basis (clinical or otherwise) that the lesions are leprogenic, and have not been presented as part of a usable and replicable criteria (see Boldsen, 2001; 2005; 2009). This inconsistency in methodological approach and rigour masks the complexity and variation of leprosy as a disease, and how it presents morphologically in skeletal remains, and hampers the contribution that macroscopic assessment of skeletal remains can make in bioarchaeological investigations. This is concurrent with the rise of the use of aDNA to confirm the presence of *M. leprae* in the absence of pathognomonic features with the implication that the presence of the aDNA is enough to confirm a diagnosis of leprosy (Cole et al., 2022). Finally, while pioneering in terms of the lesions to consider, the research by Møller-Christensen and Andersen and Manchester does not provide rigid and replicable criteria to consistently assess whether leprosy is present in skeletal remains and to what extent. The criteria that they have assembled provides a list of lesions to consider, but does not disclose how many lesions need to be present and in what combinations to diagnose leprosy unless the five rhinomaxillary syndrome lesions are present (see Andersen and Manchester, 1992), which is problematic in less extensive cases of leprosy as all five rhinomaxillary syndrome lesions are rarely all present in a single individual, with preservation and excavation biases also possibly being an issue (Inskip et al., 2017). There are also novel sites for skeletal lesions to consider based on a reappraisal of modern clinical research.

An important backdrop to this research is also the clinical and sociological context of leprosy in the medieval England and how it was perceived by physicians and in wider society. Leprosy was explained by medieval physicians as an overly dry and cold complexion (Demaitre, 2007: 177) with an excess of black bile (Dols, 1983; Rawcliffe, 2006). This overall excess was secondary to an imbalance of one of the individual humours, which had become overheated and burned to ash or putrefied within the body (Demaitre, 2007: 177; Miller and Nesbitt, 2010), leading to a specific form of leprosy based on the precise symptoms of the individual concerned and the humour affected (Brody, 1974: 37). If burned, yellow bile led to *leonine* leprosy, characterised by wrinkled facial skin, yellow in colour, and swiftly developing (Demaitre, 2007: 178). Burning of black bile caused *elephantia*, characterised by nodes and tuberosities, cracking skin, blackish in colour, and carried

the longest-term and potentially most serious prognosis (Demaitre, 2007: 177). Burning of phlegm resulted in *tyrian* leprosy, and was characterised by a white scaliness of the skin, and whitish face, with an 'intermediate' prognosis (Demaitre, 2007: 177). Finally, burning of blood led to *alopecia*, characterised by patchy hair loss, with a red face and eyes (Demaitre, 2007: 177). This subdivision of leprosy in medieval medicine has interesting implications for the comparison of 'medieval' and 'modern' leprosy. The descriptions of symptoms and prognoses indicate an awareness in medieval medicine of the variable manifestations of leprosy, arguably comparable to the lepromatous-tuberculoid spectrum that modern medicine uses today. This suggests that medicine and diagnosis from the medieval period should not be simply written off due to the 'incorrect' underlying theories of disease when compared with those of modern medicine, and that direct comparisons between 'medieval' and 'modern' leprosy can be made, in terms of clinical signs and symptoms, warranting further exploration in this research.

There are also wider social and spiritual comparisons that can be made between 'medieval' and 'modern' leprosy. For example, the soul could be affected equally by disease as much as the physical body in medieval medicine (Rawcliffe, 2006). Similar examples can be found in modern day scenarios, such as the social and spiritual marginalisation of individuals suffering from leprosy in South-East Asia, where individuals are isolated from their wider community, and carry the stigma of disease and spiritual pollution for wrongdoings in a past life (Schug, 2016), or in northern Nigeria, where individuals with leprosy are viewed by some as dirty, incurable and inferior (Dahiru et al., 2022). This contrasts with the favourable view of leprosy in some instances in the medieval period, where people with leprosy were venerated in their suffering (Rawcliffe, 2006: 60). However, there were negative perceptions in the medieval period also, such as the 'Leper's Plot' of 1321 in France, where a wave of paranoia swept across the country about an alleged plot where people with leprosy would poison wells across France to either kill healthy individuals or infect them with leprosy (Miller and Nesbitt, 2014: 96-97). This led to many individuals with leprosy being killed in riots or burnt at the stake before King Philip V issued a pardon to all people with leprosy that had been accused of wrongdoing, tacitly conceding the plot was a hoax in doing so (Miller and Nesbitt, 2014: 96-97). These examples suggest that the distinction between 'medieval' and 'modern' leprosy is perhaps not helpful and represents a false dichotomy of a disease that has always been subject to complex social and spiritual perceptions in space and time, while also remaining clinically identifiable in that time also, with medieval physicians showing an awareness of the variable signs and symptoms comparable to leprosy in a modern clinical setting, albeit with no knowledge of *M. leprae* and bacterial transmission of disease.

The above sets the scene for this research, and the following indicates the methodological approach and research aims adopted to build upon previous research.

1.2 Methodological Approach and Research Aims

1.2.1 Macroscopic Approach

This research builds on the previous work on the on the macroscopic indicators of leprosy in skeletal remains by devising a replicable assessment method called Lepro-C (Leprosy Criteria). Lepro-C provides clearly defined categorical definitions for the likelihood of leprosy displayed by an individual, and clearly defines what combinations of lesions need to be present to reach those categories. Modern clinical literature concerning leprosy was also extensively reviewed to identify any areas on the skeleton that might display evidence of leprosy that may not have been considered previously in bioarchaeological investigations.

1.2.2 Historical Evidence for Leprosy

This research also builds upon revisionist historical literature about leprosy (Rawcliffe, 2006; Demaitre, 2007) by directly engaging with medieval Latin medical texts that were in wide circulation at the time the leprosaria were in operation. This was to challenge the notion that accurate diagnoses and descriptions of leprosy were rare in medieval England (Gussow and Tracy, 1970; Brody, 1974; Covey, 2001). It was important to assess this medieval Latin material as the evidence of the awareness of the signs and symptoms of leprosy in the translated medical texts suggests that individuals displaying no/few skeletal lesions in the leprosarium assemblages may have still been suffering from leprosy, just a form that has not manifested skeletally, rather than being diagnosed with another disease when granted entry to the leprosaria, given the comparability of 'medieval' and 'modern' leprosy that this suggests.

The medical works analysed are sections of the *Viaticum* by Constantine the African (AD 1015-1098), the *Rosa Anglica* by John de Gaddesden (published *ca.* 1314), with the medieval Latin translated and analysed. The *Compendium* by Gilbertus Anglicus (published *ca.* 1240) is also discussed in the context of the Middle English translations of this work by Getz (2010), as this provides important context of the medical knowledge circulating in the lay population in the Late Medieval period. These three publications are not an exhaustive account of all the medical literature potentially available to late medieval physicians, but are considered in this research as Constantine the African was a key early figure in Western medicine through his translation of Arabic medical works, and Gilbertus Anglicus and John de Gaddesden were the two best known doctors from the British Isles

from this period; both were mentioned in Chaucer's *The Canterbury Tales*, for example (Pearn, 2012).

1.3 Aims and Objectives

The aims and objectives of this research were:

1.3.1 Aims

- Assess the skeletal expression of leprosy in skeletal remains with reference to recent clinical research.
- Increase diagnostic rigour in the assessment of leprosy palaeopathology.
- Reappraise the diagnostic capabilities of medieval physicians to inform questions about leprosy lesion distribution in leprosarium skeletal assemblages.

1.3.2 Objectives

- Determine the combination of lesions necessary to accurately diagnose leprosy in skeletal remains, with special reference to modern clinical cases to identify previously unexplored lesions in archaeological assemblages.
- Distil these combinations into a rigorous and replicable method for the macroscopic assessment of leprosy in skeletal remains, called 'Lepro-C'.
- Examine the different expressions of leprosy in child and adult individuals to consider the timeframe in which lesions occur, and any variation in lesions expressed.
- Macroscopically examine assemblages from leprosaria in medieval England to fully assess the characteristic appearance of lesions and combinations thereof.
- Apply Lepro-C to primary palaeopathology literature concerning individual leprosy cases.
- Collate information on the expression of leprosy via direct analysis of medieval medical texts, to provide historical context for the assemblages, and reframe the diagnostic capabilities of physicians in medieval England.

1.4 Structure

This thesis is divided into eight chapters that clearly consider the clinical, historical, and bioarchaeological background of leprosy, which inform the criteria that were then applied to the skeletal assemblages under study. These criteria were then applied directly to skeletal assemblages.

This multidisciplinary approach was adopted to explore how actively incorporating clinical, historical and bioarchaeological evidence in research design can inform us about leprosy in medieval England and build on previous research.

Chapter 2 explores the development of the study of leprosy in the bioarchaeological and historical fields respectively. Chapter 2 also contains the translation and assessment of medieval Latin texts to assess the diagnostic capabilities of physicians in late medieval England.

Chapter 3 explores the diagnosis of leprosy in the archaeological record, and outlines the possible differential diagnoses for lesions associated with leprosy. It systematically considers the five rhinomaxillary syndrome lesions and possible differential diagnoses, followed by a consideration of other cranial and postcranial lesions and potential differential diagnoses for them.

Chapter 4 introduces the skeletal assemblages under study, including their archaeological and historical background. The methods used to assess the skeletal material are outlined, including a description of each lesion under consideration, as well as Lepro-C being outlined in full. The statistical methods employed to interrogate the data are also outlined.

Chapter 5 details the results of the macroscopic assessment of the two skeletal assemblages under study in this research. It begins by detailing the broad demographic data and true prevalence rate of lesions and is followed by a lesion-by-lesion account of the rates of lesions by age and sex at Chichester and Winchester. The lesion-by-lesion section is separated into cranial lesions, upper postcranial lesions, lower postcranial lesions, and lesions that could occur anywhere, with the relevant statistical analyses for those lesions to age and Lepro-C categories at the end of each section respectively. The chapter ends by detailing the statistical relationships of lesions to each other, to describe what trends were present in the data.

Chapter 6 directly applies the Lepro-C criteria to previously published journal articles concerning leprosy. The purpose of this was to directly identify and assess the inconsistency in the macroscopic assessment of leprosy in skeletal remains, and how the Lepro-C method can be used to improve this going forward and provide a consistent baseline. This chapter also establishes recommendations for the description and depiction of leprosy lesions that should be adopted (where possible) in leprosy research going forward.

Chapter 7 discusses the salient outcomes of the results. It follows a thematic approach, such as discussing demography, various case studies, lesion expression, occurrence of lesions not researched in-depth previously. It also establishes recommendations for describing and identifying certain rhinomaxillary syndrome lesions. This is done with reference the historical and socioeconomic context of the assemblages where appropriate.

Chapter 8 details the conclusions, limitations of the study, and recommendations for future research.

Chapter 2: Modern Clinical Leprosy and Diagnosis of Leprosy in Medieval England

Leprosy is caused by the bacteria *Mycobacterium leprae* and *Mycobacterium lepromatosis*, and remains an endemic disease in several developing nations in the present day (see Crawford 2010; Penna et al., 2009; Penna et al., 2013; Shrivastava, 2014; Lusli et al., 2016; Muthuvel et al., 2017), particularly in large and rapidly developing countries with stark economic inequality and distinct social classes, such as Brazil and India (Deogaonkar, 2004, Chamarbagwala, 2006; Thakkar and Patel, 2014; Walker et al., 2017). This is despite leprosy being treatable via multi-drug therapy if caught early (Suzuki et al, 2012; Nascimento, 2013; Wang et al., 2016). Previous studies (Britton and Lockwood 2004, Inskip et al., 2015) have noted that *Mycobacterium leprae* has evolved slowly since ancient times, and any genetic variation between strains will not affect how leprosy clinically manifests in an individual. Therefore, modern clinical literature concerning the manifestation of leprosy in children and adults is a useful resource to assess how leprosy may present in late-medieval skeletal remains, particularly for lesions that present clinically that may have not been considered in palaeopathology previously. The following will first consider the clinical manifestations of leprosy, the history and development of research in this field, and how clinical research may be further used to inform palaeopathological studies.

2.1 Overview of Modern Clinical Leprosy

Leprosy is primarily a disease of the nervous system (Nascimento, 2013), with any skeletal involvement secondary to neuropathy. The immune response of an individual to bacilli determines the form and extent of leprosy lesions; those with high resistance to leprosy bacilli tend towards tuberculoid leprosy, characterised by unilateral skin lesions and relatively quick development of symptoms (Lastoria and Abreu, 2014; Talhari et al., 2015), and those with low resistance tend towards lepromatous leprosy, where symptoms take longer to develop and can result in bilateral absorptive lesions on the extremities, and destructive lesions in the oral and nasal region (Britton and Lockwood, 2004; Inskip et al., 2015). This results in a spectrum of lesions with borderline variants dependent on an individual's immune response (Bleharski et al., 2003). The consistent symptom in all forms of leprosy however is the loss of sensation due to neuropathy in the affected areas. Various strains of *Mycobacterium leprae* exist, however the genetic variation between each

strain is minimal, and the particular strain contracted does not affect the morphological expression of leprosy in an individual (Britton and Lockwood, 2004). The primary benefit of genetic variation between strains of *M. leprae* is to determine the geographical origins of the strain, which can be used to inform the distribution and evolution of leprosy, and by proxy, the movement of individuals and populations. The *M. leprae* bacterium has a predilection for cooler regions of the body, hence lesions tend to develop in the extremities and nasal/oral regions of the face (Andersen and Manchester, 1992).

Transmission of *M. leprae* between hosts is believed to be via long-term exposure to air-borne droplets and infected skin cells (Davey and Rees, 1974; McDougall et al., 1975; Job et al., 2008; Suzuki et al., 2012; Smith and Aerts, 2014). However, most carriers of *M. leprae* remain non-infectious, as the bacilli remain contained within infected cells, and frequent and close contact is required for transmission to occur (Suzuki et al., 2012; Smith and Aerts, 2014). Individuals at the lepromatous pole (Ridley and Jopling, 1962; 1966) shed *M. leprae* bacilli via nasal mucosa and skin cells (Job et al., 2008; Suzuki et al., 2012). After infection, the disease has a long incubation period before any symptoms become apparent. The average incubation period is 2-4 years, but it can be as little as 6 months for symptoms of the tuberculoid form, or as long as 20 years for symptoms of the lepromatous form, to appear (Lockwood, 2004; Smith and Aerts, 2014). Indeed, in spontaneous leprosy cases of chimpanzees infected during infancy, the pathological indicators of leprosy took decades (as much as 30 years) to appear (Alford et al., 1996; Suzuki et al., 2012; Han and Silva 2014). Formal clinical diagnosis of leprosy is primarily made on the presence of *M. leprae* bacilli in thickened peripheral nerves and skin lesions of the affected regions (Fischer, 2017), along with loss of sensation to those regions (Suzuki et al., 2012). Once infected, *M. leprae* then spreads via haematogenous channels (Talhari et al., 2015). Clinical cases of leprosy are also classified on a 5-point scale devised by Ridley and Jopling (1962; 1966), based on a combination of visual examination, histopathological and immunological tests. Leprosy is treatable; however the success of treatment depends primarily on how soon the disease is treated, and the underlying immunological susceptibility of the individual to adverse reactions to the leprosy bacilli (Ridley and Jopling, 1962; 1966; Suzuki et al., 2012; Nascimento, 2013; Wang et al., 2016).

The tuberculoid form of the disease in a clinical setting is characterised by a self-limiting expression of lesions (Brandao et al., 2018; Liu et al., 2018)(Fig. 2.1) with limited bacterial involvement and relatively high expression of type 1 cytokines (proteins that signal an immune response; Barns and Wizel, 2000; Teijaro et al., 2014; Yamamura et al., 1991; Bleharski et al., 2003) indicative of a strong cell-mediated immunity (Ridley and Jopling, 1966; Yamamura et al., 1991; Bleharski et al., 2003). This is contrasted by the clinical characterisation of lepromatous leprosy, in which patients present

with disseminated lesions and significantly higher bacterial loads (Bleharski et al., 2003; Santos et al., 2017), which can result in extensive and severe clinical manifestations (Fig 2.2). Interestingly, the pronounced immune response characteristic of tuberculoid leprosy can result in early and severe neuropathy that is irreversible due to increased fibrosis of nerves as a result of intense immunological activity (Dastur, 1983), demonstrating that tuberculoid leprosy can also be severe and potentially debilitating. As while lepromatous leprosy may have a more severe clinical presentation ultimately, it progresses slowly, increasing potential for recovery of nerves after the onset of symptoms (Dastur, 1983; Chaise and Roger, 1985) as opposed to the relatively acute course of tuberculoid leprosy.

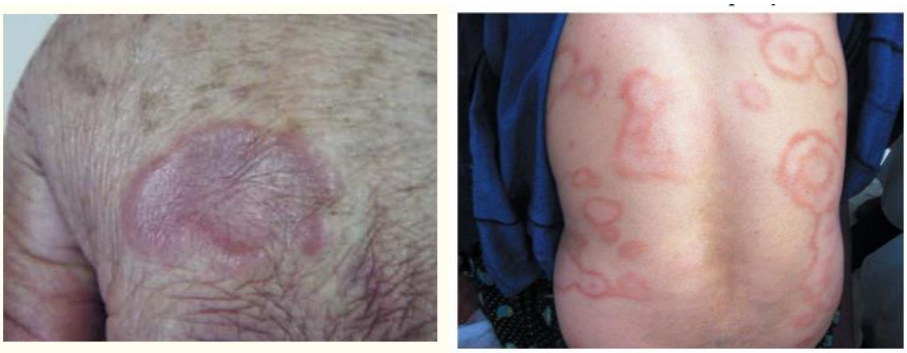


Fig. 2.1: Skin lesions caused by tuberculoid leprosy. Left image from Lastoria and Abreu (2014: 210); Right image from Esfandbod (2011: 1657).

Han et al. (2008) identified a new causative agent of leprosy, *Mycobacterium lepromatosis*, via analysis of bacteria obtained from autopsies of liver tissue of two individuals that suffered from lepromatous leprosy. This was built upon by Han et al. (2012) where they suggest that *M. lepromatosis* is endemic to Mexico, but is also present outside of central America (Han et al., 2014). Han et al. (2012) suggested that *M. leprae* and *M. lepromatosis* diverged from a common ancestor 10 million years ago, although they do not state where. This is far earlier than evidence for even the earliest hominins, however (Schrenk, 2013). This raises questions about the co-evolution between host and disease, and the continued susceptibility of hosts to the bacteria as they evolved. This is particularly interesting given the limited genetic diversity and stability of the leprosy bacterium genomes through time that Han et al. (2008) suggested, combined with the predilection for humans to be natural hosts of the bacteria (Monot et al., 2005; Han et al., 2008). Honap et al. (2018), however, note that non-human primates may become infected by leprosy bacteria in human-primate interactions, and may also be natural hosts. Armadillos (Carlock et al., 2020) and British red squirrels are also hosts (Meredith et al., 2014). Subsequent research has shown that *M. lepromatosis* is infrequently reported in medical literature, and the clinical aspects are poorly

characterised (Deps and Collin, 2021), although it is accepted as a second causal agent of leprosy (Sharma et al, 2020). Of the 21 clinical *M. lepromatosis* cases that Deps and Collin (2021) have reported on since 2008, all but two individuals displayed lepromatous leprosy, with two borderline leprosy cases. There were no tuberculoid cases, so *M. lepromatosis* primarily causes lepromatous leprosy based on the clinical data available. Dual infection of *M. leprae* and *M. lepromatosis* has also been observed (Widiatma and Sukanto, 2019; Aldama Olmedo et al., 2020).

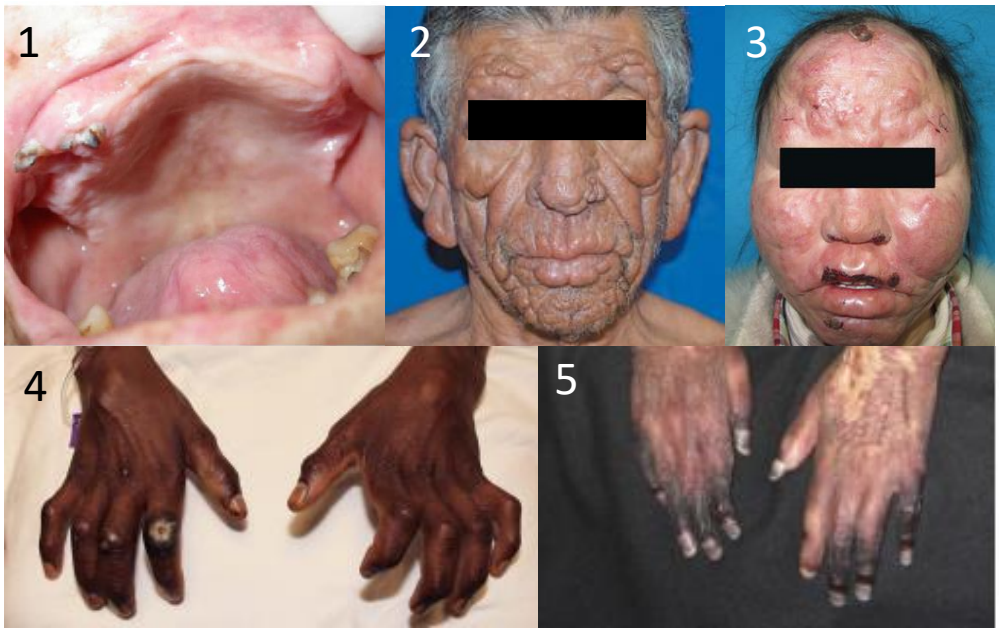


Fig. 2.2: Examples of lepromatous leprosy, demonstrating the variability of lesions that can occur. 1. absorption of the anterior maxillary alveolus (Chimenos-Kustner et al., 2006: E476); 2. Leonine facies (image from Salgado et al., 2012: 1433); 3. Leonine facies (image from Dong and Yu, 2022: 439). 4. Claw hand deformity (image from Zhao et al., 2024: 110); 5. Necrotic lesions in the hands due to diffuse lepromatous leprosy (image from Vera-Cabrera et al., 2011: 4367).

2.2 History of Modern Clinical Leprosy

2.2.1 Hansen's disease

The leprosy bacillus, *Mycobacterium leprae*, was first discovered by the Norwegian physician Gerhard Henrik Armauer Hansen (1841-1912), proposed tentatively by him in 1873 (first published in English in 1875), and conclusively in 1880. This discovery followed the rapidly increasing evidence and scientific support for the bacterial transmission of disease throughout the 1800s, and is a key development in the history of international medicine by further demonstrating the complex relationship between bacterial disease and social conditions (Irgens, 1984), which were initially developed in earlier investigations by physicians such as John Snow (1813-1858) and Edwin

Chadwick (1800-1890) when working on modes of transmission of cholera (Goldstein, 2012) and improving living conditions for the poor in Victorian England (see Green et al., 2018) respectively. Leprosy in a clinical context is commonly referred to as 'Hansen's Disease' (see Suzuki et al., 2012; Nascimento, 2013; Sen et al., 2013; Payne et al., 2015, for example). There is a move in palaeopathology to refrain from using 'names' to refer to disease (Tittlebaum, *pers. comm.*), so this term is not adopted in this thesis. This is because 'named' diseases can carry problematic associations. For example in Hansen's case, the experiments he carried out were ethically problematic, such as a case where he inserted tissue from one patient into the eye of another under duress (Marmor, 2002). The affected woman subsequently pressed charges against Hansen and he lost his position at Bergen Hospital in 1879 (Marmor, 2002). Interestingly, there seems to be a move the other way in the clinical literature, where there is a call to use 'Hansen's disease' instead of 'leprosy' to reduce stigma around the disease in present populations (Deps and Cruz, 2020). This highlights the difficulty of establishing appropriate nomenclature across research areas, as there are pros and cons to both approaches.

2.2.2 Clinical classification of leprosy by Dennis Ridley and William Jopling

Clinical leprosy is divided into five primary forms; tuberculoid, borderline tuberculoid, borderline, borderline lepromatous and lepromatous. This system was proposed in 1962 by Dennis Ridley (1918-2009) and William Jopling (1911-1997), both medical physicians specialising in leprosy. The system is based on clinical, histological, bacteriological and immunological patterns in patients observed by them while working at the Hospital for Tropical Diseases, London, and Jordan Hospital, Earlswood, Surrey, England in the 1950s (Ridley and Jopling, 1962). They state that five grades of classification slowly evolved from their attempts to consistently and conveniently classify leprosy patients along the tuberculoid-lepromatous spectrum, while also acknowledging that every degree along the spectrum may be encountered at some point. The 5-grade classification system was further developed using results obtained from retrospective analysis of 35 patients from the Royal Jordan Hospital, combined with revisions from their subsequent study of 47 patients from 'Sungei Buloh Settlement, Malaya' (present-day Singapore) in 1958. The study of the 47 patients from Sungei Buloh was purely bacteriological. Of the 82 patients observed, all but 6 were followed for at least 12 months. Ridley and Jopling (1962) stated that the final definition of grades proposed was based on assessment of the clinical and histological characteristics of the 82 patients and their relative bacteriological response to antibiotic treatment.

Ridley and Jopling further developed the method in 1966 (Fig. 2.3), clarifying the characteristic presentation of skin lesions in relation to individual immune status and grade of diagnosis, with images of these skin lesions. Ridley and Jopling were aiming to monitor the stable progression of

the disease to define the classification grades more accurately, however the occurrence of leprosy reactions hints at an added complexity (and variability) to the clinical progression of the disease that cannot be ignored however much they were controlled for in their research. This also shows that these classifications provide a static view of leprosy at a given point in time and ignore the temporal complexity and variability of the disease. This should not be such a concern in skeletal remains, as they inherently can only provide a static view of individuals. The images provided are also a valuable reference tool to support the detailed written descriptions of lesions and how they should be appraised. The Ridley-Jopling system remains the accepted method of classifying leprosy in clinical contexts (Nascimento, 2013).

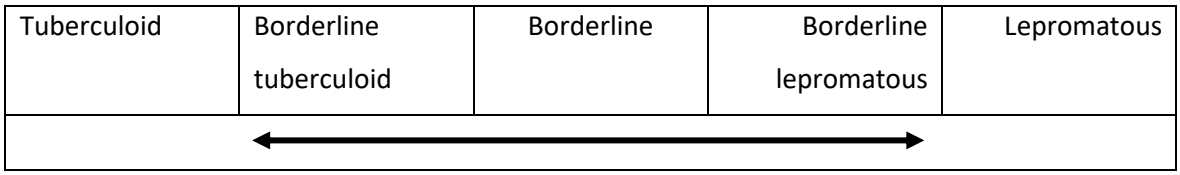


Fig. 2.3: The Ridley-Jopling scale for clinical leprosy (Ridley and Jopling, 1962; 1966)

2.3 Clinical Manifestations of Leprosy

2.3.1 Patterns of Neuropathy

Infection by *M. leprae* results in a complex pattern of neuropathy of immunological origin involving the autonomic, sensory and peripheral nerves (Van Brakel et al., 2005; Santos et al., 2017). The most common clinical presentations of leprosy are mononeuropathy, multiple mononeuropathy, and confluent mononeuropathy (de Freitas et al., 2003, 2004; Van Brakel et al., 2005; Nascimento, 2013; Santos et al., 2017, Jaiswal et al., 2018), collectively defined as nerve damage occurring outside of the central nervous system affecting one or more nerves (Raff et al., 1968). Leprogenic mononeuropathy more commonly affects the nerves of the upper limbs (Pedraza Hueso et al., 2014), particularly the peripheral ulnar, median and superficial radial nerves (Nascimento, 2013). The posterior auricular nerve in the cranium, and the common fibular, superficial fibular and posterior tibial nerves of the lower limbs, can also be affected (De Freitas et al., 2003). Jardim et al. (2004) noted that mononeuropathy is the most common clinical presentation of leprosy, in which the ulnar nerve is the most frequent nerve affected (Nascimento, 2013).

M. leprae primarily affects the dermal cells and Schwann cells in the peripheral nerves (Suzuki et al., 2012). The initial clinical indicators of leprosy are sensory, with small-fibre neuropathies predominating in the early stages, followed by larger fibres and motor/autonomic nerve neuropathy (Nascimento, 2013). The primary sites of infection, in addition to the peripheral nerves, are the skin, nasal mucosa, eyes, and reticulum-endothelial system (Nascimento, 2013). These manifest as skin

hypopigmentation and loss of sensation in affected regions initially ('glove and stocking' type), along with an increase in nerve thickness due to inflammation caused by the direct presence of leprosy bacilli (de Freitas et al., 2003; Nascimento, 2013). This is followed by cutaneous lesions in low-temperature body regions, along with dysfunction of peripheral autonomic processes, such as dry skin due to failure of sweat glands (Nascimento, 2013), as well as ulceration leading to secondary invasion of pyogenic bacteria through open wounds (Andersen et al., 1994). However, the progression of neuropathy, and any concurrent skin lesions, is highly variable and dependent on the immune response of the individual (Britton and Lockwood, 2004; Nascimento, 2013; Inskip et al., 2015). It is also possible for an individual to exhibit 'pure-neuritic leprosy', wherein no skin lesions accompany underlying neuropathy (Jardim et al., 2004; Kumar, 2016; Santos et al., 2017).

2.3.2 Leprosy Reactions

Leprosy reactions are acute periods of increased inflammation and immunological activity (Sarno and Pessolani, 2001; Nery et al., 2013; Kahawita and Lockwood, 2008; Walker and Lockwood, 2008; Leon et al., 2016). Type 1 reactions are characterised by acute inflammation in nerves and cutaneous areas already affected by leprosy, i.e. a worsening of pre-existing lesions. Type 2 reactions, also known as *Erythema Nodosum Leprosum* (ENL)(Fig. 2.4), are characterised by the development of new subcutaneous nodules (Ernst and Renault, 2015). ENL can affect many organs simultaneously, including the eye, with arthralgias and neuritis also. It can be very painful (Renault and Ernst, 2015), and can also be accompanied with systemic fever and inflammation (Walker et al., 2017), and swelling and oedema in the face and/or extremities (Siddaraju, 2007). While episodes of ENL are generally acute, they can recur and develop into a chronic state (Lambert et al., 2017). Episodes most often occur over a period of 12-14 months, but can happen over periods of 7 years or longer (Pocaterra et al., 2006; Kahawita and Lockwood, 2008). There is also Lucio's phenomenon, which is a reaction to diffuse lepromatous leprosy characterised by necrotising cutaneous vasculitis on the lower extremities. This is a rare reaction limited mostly to Mexico and Central America, but sporadic cases are reported worldwide (Sharma et al., 2019).

Leprosy reactions are of interest to the palaeopathologist as acute and repeated episodes of inflammation, particularly ENL with systemic fever, may result in periosteal new bone formation, where the mix of active and healed new bone formation may be indicative of these repeated acute reactions to leprosy infection.

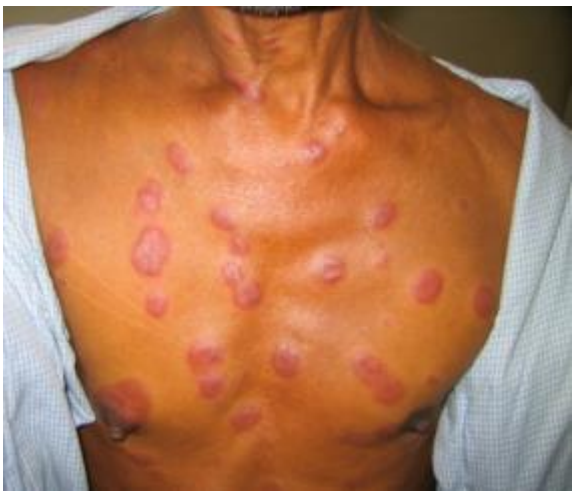


Fig. 2.4: Skin lesions caused by erythema nodosum leprosum. Image from Kahawita and Lockwood (2008: 330).

2.3.3 Neuropathy, Arthritis and Leprosy

Nerve entrapment as a result of hypertrophy occurs in regions where they pass close to bone. Donaghy (2003) notes that the ulnar nerve in patients suffering from leprosy may expand 4-5 times the size of its usual diameter. Significant suppression of the enlarged ulnar nerve can occur through the cubital tunnel of the elbow due to the compact anatomy of that region (Fig. 2.5), causing further inflammation of the nerve and surrounding fascia at this site (Donaghy, 2003: 14). The presence of acid-fast bacilli has also been confirmed in patients suffering from this syndrome upon biopsy. Fonseca et al., (2018) also presented evidence for marked thickening of the greater auricular and peripheral nerves in a 39-year-old Brazilian patient suffering from lepromatous leprosy. Of particular interest is the marked thickening of the ulnar nerve 20mm above the elbow, which Fonseca et el. (2018) note is common in leprogenic nerve thickening. Payne et al. (2015) also note nerve thickening leading to entrapment of the nerves in the fibro-osseous tunnels, particularly at the elbow, directly observing this in an 11-year-old patient. They state that extensive entrapment may result in venous obstruction, capillary stasis, oedema, and ischemia in the affected regions. Also, in a study of 85 multibacillary (lepromatous (LL) and borderline lepromatous (BL)) leprosy patients, Lugao et al. (2015) observe (via ultrasonography) an abnormal thickness of the ulnar nerve in the area of the cubital tunnel in 81% of LL patients. This clinical research suggests that ulnar nerve enlargement in the area of the cubital tunnel frequently occurs (Vital et al., 2013), and that there are potentially significant effects to the surrounding tissues as a result. This is not limited to the ulnar nerve. Wan et al., (2016) note that compressions and entrapment of nerves can occur in both the upper and lower extremities, with the peroneal nerve (as it passes the knee), and the tibial nerve within the foot frequently affected (see also Dastur 1983; Nickerson, 2010; Ooi and Srinivasan, 2004; Payne et

al, 2015). The hematogenous spread of *M. leprae* bacteria (Talhari et al., 2015) can result in skip lesions along the tibial and fibular nerves (Richard et al., 2001), which may then also become enlarged (Khambati et al., 2009; Ding and Legua, 2019), potentially resulting in a complex series of affected and unaffected areas.

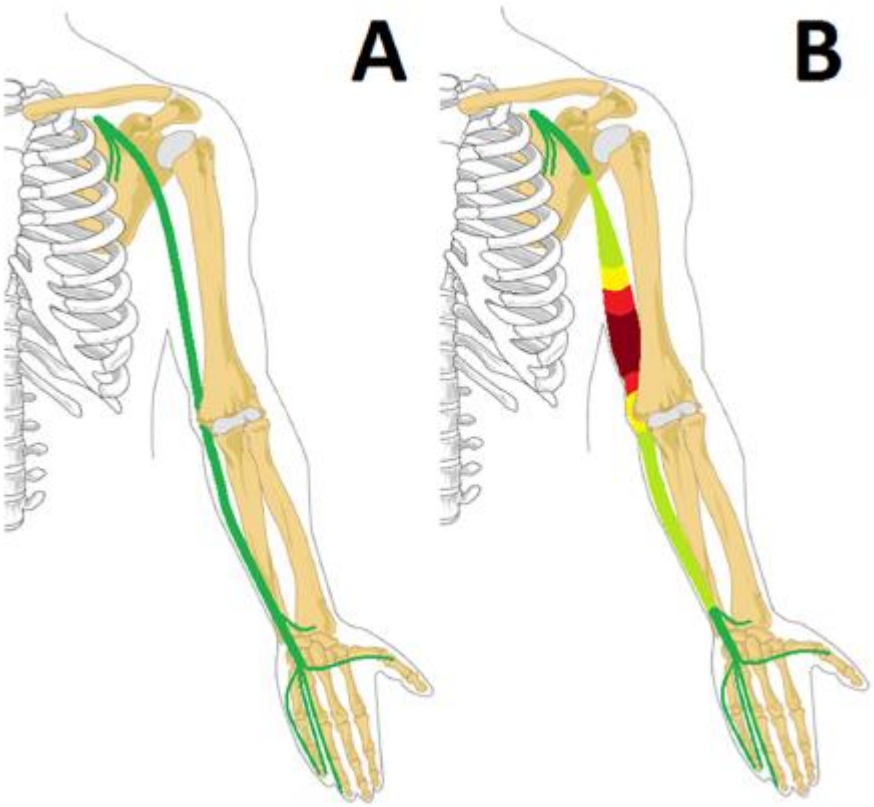


Fig. 2.5: Ulnar nerve enlargement in leprosy. A. the normal ulnar nerve; B. enlarged nerve due to leprous neuropathy. Image from Bathala et al. (2017: 9).

If nerve thickening of an adequate and chronic extent occurs close to bone it is reasonable to suggest that this will result in a lesion, particularly in the elbow. This would be purely dependent on the potential of nerve thickening to elicit either a bony reaction if occurring close to the periosteum and disturbing it, or by inducing an inflammatory response to the surrounding soft tissues, which if sustained and of serious enough scale, may elicit a bony response if this inflammation proceeds to affect the periosteum (Weston 2008; 2011). Bacilli present in the soft tissues may also radiate and lead to primary bony lesions due to leprosy bacilli invasion (fine pitting) as detailed in Andersen and Manchester (1992). Ooi and Srinivasan (2004) note that in rare cases, individuals affected by lepromatous leprosy may display secondary amyloidosis of the kidneys and liver, which Fenves et al. (1986) and Konishiike et al. (1994) show can result in cystic lesions of the bones of the carpal tunnel and distal humerus respectively if amyloidal material spreads through the body and builds in the synovial fluid of the joints. This is due to cystic granulatomous tissue containing amyloidal

cells building up in the affected areas. In these cases, the entrapment of nerves is secondary. This is, however, a direct link to bony lesions in areas of entrapment with an evident clinical precedent, which if found in conjunction with leprous lesions could point to leprosy with secondary amyloidosis. While this is a very specific aetiology, lesions to these areas suggest that significant disruption to the soft tissues in areas of entrapment may result in bony lesions – particularly given the potential venous obstruction, capillary stasis, oedema, and ischemia that may result from cubital tunnel syndrome due to leprous nerve enlargement as noted by Fonseca et al. (2015). Therefore, lesions to the proximal ulna and distal humerus will be explored in this research to gain insight into how nerve thickening due to leprosy may present in skeletal remains.

Chauhan et al. (2010) also note that punctuated episodes of inflammatory arthritis of the wrists, elbows and shoulders may occur in clinical cases, as well as inflammatory arthritis or Charcot's arthropathy of the knees and ankles, or progressive destruction of bone and soft tissues at weight bearing joints, often the secondary outcome of neuropathy (Kaynak et al., 2013) of the knees and ankles. This is possibly via direct infiltration of the synovium by leprosy bacilli that stimulates an inflammatory response, and not because of secondary pyogenic infection (Graham et al, 2010; Chauhan et al., 2010; Bhat and Prakash, 2012; Alam and Emadi, 2014). Chauhan et al. (2010) conclude that even where leprosy remains an endemic disease, inflammatory arthritis due to leprosy is often overlooked (see also, Alam and Emadi, 2014). This suggests that erosive lesions to these regions may be observed in skeletal remains, morphologically corresponding with observations of inflammatory arthropathy in skeletal remains (Rogers and Waldron, 1995; Waldron, 2008; Mays et al., 2017). Septic arthritis as a result of leprosy has been touched upon at in palaeopathological literature (see Andersen et al., 1994; Lewis 2017), however arthritis and its relationship to leprosy generally in palaeopathological contexts has not been rigorously appraised. Lesions indicative of inflammatory arthropathy, shown by Mays et al. (2017) to be highly variable depending on the form of inflammatory arthropathy triggered, would of course have to be observed in conjunction with 'classic' leprosy lesions, such as rhinomaxillary syndrome for a link to be suggested.

Lesions resulting from nerve enlargement and entrapment, and/or inflammatory arthritis, may be useful phenomena when studying leprosy in individuals from archaeological collections, where no surgical intervention would have been available, and where the chronic effects of inflammation at these sites may lead to an observable bony reaction. The precise morphology of lesions that may occur is uncertain, as Bataille et al. (2012) show in rats that the innervation of bones is complex and multi-factorial, and that the subsequent reaction of the bone to such disturbance of the nerves depends as to how the pathogenic stimulus affects the sympathetic nervous system, and by the

embryological origin of the bone, which in turn dictates whether osteogenic cells are differentiated into osteoblasts or osteoclasts respectively (Bataille et al., 2012). Therefore, how precisely leprogenic neuropathy may induce or inhibit bone formation in regions prone to nerve compression and entrapment (if at all) is not immediately clear.

2.3.4 Radiological Indicators

Rothschild and Rothschild (2001) conducted an extensive study of radiographs from patients suffering from leprosy from a hospitals in Carville, LA and Toronto, Canada covering the period from pre- to post-modern treatment eras of clinical leprosy (covering 1900-2001). Their findings showed that the post-cranial osseous manifestations of leprosy have changed little over that time, with individuals presenting similar lesions across the period covered in the research. This correlates with the findings of palaeopathological studies (see Andersen and Manchester, 1992, 1994; Britton and Lockwood, 2004; Inskip et al., 2015) that suggest that leprosy has changed little as a disease over time, despite several regional strains arising (Britton and Lockwood, 2004). The radiological findings of Rothschild and Rothschild (2001) also complement the radiological and macroscopic indicators of leprosy as identified by Anderson and Manchester (1987; and Ali, 1992; and Roberts, 1994)(Fig. 2.6), supporting the comparability of leprosy observed in modern clinical settings to that of leprosy observed in archaeological skeletal remains.

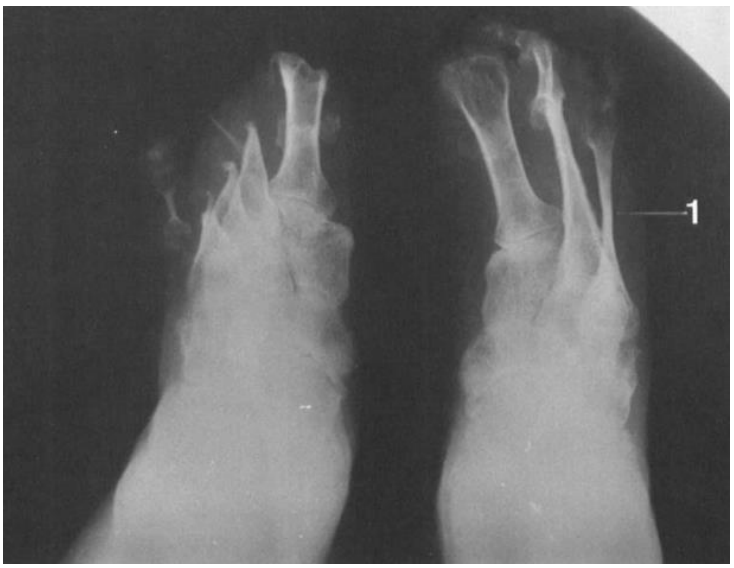


Fig. 2.6: Clinical x-ray showing concentric remodelling of metatarsals in the left and right feet in leprosy. Image from Andersen et al. (1992: 215).

2.3.5 Pediatric Leprosy

In pediatric leprosy, the distribution of cases across the Ridley-Jopling classification system differs from that seen in adults. Children tend to present with tuberculoid leprosy (Nair et al., 2017; Pradhan et al., 2019). Babu et al. (2018), in a study of rates of childhood leprosy at the Father Muller Medical College in Managalore, India, show that of the 45 children with leprosy reported at the clinic between 2005 and 2015, 41 (91%) presented with tuberculoid or borderline-tuberculoid leprosy, with the remainder being 'indeterminate'. There were no reported cases of lepromatous leprosy. In India, children aged 10-15 years are most frequently affected (see Nair et al., 2017; Babu et al., 2018; Ghunawat et al., 2018; Pradhan et al., 2019), with Nair et al. (2017) suggesting this is reflects the long incubation period of the disease. This coincides with the adolescent immune transformation at puberty (Lewis, 2017). However, these studies also report cases of leprosy in those as young as 1-5 years (Nair et al., 2017; Ghunawat et al. (2018). Indeed, Brubaker et al. (1985) reported 91 cases of leprosy in infants less than one year of age, suggesting that they must have been infected *in-utero*. Congenital leprosy is a controversial topic (Lewis, 2017). Duncan (1986) suggested that the stage of pregnancy, combined with the bacterial load experienced by the fetus (particularly in immunological unstable mothers), may heavily influence the clinical presentation of leprosy in early childhood. The high vascularity of the placenta may also result in large amounts of bacilli being transmitted to the fetus if its structural integrity is compromised (Duncan et al., 1983), but subsequent studies have remained inconclusive on the nature and extent of placental transmission of *M. leprae* from mother to baby, and implications of this for the immune response to the bacteria (Duncan, 1993; Singh et al., 2020).

The clinical manifestations of childhood leprosy tend to be limited to an array of skin lesions combined with peripheral neuropathy, consistent with tuberculoid and borderline-tuberculoid cases. Physical deformity in these studies is infrequent (Nair et al., 2017; Babu et al., 2018; Ghunawat et al., 2018; Pradhan et al., 2019), however more severe physical deformity may still arise (Viera et al., 2018). Kar and Job (2005) observe an incidence of 10.5% of 'Grade II' deformity in children with leprosy (29/275) in their retrospective study of childhood leprosy at the Scheiffelin Leprosy Research and Training Center, Karigiri from cases between 1994-2003. 'Grade II' deformity in this case relates to the most serious category for deformity in the World Health Organisation's disability grading system for leprosy first devised in 1960 (Brandsma and Brakel, 2004). The system refers to deformity of the soft tissues only (although this may imply deformity to underlying bony structures also), including 'ulcers', 'severe cracks', 'severe atrophy' of the hands and feet, and severe visual impairment (including lagophthalmos (an inability to fully close eyelids)). Of the 275 children in the study, a total of 238 (86.5%) displayed paucibacillary leprosy, of which 20 (8.4%) displayed

grade II physical deformity. Of the 29 children with physical deformities across the sample, 26 (89.6%) were in the 10–15-year age group.

Effective diagnosis of childhood leprosy in clinical contexts is challenging (Ortiz et al., 2016). The diverse array of clinical manifestations and ability of leprosy to mimic other diseases, means that leprosy often remains undiagnosed in children until much later in life (Ortiz et al., 2016; Nair et al., 2017; Babu et al., 2018; Ghunawat et al., 2018; Pradhan et al., 2019), hence, the real epidemiological trends of the disease are difficult to assess. Rates are higher in hyperendemic areas (Lewis, 2017).

2.4 Diagnosis of Leprosy in Medieval England.

An essential aspect of this research was to explore how leprosy was diagnosed in late medieval England, and how this may reconcile with the modern clinical evidence for leprosy and the skeletal evidence.

Primary medical texts provide direct insight into the signs and symptoms used by medieval physicians to diagnose leprosy at the time the leprosaria under study were in operation. The last section of this chapter will describe the general medical framework of the late medieval period, to provide context for the medical works under consideration. It will then consider the diagnosis of leprosy by analysing key contemporaneous medical sources. The first is the Latin *Viaticum* by Constantine the African (AD 1015-1098)(published ca. 11th century). The second is 'de lepra' in the *Rosa Anglica* by John de Gaddesden (published *ca.* 1314). Direct translation of passages will be provided where appropriate, however previous translations from other works will also be consulted. The *Compendium* by Gilbertus Anglicus (published *ca.* 1240) is also discussed in the context of the Middle English translations of this work by Getz (2010). These three publications are not an exhaustive account of all the medical literature potentially available to late medieval physicians, but are considered here as Constantine the African was a key early figure in Western medicine through his translation of Arabic medical works, and Gilbertus Anglicus and John de Gaddesden were the two best known doctors from the British Isles from this period; both were mentioned in Chaucer's *The Canterbury Tales*, for example (Pearn, 2012). Gilbertus Anglicus and John de Gaddesden are an appropriate sample to stop at as their works underpinned medical practice in England for the next 400 years, and formed part of the core curriculum (Pearn, 2013).

2.4.1 Humoral Theory and Leprosy

Humoral theory was the prevailing medical framework of the medieval period and concerned the delicate balance of the four bodily humours required to maintain health (Demaitre, 2007; Rawcliffe, 2006; Miller and Nesbitt, 2014). Classical humoral theory was formalised by Hippocrates (*ca*. 460 BC) and was based on previous cosmological theories of the elements of the universe (Stelmack and Stalikas, 1991). The four primary humours are yellow (choleric) bile, black (melancholic) bile, blood and phlegm (Demaitre, 2007; Rawcliffe, 2006; Miller and Nesbitt, 2010)(Fig. 2.7). According to Hippocrates, the four humours were a manifestation of the principal qualities of the elements of fire, earth, air and water respectively (Brody, 1974; Dols, 1983; Stelmack and Stelikas, 1991). The balance and relative mix of each determined an individual's health (Ross and Margolis, 2018), with each waxing and waning through the four seasons of the year, and four stages of an individual's life (Stelmack and Stelikas, 1991). Humoral theory was developed further by Galen, wherein the balance of the humours could have an active influence on the temperament of an individual (Ross and Margolis, 2018), which by extension could have further implications on the likelihood of disease (Stelmack and Stelikas, 1991; Mattern, 2011). The optimum balance of the humours was termed *eucrasia*, with any imbalance known as *dyscrasia* (Papavramidou, 2018). To be dyscrasic in the humours could have disturbing implications for the development of leprosy (Demaitre, 2007; Rawcliffe, 2006; Miller and Nesbitt, 2014), with an imbalance of each humour leading to a different form of leprosy.

Fig. 2.7: 15th century depiction of the four humoral types (clockwise from top right; sanguine, phlegmatic, choleric and melancholic). Image from Rawcliffe (2006: 66).

Leprosy was explained by medieval physicians as an overly dry and cold complexion (Demaitre, 2007: 177) with an excess of black bile (Dols, 1983; Rawcliffe, 2006). This overall excess was secondary to an imbalance of one of the individual humours, which had become overheated and burned to ash or putrefied within the body (Demaitre, 2007: 177; Miller and Nesbitt, 2010), leading to a specific form of leprosy based on the precise symptoms of the individual concerned and the humour affected (Brody, 1974: 37). If burned, yellow bile led to *leonine* leprosy, characterised by wrinkled facial skin, yellow in colour, and swiftly developing (Demaitre, 2007: 178). Burning of black bile caused *elephantia*, characterised by nodes and tuberosities, cracking skin, blackish in colour, and carried the longest-term and potentially most serious prognosis (Demaitre, 2007: 177). Burning of phlegm resulted in *tyrian* leprosy, and was characterised by a white scaliness of the skin, and whitish face, with an 'intermediate' prognosis (Demaitre, 2007: 177). Finally, burning of blood led to *alopecia*, characterised by patchy hair loss, with a red face and eyes - the 'safest' of all forms of leprosy (Demaitre, 2007: 177). This subdivision of leprosy in medieval medicine was received from Islamicate medicine, particularly Avicenna (c. AD 970-1037) (Demaitre, 2007; Miller and Nesbitt, 2014), and has interesting implications for the consideration of modern leprosy versus the leprosy of the medieval age. The descriptions of symptoms and prognoses of *elephantia* and *leonina* above

indicate an awareness of the variable manifestations of leprosy in medieval medicine, arguably comparable to the lepromatous-tuberculoid spectrum that modern medicine uses today (Ridley and Jopling, 1966). This demonstrates that medieval physicians had an appreciation of the subtleties of the physical manifestations of disease, albeit classifying them differently due to the underlying theoretical framework. The *tyrian* and *alopecian* types of leprosy have no obvious modern parallel (based on the descriptions above), although these may represent borderline or intermediate cases on the leprosy spectrum - leprosy is also known to mimic diseases (Kundacki and Erdem, 2019). These subtle observations of the variability of a complex disease indicate that medicine and diagnosis from the medieval period should not be simply written off due to the 'incorrect' underlying theories of disease when compared with those of modern medicine.

2.4.2 Practical Notes on the Translations

Latin translation is not straightforward. Medieval Latin texts are characterised by abbreviations that can be specific to the particular text, which can make it challenging to decipher what the Latin sentence to be translated even is. Nonetheless there are some broad patterns, so abbreviations in the texts below were assessed using Heimann and Kay's (1982) translation of Adriano Capelli (1899), who detailed the abbreviations present in medieval Latin texts, as well as the 'Capelli online' resource, offered by Universitat Zurich (available here: https://www.adfontes.uzh.ch/en/ressourcen/abkuerzungen/cappelli-online). Once the Latin was transcribed, it was translated with reference to the 'Logeion' medieval Latin dictionary offered online by the University of Chicago (available here: https://logeion.uchicago.edu/).

The translation of medieval Latin sources is an imperfect system, as medieval Latin is a very efficient language in a way that modern English is not. A lot of meaning is contained in relatively few words, with various possible meanings for passages depending on the interpretation. The resources above eased the translation process and were an invaluable aid in interpreting the passages when translating them into modern English, and the medical focus of the works translated gave a firm foundation to appropriately interpret the Latin. The transcriptions for the Latin passages are detailed in Appendix A.

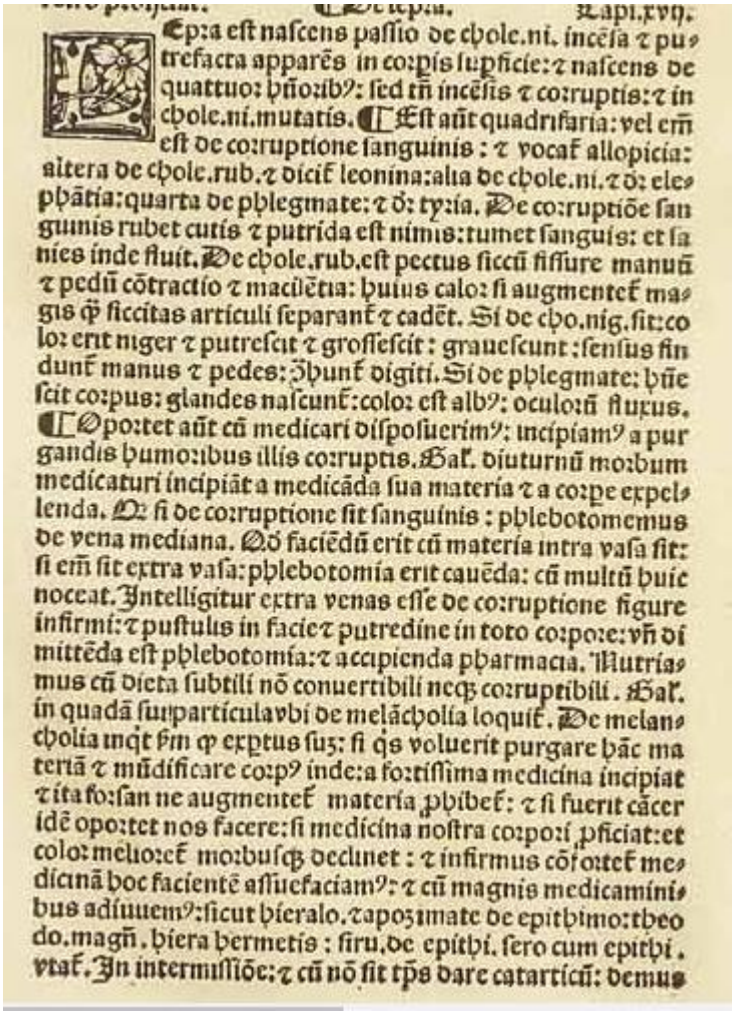
2.4.3 Constantine of Africa

Constantine of Africa (AD 1015-1098) was a key scholar in Western Medieval medicine, who after arriving in Salerno in 1077 from North Africa, became a monk at Monte Cassino and set about translating and compiling 37 Arabic medical texts into Latin (Wilkinson, 2019). Constantine's works circulated widely into the 17th Century and provided the foundation for future works in medicine (Wilkinson, 2019). This is also significant as it demonstrates that the key medical theory and

knowledge underlying these texts did not originate in medieval medicine, but had a much deeper origin. Of particular interest here is the *Viaticum*, a translation of Ibn al-Jazzar's *Zad al-musafir* (ca. 10th century)(Sigerist, 1936), which was intended as a shorter reference work for medieval physicians as to the signs and symptoms of particular diseases and their remedies (Long, 2015). While a translation of an earlier Arabic work, the *Viaticum* was translated and compiled according to Constantine's discretion and theoretical outlook (Long, 2015). This contrasts with the view of Brody (1974), who claimed that medieval physicians only plagiarised earlier works. The section on leprosy in the *Viaticum* allows us to gain insight into what Constantine considered to be the essential signs and symptoms of leprosy distilled in a format that was intended for practical use. This may have informed, or been a foundation for, the later works by John de Gaddesden and Gilbertus Anglicus considered below.

2.4.3.1 Translation of Sections on leprosy from the Viaticum

The following considers translations made from the text contained on page 801 of a 1515 print of the *Viaticum* (digitised version accessed via Herzog August Bibliothek; http://diglib.hab.de/drucke/ma-4f-35/start.htm?image=00801).



Lepra est nascens passio de chole.ni. incensa & pu-
trefacta apparēs in corpis superficie: & nascens de
quattuor humoribꝰ: sed tñ incensis & corruptis: & in
chole.ni.mutatis. ¶ Est aūt quadrifaria: vel eñ
est de corruptione sanguinis: & vocat allopicia:
altera de chole.rub.& dicit leonina: alia de chole.ni.& ō elephātia: quarta de phlegmate: & ō tyria. De corruptiōe sanguinis rubet cutis & putrida est nimis: tumet sanguis: et sanies inde fluit. De chole.rub.est pectus siccū fissure manuū & pedū cōtractio & macilēcia: huius calor si augmentet magis q̄ siccitas articuli separant & cadēt. Si de cho.nig.sit: color erit niger & putrescit & grossescit: grauescunt: sensus finduñ manus & pedes: ꝯhunt digiti. Si de phlegmate: hūe scit corpus: glandes nascunt: color est albꝰ: oculorū fluxus.
¶ Oportet aūt cū medicari disposuerimꝰ: incipiamꝰ a purgandis humoribus illis corruptis. Gal. diuturnū morbum medicaturi incipiāt a medicāda sua materia & a corpe expellenda. Et si de corruptione sit sanguinis: phlebotomemus de vena mediana. Ꝯ faciēdū erit cū materia intra vasa sit: si eñ sit extra vasa: phlebotomia erit cauēda: cū multū huic noceat. Intelligitur extra venas esse de corruptione figure infirmi: & pustulis in facie & putredine in toto corpore: vñ dimittēda est phlebotomia: & accipienda pharmacia. Nutriamus cū dieta subtili nō conuertibili neq; corruptibili. Gal. in quadā suapartícula vbi de melācholia loquit. De melancholia inqt ſm q̄ exptus sum: si qs voluerit purgare hāc materiā & mūdificare corpꝰ inde: a fortissima medicina incipiat & ita forsan ne augmentet materia phibet: & si fuerit cācer idē oportet nos facere: si medicina nostra corpori pficiat: et color melior et morbusq; declinet: & infirmus cōfortet medicinā hoc facientē assuefaciamꝰ: & cū magnis medicaminibus adiuuemꝰ: sicut hieralo. Capozimate de epithimo: theodo. magñ. hiera hermetis: firu. de epithi. fero cum epithi. vtaf. In intermissiōe: & cū nō fit tps dare catarticū: demus

tyriacā magnā factā cū pinguedine & carne tyri. Gal. nunq̄ inquit: vidi in vita mea hoiem hac infirmitate plenarie liberatum nisi q̄ biberit vinū in quo tyrus ceciderit: & ibi cōputruerit: hunc enim vidi excoriari: & cute expoliari cū vinū illud ebiberit: vnde certificaui cū testimonio vsuali qō dixerūt antiqui de carne tyri: vel de pinguedine & sui iuuamenti magnitudine in hac & in oī dura passiōe. ¶ Purgato aūt corpore supradicto medicamine: dem⁹ selithe tyriacā & similia corpus custodientia: putredinē mundificantia: precipiat vt balneetur: sed nō tamen aquis dulcibus. Iterū iuuat incensio & diete obseruatio: & cibi paruitas. Interrogat⁹ autem Gal. que medicina summa habeatur: inquit: abstinentia.
¶ De morphea

Leprosy arises from the burning of black bile, with visible lesions on the skin. It arises from the burning and corruption of the four humours. There are four types; Alopecia, from the corruption of blood; Leonine, from red bile; Elephantia, from black bile. The fourth, from phlegm is Tyria.

Corruption of blood causes red skin with excessively rotten lesions, with swollen areas that expel diseased discharge. Red bile causes a dry chest, with hand and foot contraction and emaciation. If the warmth from this kind increases, the first joints [of hands and feet] can fall off. With corruption of black bile there is a black colour

> with putrefaction and swelling, that becomes heavy. Sense is lost in the hands and feet, and the fingers contract. With corruption of phlegm, the body grows moist and lumps appear; it is white; there is discharge from the eyes.
>
> It is necessary, having planned the treatment, to begin by cleaning the corrupted humours. Healing of long-lasting sickness should begin by treating its physical elements and expelling them from the body. For corrupted blood, be sure to take it from a vein in the middle. This is to be done when the matter is inside the body for if it is outside phlebotomy should be avoided as it will do much harm. It can be discerned to be outside the veins from disfigurement of the patient's face. And pustules on the face and rottenness across the whole body. Then phlebotomy should be ceased and pharmaceuticals used. A careful/skilled diet should be planned, neither changeable nor corruptible. Galen speaks in a particular place about melancholy/bile. He spoke from his expertise/experience thus: if anyone should wish to purge this matter and to cleanse the body of it, he should start with the strongest medicine and thus, perhaps, prevent the matter from increasing. And if it has become a cancer we should proceed thus; if our medicines progress the [strength of] the body, and the colour improves and the sickliness decreases and the patient is comforted, we should persevere with this treatment. And with powerful treatments we shall give help.

The section ends with technical details on the medical compounds to be used and the strength of them, particularly epithma and theriac. This demonstrates that treatment can be attempted, although it will be tough and may not succeed. Along with potentially problematic medicines, it suggests a degree of blood-letting is required. It also notes that leprosy will get worse if there is no treatment at all. However, if the medicines are successful in purging the body then the patient can be bathed, although not with sweet waters - waters enriched with aromatic herbs (Hajar, 2012).

The piece reflects awareness of the chronic course of the disease and the careful balancing of the humours and bodily fluids required. There is direct reference to the lesions caused by leprosy that we would recognise today, particularly the loss of sensation and potential loss of the digits in the more serious forms of the disease. There is also acknowledgement of the dry skin caused by leprosy, which we know today to be caused by neuropathy preventing the proper function of sweat glands (Utino et al., 2017). The mention of 'cancer' is interesting, however, as in this medieval context cancer and leprosy were related afflictions; 'cancer' was a localised disease, with leprosy considered to be a 'cancer of the whole body' (Demaitre, 2007). This demonstrates that while there are clear parallels here between medieval and modern descriptions of leprosy, concepts of which diseases

are related, and disease names themselves are not always transferable to the present. The concept of cancer being a localised form of leprosy, *per se*, suggests that 'cancer' in this instance may in fact relate to the tuberculoid form of the disease. That the text mentions 'if it has become a cancer' also suggests that there was an awareness that leprosy was not a disease that remained static, although in this context it is difficult to know whether Constantine was talking about symptoms improving or worsening. The modern clinical parallel to this may be Type I and II leprosy reactions, (acute periods of increased immunological activity), that can resolve by themselves (particularly in tuberculoid or borderline tuberculoid forms). Therefore, 'if it has become a cancer' may relate to symptoms improving, given the cancer/leprosy paradigm in medieval medicine mentioned above, with the improvement attributed by Constantine to the purging and medicines administered which may in fact have been acute immune fluctuations understood as leprosy reactions today. It could also be the case that an individual displaying evidence of leprosy had symptoms that improved overall, or at least became more localised, which if considered in a modern clinical context may have been a case where someone with a borderline form of the disease improved/downgraded to the tuberculoid form, which is observed in modern clinical cases (Ooi and Srinivasan, 2021). Borderline forms of leprosy are inherently unstable, however, so could also worsen to lepromatous leprosy, the more serious form of the disease (Goldman and Schaefer, 2020).

The above, however, does suggests an awareness of the signs and symptoms of leprosy as we would understand it today, particularly with the lesions and neuropathy to the hands and feet, even though the underlying humoral theory and subsequent treatment is incongruous with modern medicine.

2.4.4 John de Gaddesden and the Rosa Anglica

John de Gaddesden (John of Gaddesden) (*ca.* AD 1280 – 1361), as his name implies, he came from the village of Gaddesden in Hertfordshire (today known as Little Gaddesden)(Pearn, 2012). He was educated in Oxford, possibly entering as young as 14 (Cholmeley, 1912: 12). Study at this time was long and intensive. There were six years of 'grammar' and Baccalaureate study, followed by a further three years of Master's study, and then four years medical study (Cholmeley, 1912: 19). All told, it is believed that Oxford statutes allowed John to practice medicine from 1309 (Pearn, 2012), and that he published the *Rosa Anglica* in 1314 (Cholmeley, 1912: 19). Indeed, John eventually rose to be the first Englishman to be Court Physician to an English Monarch (Capener, 1961: 14). The *Rosa Anglica* covers all known aspects of surgery and medicine of the time by presenting knowledge from Messue, Pavia, Henri de Mondeville, Haly Abbas, Avicenna and Constantine the African combined with commentary from John on his own clinical experience (Pearn, 2012) and was intended as a single reference point for surgeons and physicians going forward (Pearn, 2012). The *Rosa Anglica* is divided into 5 sections, covering a wide range of subjects from 'fevers' to 'Women's diseases', as

well as extensive sections on diseases of the skin, including leprosy (Capener, 1961). It remained in wide circulation in either handwritten or, later, printed copy for over 300 years.

2c.5.1 The *Rosa Anglica* and Leprosy

The copy of the *Rosa Anglica* under study here is from a scan of a 1502 printed edition of the work held by the Wellcome Library (shelfmark: 2846/D, accessed on ProQuest via the University of Oxford's online access database, SOLO (https://solo.bodleian.ox.ac.uk/)). The section on *De Lepra* covers ten pages and provides an in-depth consideration of the signs and symptoms of leprosy, following the humoral theory that was prevalent at the time. Sections of this work have been directly translated below.

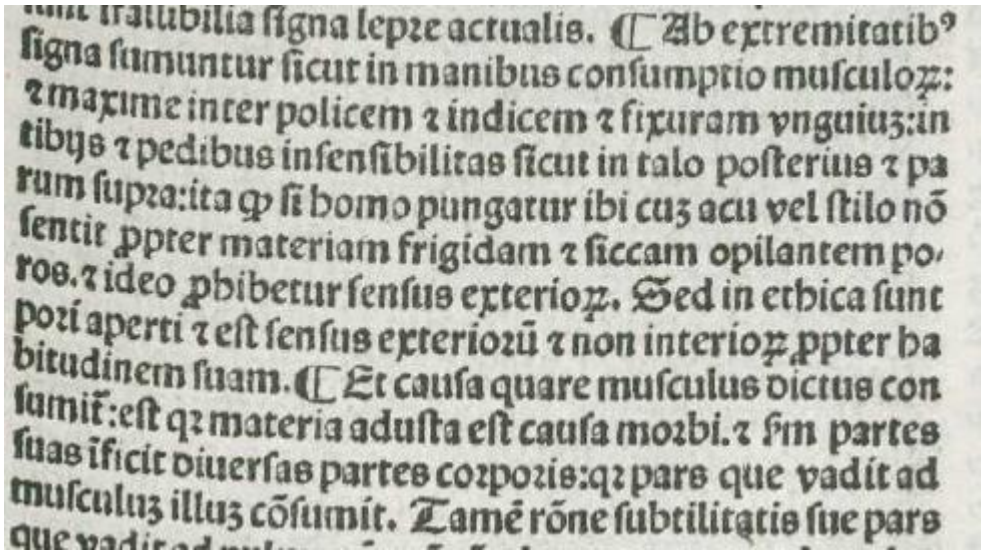
The *Rosa Anglica* has not been extensively translated, however Cholmeley (1912) translates a few passages from it concerning leprosy, so the observations there are worth comment here briefly, noting that the medical and archaeological knowledge of leprosy has advanced significantly since Cholmeley (1912) was published. Cholmeley (1912) notes that John prioritised the appearance of the facial signs of leprosy before a diagnosis could be confirmed stating that 'no-one is to be adjudged a leper and isolated from all his fellows until the appearance and shape of his face are destroyed' (Gaddesden, 1502, as translated in Cholmeley, 1912: 47). John does note that individuals can be 'leprous' before the appearance of these signs (Cholmeley, 1912), which demonstrates an awareness of the variability of leprosy, which is reflected in modern clinical leprosy. This does however suggest that entry to leprosaria was only encouraged when leprosy was already in the advanced stages of the disease, meaning that leprosy may have been more widespread in the population than known from leprosaria assemblages, and this is reflected in the macroscopic evidence of leprosy observed in non-leprosarium assemblages in England (Roberts, 2020: 323-328). Indeed, John directly notes that, for the purposes of entry to a leprosarium, the presence of 'cancer' of the feet and skin (i.e. the postcranial destructive lesions associated with leprosy) are not to be viewed as extensive enough evidence disease even when associated with 'nodulous eruption' (Cholmeley, 1912: 47). While other diseases, such as syphilis, may also cause destructive lesions to form in the face, confusion on this point from a physician working with Gaddesden's writings seems unlikely, as the below shows John had an acute awareness of the neuropathy and loss of sensation in the extremities and facial region associated with leprosy. John insists that cases of leprosy be advanced before 'isolation from fellows'. This may highlight an apparent ambivalence towards committing an individual to a leprosarium at the time the *Rosa Anglica* was published, although this could simply be due to leprosarium having limited capacity, as they only had limited space (see Magilton, 2008). The fact that there are many cases of leprosy observed outside of leprosarium

from this time (Roberts, 2020) supports this. So, it is important to build upon Cholmeley (1912) by directly translating passages from the *Rosa Anglica* describing the signs and symptoms of leprosy.

2.4.4.1 Translation of Passages from Rosa Anglica

The following considers passages directly translated from the *Rosa Anglica*. The full section on leprosy in this 1502 print comprises 10 pages of detail on the diagnosis and treatment of leprosy, the full translation of which is beyond the scope of this thesis. However, a passage from page 46 concerning the signs and symptoms of what Gaddesden considered to be leprosy has been translated. The passage has been divided into 6 sections, with comments provided separately for each section. This passage was divided into 6 sections so that each portion could be translated and analysed more efficiently than keeping it as 1 long passage.

2.4.4.1.1 P. 46 from Cap. ab extremitatibus. (Section 1)

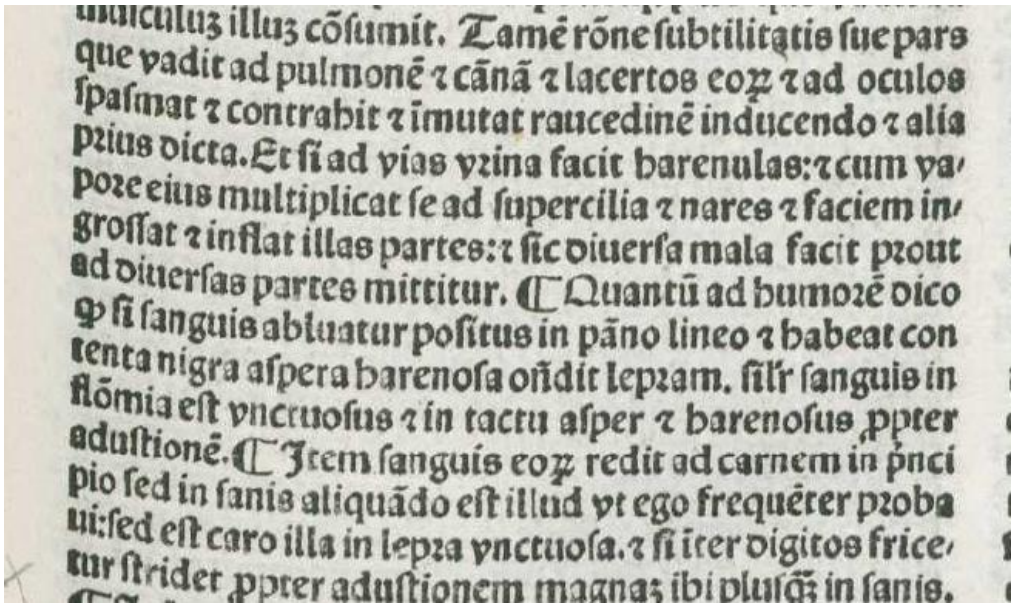


> *"The signs/effects take hold from the extremities, such as wasting of the muscles in the hands, and especially between thumb and first finger, and the base of the digit. In the shins and feet loss of feeling as also in the rear and higher. Thus, if a man is pierced there with a sharp point or stake he will not feel it on account of the cold, dry matter blocking his channels; thus external sensation is cut off. But in truth the channels are open and it is external feeling not internal [which is affected] due to the nature of the disease. Cap. And this is because it consumes the said little muscle; thus combusted matter is the cause of morbidity. And separate parts kill different parts of the body; in whatever part it takes hold it consumes the musculature there."*

This section shows a direct awareness of some of the key symptoms of modern leprosy, namely the disease developing in the peripheral appendages of the body, rather than the axial skeleton. It also

directly noted the loss of sensation in these regions, albeit attributed to a blocking of humoral channels rather than the neuropathic effects of leprosy known to modern medicine. The passage attributes this loss of sensation to the burning associated with a proliferation of black bile. However, despite issues with the underlying theory when compared with modern medicine, this shows a good awareness of the principal symptoms of leprosy. Gaddesden noted that leprosy 'consumes the musculature' of wherever part leprosy takes hold. It is not clear whether he means parts already mentioned, or whether he was making reference to any region of the body that may experience loss of sensation or muscle wasting due to illness. The reference to external feeling and not internal being affected is comparable to Andersen et al.'s (1994) observation that deep pain sensation remains for a long time after cutaneous sensation is lost in lepromatous leprosy.

2.4.4.1.2 Section 2

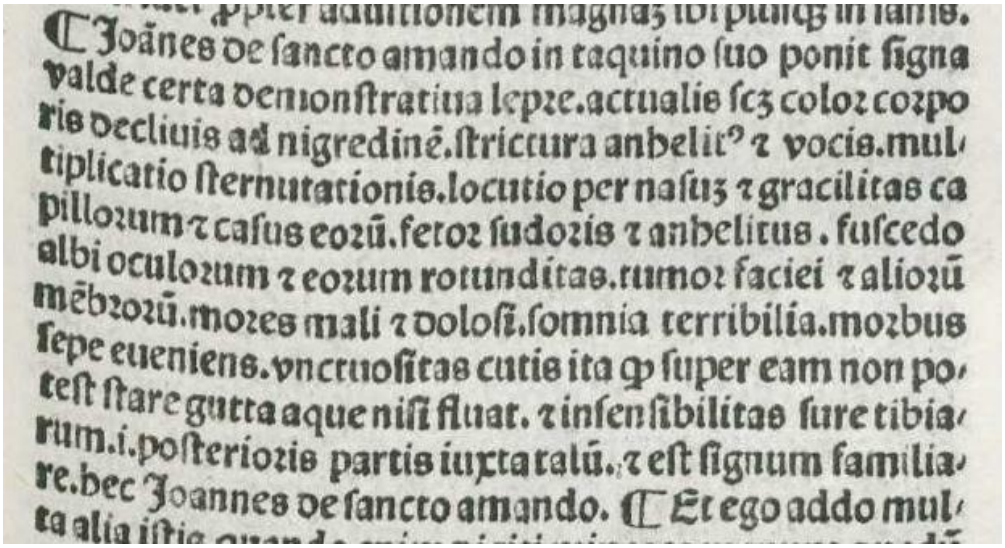

musculuz illuz cõſumit. Tamẽ rõne ſubtilitatis ſue pars
que vadit ad pulmonẽ ⁊ cãnã ⁊ lacertos eoꝝ ⁊ ad oculos
ſpaſmat ⁊ contrahit ⁊ imutat raucedinẽ inducendo ⁊ alia
prius dicta. Et ſi ad vias vrina facit barenulas: ⁊ cum va-
pore eius multiplicat ſe ad ſupercilia ⁊ nares ⁊ faciem in-
groſſat ⁊ inflat illas partes: ⁊ ſic diuerſa mala facit prout
ad diuerſas partes mittitur. ¶ Quantũ ad humorẽ dico
ꝙ ſi ſanguis abluatur poſitus in pãno lineo ⁊ habeat con
tenta nigra aſpera barenoſa oñdit lepram. ſil̃r ſanguis in
flõmia eſt vncuoſus ⁊ in tactu aſper ⁊ barenoſus ꝓpter
aduſtionẽ. ¶ Item ſanguis eoꝝ redit ad carnem in ꝓnci
pio ſed in ſanis aliquãdo eſt illud vt ego frequẽter proba
ui: ſed eſt caro illa in lepra vncuoſa. ⁊ ſi iter digitos frice-
tur ſtrider ꝓpter aduſtionem magnaz ibi pluſq̃ in ſanis.

"However, by reason of its subtlety the part which proceeds to the lung and windpipe and their arms and to the eyes will spasm and contract and alter by inducing hoarseness and the other symptoms already mentioned. And if [it proceeds] to the urinary tracts it makes little granules; and with its vapour it multiplies itself to the brow/eyebrow and nose and enlarges the face and inflates its parts. Thus it causes diverse evils according to the different parts it reaches. Take how much liquid I say to use, because blood, if when wiped away [from the lesions] using a straight linen cloth turns black and rough and sandy [in the cloth], shows leprosy. Similarly, blood taken in bloodletting is also rough and sandy on account of burning [of the humors]. Also, blood is returned to the flesh at first, but in the once healthy I test often as the

flesh in cases of leprosy is greasy. And if fingers hiss when rubbed there is great burning more than is healthy."

Gaddesden further describes what might happen if leprosy gets worse, noting that it proceeds to the lungs and face, with spasming in those regions. His reference to the lungs may be due to the raspy breathing that may develop in advanced lepromatous leprosy due to extensive damage to the rhinomaxillary regions of the face, or infection of the upper respiratory tract mucosa (Torun and Karaman, 2021). Leprosy does not usually infect the lungs themselves, but pulmonary issues can occur in modern cases of leprosy in patients where lifestyle choices, such as chronic smoking, may predispose patients to lung infection (Torun and Karaman, 2021), or where there is an overall depressed immune response which lifestyle factors make worse (Inskip, *pers. comm.*). Modern clinical leprosy can also have ocular effects, including spasm of integral eye muscles. Kaushik et al. (2017) note that leprosy can cause iridocyclitis, an inflammation of the iris and ciliary bodies which can be accompanied by ciliary muscle spasm (Bairappagari, et al., 2017). Leprosy also damages the facial nerve at the main trunk, preventing the function of the orbicularis oculi muscle, leading to lagophthalmos (Ahn et al., 2016). This results in the patient being unable to close the eyelids, leading to eye damage from dryness and exposure. Therefore, Gaddesden's note about eye spasming is a feasible symptom of leprosy, demonstrating astute observation. Gaddesden's reference to leprosy spreading to the nose and enlargement of the face are comparable to the rhinomaxillary syndrome and *facies leprosa* (Møller-Christensen, 1962; Andersen and Manchester et al., 1992). The next sections on the assessment of the urine and blood are less applicable to modern clinical leprosy, reflecting the split between good consistency between the symptoms observed in late medieval and modern clinical practice concerning leprosy, and the methods of assessing the presence of the disease. The reference to 'granules' in the blood and the urine is less clear, although Da Silva et al. (2018) show that individuals with leprosy have a heightened procoagulant factor, meaning their blood is thicker and predisposed to clotting, so Gaddesden may have been observing blood that coagulated/congealed more readily than in non-leprosy patients. Seeing how blood congealed or how urine evaporated were diagnostic approaches in late medieval medicine (Demaitre, 2007). The burning of the fingers when rubbed may be a reference to increased black or choleric bile, and the 'burning' that occurred internally should these humours increase and be imbalanced against the others, or it may be to a sensation that the patient felt when fingers were rubbed during active cases of leprosy where neuropathy was in progress.

2.4.4.1.3 Section 3

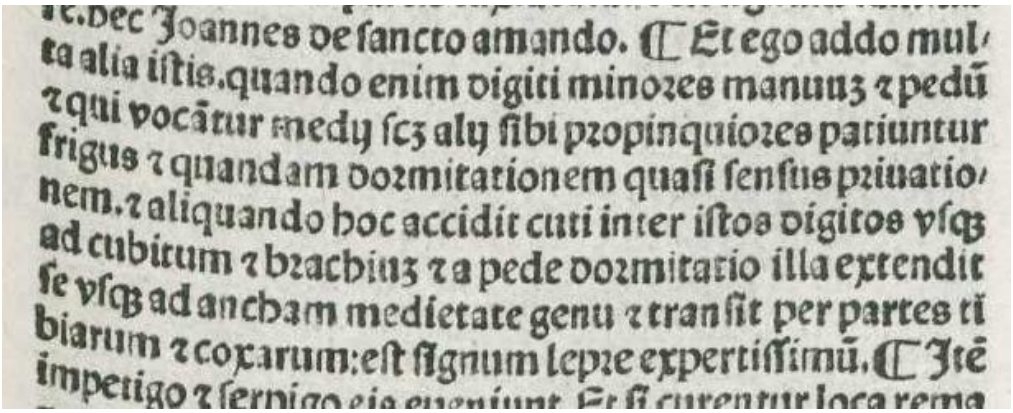

Joānes de ſancto amando in taquino ſuo ponit ſigna
valde certa demonſtratiua lepre.actualis ſcz coloꝛ corpo
ris declinis ad nigredinē.ſtrictura anhelitꝰ ꝛ vocis.mul
tiplicatio ſternutationis.locutio per naſuꝫ ꝛ gracilitas ca
pillorum ꝛ caſus eoꝛū.fetoꝛ ſudoꝛis ꝛ anhelitus. fuſcedo
albi oculoꝛum ꝛ eoꝛum rotunditas.tumoꝛ faciei ꝛ alioꝛū
mēbroꝛū.moꝛes mali ꝛ doloſi.ſomnia terribilia.moꝛbus
ſepe eueniens.vnctuoſitas cutis ita ꝙ ſuper eam non po
teſt ſtare gutta aque niſi fluat. ꝛ inſenſibilitas ſure tibia
rum.i.poſterioꝛis partis iuxta talū. ꝛ eſt ſignum familia
re.hec Joannes de ſancto amando. Et ego addo mul
ta alia iſtic

"John of St Amand in his 'taquino' lays down signs strongly demonstrative of active leprosy. Including discoloration of the body towards blackness, difficulty in breathing and voice. Increased sneezing. Nasal speech, thinning and falling hair, heavy sweating and breathing difficulty. Darkening of the whites of the eyes and the eyeballs, tumour of the face and other members. Bad and doleful behaviour, terrible sleep. Death frequently results. The greasiness of the skin is such that a drop of water cannot stand and will flow. And insensibility of the tibia and the posterior parts next to the ankle. And this is a familiar sign. This is [from] John of St Amand."

Here Gaddesden makes reference to John of St Amand (c. 1230-1303), who taught at the University of Paris and wrote extensively on medicine, noting that the body may become discoloured towards blackness. This probably refers to the purpura and skin blemishes associated with leprosy in modern clinical medicine (Horta-Baas et al., 2015), but it could be a reference Lucio's phenomenon, the leprosy reaction that can occur characterised by necrosis of skin lesions, but this is rare in modern clinical cases (Sharma et al., 2019). Further reference is made to nasal sounding speech and hair loss. The nasal speech can be attributed to the rhinomaxillary inflammation and eventual destruction of those nasal elements that occur in advanced leprosy (Andersen and Manchester, 1992), with advanced ulceration of these regions perhaps leading to breathing difficulty. The whites of the eyes becoming dark, and subsequent swelling may be due to *facies leonina* where the whole facial region can become swollen (Salgado and Barreto, 2012). Impaired eye closure, such as chronic lagophthalmos in leprosy (Courtright and Lewallen, 1995) can also lead to keratitis and ocular ulcers (George et al., 2020), so perhaps this might be the darkness Gaddesden refers to. Gaddesden also notes the greasiness of the skin, meaning that water will run off the skin if

applied to it. The relation of greasiness of the skin to leprosy is not so clear, as the neuropathy in leprosy can in fact damage the nerves regulating sweat glands, particularly in tuberculoid leprosy (Utino et al., 2017) causing regions to become red and dry rather than greasy. This section ends with Gaddesden noting (via John of St. Amand) that the lack of sensation in the legs may progress to the tibia, demonstrating a keen awareness of the progression of the disease in a manner that fits present day observations of the disease.

2.4.4.1.4 Section 4

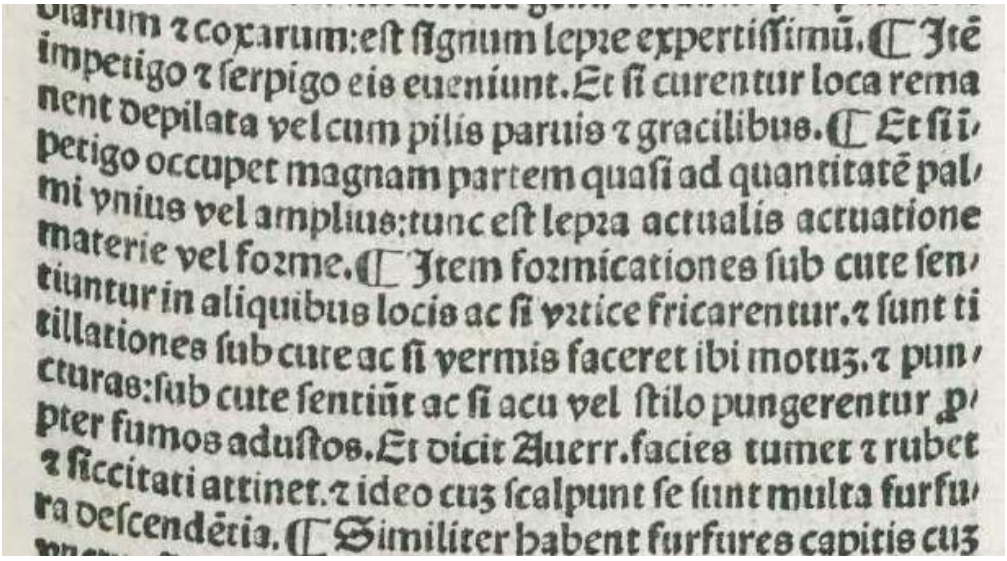


> *"And I add many other things. For instance, when the small digits of the hands and feet and those which are called 'middle' or second feel colder than those next to them, with 'sleep like' deprivation of feeling; and when this happens you should cut the skin between the fingers, and at the elbow, the upper arm and a foot. The slumber extends by itself to the middle of the knee, and through parts of the leg and the hip – this is a mark of leprosy in my experience."*

Gaddesden here notes further progressive symptoms of leprosy, specifically the related loss of sensation in the fingers. The 'sleepiness' referred to may be due to the sluggish movement of any remaining appendages affected by leprosy as a result of ongoing neuropathy. He suggests cutting the skin in these regions, presumably as a test as to whether sensation remains in those places, or perhaps as an attempt to purge any material from that area in a hope to alleviate any ill effects of the disease. He again notes the progressive nature of leprosy, by commenting that the 'slumber' i.e., the loss of feeling, extends to the middle of the knee by itself, and through parts of the leg and the hip. This demonstrates awareness of the physiological symptoms, and chronic course, of leprosy as a disease to an extent. Loss of feeling in the hip is not a symptom noted in clinical leprosy, so the range of effects noted here does not fully align with modern clinical observations. However, Agrawal et al. (2020) note a case of leprosy-induced hip arthritis in a 32-year-old individual (a modern case), so leprosy can involve the hip bones, but this is a rare observation, and it is not clear that this is what

Gaddesden is referring to. It nonetheless demonstrates an awareness of the variability of neuropathy in leprosy infection.

2.4.4.1.5 Section 5

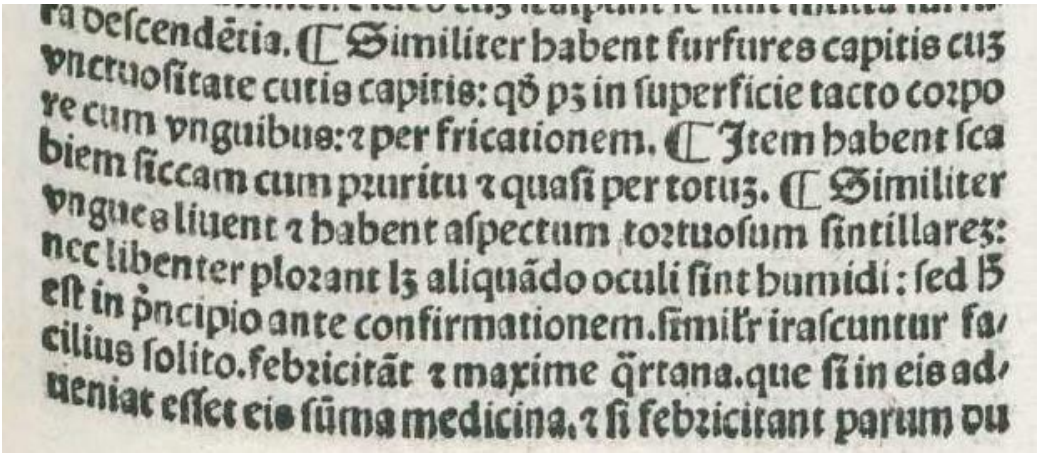


> "*Also, impetigo and serpigo occur. If cured, the spots remain, with the skin either bald or with very fine hair. If the impetigo spreads to the width of a palm, or further, then this is active leprosy operating in matter and form. Also, some people have a crawling sensation under the skin in places, as if a stinging nettle has been rubbed [on the skin]. There is also a tickling under the skin as if a worm is moving under there. There is also a pricking sensation under the skin, as if a needle or pen is piercing burning smoke. And* Averroes *says the face swells with redness and dryness. Therefore, when scratching there are many scales falling.*"

Gaddesden notes that skin rashes (impetigo and serpigo) can occur. Serpigo in particular is an interesting observation, as in Latin this relates a creeping skin disease with a tendency to spread, akin to modern-day ringworm (Bechet, 1936, Beswick, 1962). This is interesting as ringworm results in discoid lesions directly comparable, morphologically speaking, to the discoid skin lesions that occur in leprosy, particularly the tuberculoid form or borderline variants thereof, where skin rashes can be extensive (Lastoria and Abreu, 2014; Horta-Baas et al., 2015). This displays a direct awareness of the types of skin lesions that can occur in modern leprosy in a medieval context, and some of the permanent effects even if active lesions resolve ('spots', which may possibly be leprous granuloma, remain, with hair loss in that place). He then goes on to note various sensations that may be felt under the skin in those suffering from leprosy, which seem to be somewhat repetitive and essentially amounting to the same symptom, but nonetheless showing awareness of the uncomfortable sensations that may occur in the patient as neuropathy progresses. He also notes that the face swells

with a redness and dryness, with flakes falling off when scratching occurs. Facial redness and swelling is a clinical symptom of leprosy, particularly during leprosy I and II reactions (Chen et al., 2021)(acute periods of increased inflammation that can occur in chronic leprosy).

2.4.4.1.6 Section 6


ra deſcendẽtia. ℂ Similiter habent furfures capitis cuꝫ
vncuoſitate cutis capitis: qꝫ pꝫ in ſuperficie tacto coꝛpo
re cum vnguibus: ꝛ per fricationem. ℂ Item habent ſca
biem ſiccam cum pꝛuritu ꝛ quaſi per totuꝫ. ℂ Similiter
vngues liuent ꝛ habent aſpectum toꝛtuoſum ſintillareꝫ:
nec libenter ploꝛant lꝫ aliquãdo oculi ſint humidi: ſed ꝫ
eſt in p̀ncipio ante confirmationem. ſimilr iraſcuntur fa/
cilius ſolito. febꝛicitãt ꝛ maxime q̃rtana. que ſi in eis ad/
ueniat eſſet eis ſũma medicina. ꝛ ſi febꝛicitant parum ou

> *"Likewise, they have scales and greasy skin on the top of the head. This is exposed when touching the top of the body with fingernails, and through rubbing. Likewise, they have dry and itchy scabies, as if through the whole. Similarly, nails are black and blue, and are badly crooked and splitting. Nor can they cry freely as when the eyes are full of liquid; but this is a new thing and not yet confirmed. [The patient] also gets angrier more easily than is accustomed to [previously]. Feverishness is at its maximum on the fourth day. If they reach this point give them the strongest medicine. If feverishness is too little harden their fever."*

In this section Gaddesden further notes the superficial skin ailments associated with leprosy, such as scaliness and greasy skin on the top of the head, which becomes particularly apparent when touched with fingernails or rubbed. There is a generalised dry and itchy scabies. He notes also that nails become black and blue and crooked, which may be indicative of the progressive neuropathy, and the lack of care and attention of these regions by the patient once the disease has progressed to this point. In any case it is a feasible symptom of leprosy. He suggests that the patient cannot cry; impaired tear production is observed in modern clinical cases of leprosy (Pavezzi et al., 2020). He also notes that the patient may get angrier than they were accustomed to previously. Emotional instability has been noted in modern clinical cases of leprosy, but this is in the context of the negative mental health effects secondary to the physical effects of the disease, and also the negative social factors due stigmatisation of the disease (Somar et al., 2020), although hormonal imbalances can occur also (Dabi et al., 2023). It is unclear whether Gaddesden considers the increased anger in patients as a side effect of the unpleasant physical symptoms, or due to leprosy

and anger being inherently linked on a more fundamental level. Demaitre (1996: 32), however notes that emotions were viewed as affecting the humors, with 'accidents of the soul', such as prolonged anger being a viable cause of leprosy (de Tharanta, 1418; in Demaitre, 1996: 32), so it is feasible that Gaddesden considers anger and leprosy to be inherently linked at a humoral level, although there were bound to be social factors that also may have also driven heightened anger.

2.4.5 Gilbertus Anglicus (d. ca. 1250) and the Compendium

The precise biography of Gilbertus Anglicus (Gilbert the Englishman) is unclear, however he was probably born *ca.* 1180 AD, and died somewhere between 1240 and 1250 (Gonzalez-Hernandez and Dominguez-Rodriguez, 2008), although even these broad dates have been debated (Handerson, 1918). He was the author of one of the most significant texts of the English Middle Ages, the *Compendium Medicinae* (Getz, 2010). The *Compendium*, originally written at some point between 1230-1264 (Handerson, 1918, p. 23) is divided into seven books, and systematically covers all known medicine and surgery of the age from head to toe (Getz, 2010). The work continued to be translated and circulated in many European languages until the mid-17th century (Getz, 2010), however it also saw wide contemporary circulation of excerpts in Middle English in the Middle Ages, suggesting a strong lay and general readership outside of learned medical circles working in Latin, distinguishing it from the works assessed above. While Gilbertus himself claimed no particular originality in the *Compendium*, writing that it is a compilation of work by prior masters (Handerson, 1918), the fine detail of the prescriptions and processes of disease presented by Gilbert (Handerson, 1918) are why this work remained a distinguished reference for several centuries after its publication (Pearn, 2012). It is also noted for its extensive presentation of surgical processes, but does not credit any surgeons directly (Handerson, 1918).

Little is also known of Gilbert's university affiliations, with Getz (2004) suggesting that Oxford and Cambridge did not have established medical faculties of any note at this time. However, Handerson (1918) indicates that he spent time at Salerno under the tutelage of Roger of Parma (*d. ca.* 1195), where he would also have had access to the works that he directly references (as noted above).

2.4.5.1 The Compendium and Leprosy

The discussion of leprosy in the compendium covers 20 pages, covering in minute detail the elephantine, leonine, tyrian and allopecian forms of the disease (Handerson, 1918: 49), centred around the dispersion of black bile. The precedence of the knowledge of leprosy presented in the *Compendium* has been subject to debate, with Handerson (1918) noting that Dr John Friend suggested in 1725 that the sections on leprosy are copied from Theodoric of Cervia (d. 1298). Handerson, however, places the publication of the *Compendium* at 1240, before the publication of

Theodoric's Chirurgia in 1266, perhaps suggesting that any copying must have been the other way round.

Gilbert directly notes loss of sensation in the extremities as a primary symptom of leprosy, with possible loss of digits, and distortion of the joints of the hands and feet, and anterior facial features (Handerson, 1918: 49). This is very comparable with modern clinical leprosy, and displays a keen awareness of symptoms. Perhaps more significant in Gilbert's writings on leprosy are the clear links between leprosy and sex, particularly as it applies to women and menstruation, and the heightened libido of those suffering with leprosy. Gilbert says that corrupt menstrual blood can affect the fetus and lead to congenital leprosy, and there is also another chapter concerning the sexual transmission of leprosy more generally (Handerson, 1918). This compares well with Demaitre's (2007) observations of the link made between leprosy and sex more widely in Europe in the late-medieval period, and strongly suggests that sexual promiscuity was also an act fraught with potential sin in England, despite leprosy generally perhaps being viewed somewhat positively due to the leprosy sufferer's closer spiritual proximity to God. If nothing else, this highlights an ambivalence towards leprosy and how it related to other facets of medieval life, in this case sex, and displays that the picture remains complicated and variable in time and place. Handerson (1918) suggests that the chapter on the sexual transmission of leprosy suggests a possible confusion of the disease with syphilis. This seems unlikely given the acute awareness of the symptoms of leprosy described by Gilbert.

Interestingly, descriptions of (and treatments for) Leprosy are not present in Middle English (ME) Gilbertus (ME Gilbertus exists in around 12 manuscripts, written within 50 years of each other (Getz, 1991: ixv)). The absence of leprosy from ME Gilbertus intended for a wider, lay readership suggests that leprosy remained a topic for learned physicians working with the original Latin texts. It seems that formal diagnosis of leprosy, and therefore entry to leprosaria, remained a process to be carried out by qualified and learned physicians that could work with the original Latin text. This is perhaps not surprising, given the high spiritual stakes in the diagnosis of leprosy, and the belief that those with leprosy were spiritually close to the lord (Demaitre, 2007; Rawcliffe, 2009). This is supported by the complex diagnostic processes presented by Demaitre (2007) and Rawcliffe (2006), wherein leprosy was diagnosed by established physicians over multiple sessions, or via committee of which a learned physician would be part. The selective approach of copyists when translating the Gilbertus into Middle English when deciding what to include from the Latin texts (Getz, 2010) also suggests that leprosy remained a specialism. It must also be said that the omission of leprosy from ME Gilbertus may also be based on more pragmatic concerns of not letting the lay population diagnose a complex disease, particularly as Demaitre (2007) noted that there were instances of individuals

feigning illness in attempts to enter leprosaria (living conditions in leprosaria could be quite comfortable (Roffey and Tucker, 2012)). However, this perhaps then ran the risk of DIY diagnosis by a quack, which was present in medieval society at this time (Mandel, 1987), but it does not then follow that patients diagnosed by these individuals would have been granted access to the leprosarium. It is up for question whether the lack of leprosy in ME Gilbertus affected the diagnosis of leprosy by lay populations in practice, as those who could read ME may have been able to read some Latin (although whether they had access to Latin texts is yet another question), and Demaitre (2007) notes that barbers and local committees may have sometimes diagnosed leprosy in the population (although Demaitre (2007) focuses on late medieval France). Despite this, the absence of leprosy in ME Gilbertus does at least suggest an underlying desire to not encourage the diagnosis of complex diseases by the general population.

2.4.6 Summary

The importance of directly assessing these works is two-fold. It avoids transposing modern ideas of disease onto a population that conceptualised disease very differently, which otherwise may unduly affect the consideration of the social context of the assemblages and our view of the aptitude of those diagnosing disease. Secondly, it gives direct insight into the diagnostic process adopted, both for the symptoms associated with leprosy, and the perceived causes. The above demonstrates that the signs and symptoms of leprosy described in these medieval texts are comparable to tuberculoid and lepromatous leprosy in a modern clinical setting, despite the incongruity of galenic humoral theory with modern medicine. This adds significantly to the broader revisionist work concerning leprosy in the medieval period by Rawcliffe (2006) and Demaitre (2007).

This also directly challenges the notion that accurate diagnoses and descriptions of leprosy were rare (Gussow and Tracy, 1970; Covey, 2001), and the view that leprosy was frequently misdiagnosed (Brody, 1974; Covey, 2001). Interpretations of leprosy being poorly described or 'misdiagnosed' in previous literature do not appropriately consider how diseases/symptoms were classified and spoken of in their medieval context, with the nomenclature taken at face value. Brody (1974: 41) notes that 'medieval doctors' could not properly describe leprosy as they could not tell it apart from scabies, psoriasis, eczema 'and a host of other skin conditions'. However, the fact that medieval physicians showed an awareness of the potentially similar presentation of leprosy to these other diseases that cause skin lesions is to their credit, as even in a modern clinical context leprosy is difficult to differentially diagnose due to its inherent clinical variability (Forno et al., 2010), and can actively mimic these skin conditions, particularly scabies (Glennie et al., 2021) and psoriasis (Vora et al., 2015). Indeed, it is often misdiagnosed in the present day (Henry et al., 2016). Therefore, it was potentially to the benefit of a patient that medieval physicians did not commit to a single view

of how leprosy may present and accepted that leprosy may present similarly to other diseases. These diseases can also be comorbid, such as leprosy and psoriasis, although this is rare (Li et al., 2022).

There are also issues with literature concerning leprosy in the medieval period misinterpreting other contemporaneous literature. For example, Covey (2001) suggests that leprosy was confused for skin ailments such as ringworm, citing Cohn (1989). However, Cohn (1989: 25) actually refers to those suffering with ringworm being noted as 'unclean' as those suffering from leprosy and is not specifically referring to any confusion on the part of medieval physicians diagnosing leprosy. In any case, the Latin term for ringworm – serpigo – when considered in the context it was written, pertains to a discoid skin lesion, which are commonly seen in modern clinical leprosy, particularly the tuberculoid form of the disease (Bleharski et al., 2003; Santos et al., 2017). So when considered in the context it was written, and then compared to modern day clinical literature, rather than *vice versa*, we see that 'ringworm' in the medieval sense is a valid symptom of leprosy. This further highlights some of the historiographical issues of considering medieval disease diagnosis. Care must be taken to not confuse/conflate the signs and symptoms described in the medieval medical literature, and the nomenclature thereof, with modern day nomenclature and concepts of disease.

It would also be naïve to assume that diagnoses of leprosy took place outside of social and economic pressures (Rawcliffe, 2006; Demaitre, 2007; Miller and Nesbitt, 2014), and this is not to say that individuals were never admitted to leprosarium with a condition that might mimic leprosy in medieval England (we also do not know the precise works consulted when diagnosis was made for the specific individuals in this dataset). However, the above shows there is sufficient evidence to reappraise the diagnostic capabilities of medieval physicians if the descriptions of signs and symptoms are considered through their lens, by directly engaging with their material. The knowledge did exist in medieval England to successfully diagnose leprosy, and this will feed into the discussion of the skeletal remains under study, as it appropriately reframes the diagnostic capabilities of medieval physicians, particularly for individuals displaying no skeletal lesions in the leprosarium assemblages. Leprosaria had stringent entry criteria (Rawcliffe, 2006), and it was unlikely that someone was admitted without being formally diagnosed, which was a long process (see *Iucidum Leprosorum: Medical Judgment* in Demaitre (2007: 34-75)). Therefore, there was a reasonable chance that the individuals under assessment in this research had been diagnosed with leprosy correctly, and been admitted to the leprosaria under that basis, and shows that 'medieval' and 'modern' leprosy are directly comparable, despite differences in the underlying medical frameworks used to explain and categorise disease. This is reflected in the evidence of leprosy seen

in the cemetery populations under study in this research while the institutions functioned as leprosaria (they later transitioned to almshouses for the general care of the poor and sick).

Chapter 3: The Diagnosis of Leprosy in the Archaeological Record

The palaeopathological study of leprosy has seen varying progress over the past 50 years, marked primarily by two distinct bodies of work (Møller-Christensen, 1953; 1961; 1967; 1978; Andersen & Manchester 1987; 1988; 1992; Andersen, et al., 1992; 1994). The following sections will explore the skeletal lesions initially proposed as diagnostic criteria for leprosy by this early research, before assessing how these studies have been utilised by current researchers in the field.

3.1 Developments in the Diagnosis of leprosy

3.1.1 Vilhelm Møller-Christensen

The Danish medical historian and palaeopathologist, Vilhelm Møller-Christensen (1903-1988), was the first to catalogue the range of leprous changes in skeletons excavated from St George's leprosarium in Naestved, Denmark. Moller-Christensen published his observations over a period of 25 years (Moller-Christensen, 1953; 1961; 1967; 1978). This research was inspired by a female skeleton he observed in 1944 displaying lesions he could not identify, but suspected were caused by leprosy (Bennike, 2012).

In *Bone Changes in Leprosy* (1961), Møller-Christensen provided a systematic review of skeletal lesions identified in 328 medieval individuals recovered from the Danish leprosarium, 123 of which were complete. Using knowledge of the clinical manifestations of the disease on the soft tissue, he introduced a series of lesions, many that are still used today. Particular attention was paid to the skeletal changes that underlie the facial lesions of leprosy, with separate sections for the nose, mouth and eyes (Møller-Christensen, 1968), and a chapter dedicated to *facies leprosa.* Direct observations of modern patients at Bergen Leprosy Clinic in Norway and patients from Thailand, provided further clinical support for the lesions outlined. In contrast, the list of lesions associated with the disease in the extremities was compiled through observations on the skeletal material itself, rather than being extrapolated from clinical studies. Møller-Christensen categorised these lesions as primarily absorptive and pyogenic in the hands and feet, with proliferative lesions noted on the tibiae and fibulae. Each lesion was illustrated with a series of photographs and written descriptions, with a discussion of the suite of lesions provided for the 123 complete individuals at Naestved. In this book, Møller-Christensen first introduced lesions considered diagnostic for *facies leprosa* on the hard palate, maxillary alveolar process, anterior nasal spine, maxillary sinus, and the

orbits (Table 3.1), introducing a three point 'severity' scale he would expand upon in 1978. Despite providing this grading scheme, lesions were frequently tabulated as 'present' or 'absent'. However, the detailed illustrated appendix (plate section) provided images for each of the 123 individuals alongside a table denoting the number and severity of lesions. Møller-Christensen (1967) identified horizontal tibial striations on various individuals in the Naestved sample, suggesting that they may be leprous in origin. Horizontal tibial striations are noted in modern contexts as a form of stress fracture, accompanied by thickening of the anterior tibial cortex (Daffner, 1984), mostly in a sporting context (Batt et al., 2001).

Table 3.1: List of lesions outlined by Møller-Christensen (1961; 1978).

Cranial Lesions	**Clinical basis**
Atrophy of anterior nasal spine	Yes
Atrophy of alveolar maxillary process	Yes
Inflammatory pitting of hard palate (oral and nasal	Yes
Usura orbitae (*cribra orbitalia*)	*No – not for leprosy (see Lee and Magilton, 2007)*
Post-cranial Lesions	
Proliferative lesions to long bones	Yes
Erosive and absorptive lesions to phalanges	Yes
Horizontal Tibial Striations	Yes

In *Leprosy Changes of the Skull* (1978), Møller-Christensen provided a more formal approach on how to identify changes to the face (except cribra orbitalia) using his three-point scale: (I°) *earliest recognisable pathological changes*; (II°) *some absorption, pitting or more advanced changes*; or (III°) *even further pathological change/obliteration* of the location or bone in question.

Despite the generic descriptors established for each grade initially, the three-point scale differed depending on the specific area being described. For example, a III° lesion of the oral surface of the hard palate is one that shows 'still more advanced destructive changes and perforations' (1978: 16), whereas a III° score for atrophy of the maxillary alveolar process is defined as: 'bone atrophy that is severe, and at least one tooth, generally of the central incisors, has presumably been lost *in vivo*, or the alveoli have been obliterated' (1978:16). Evidently, a III° score for the maxillary alveolar process is more informative in the context of this criteria than a III° score for the oral surface of the hard palate, due to the more specific definition for that grade. Some of the grade descriptions are less detailed than others. In discussing '*usura orbitae*' (now known as cribra orbitalia) in 1961, the precise dimensions of the pitted lesion and the area covered were scored, while later similar pitted lesions on the hard palate of the maxilla were not scored in such a precise way.

Møller-Christensen (1978) provides extensive descriptions (with accompanying images) of differential diagnosis for the cranial lesions, with particular attention paid to venereal syphilis. Thirty-two cases of facies leprosa were identified and illustrated in the Naestved individuals. The criterion provided by Møller-Christensen (1978) is an effective way to record both the presence and severity of lesions according to location.

These publications were the first to provide detailed descriptions, scoring schemes and illustrations that showed the variety of expression of the lesions associated with leprosy (Fig. 3.1). Earlier research by Moller-Christensen and Sandison (1963) on an anatomy collection argued for *cribra orbitalia* being related to eye infections in leprosy, but subsequent research has shown no significant link between the two (Magilton et al., 2008).

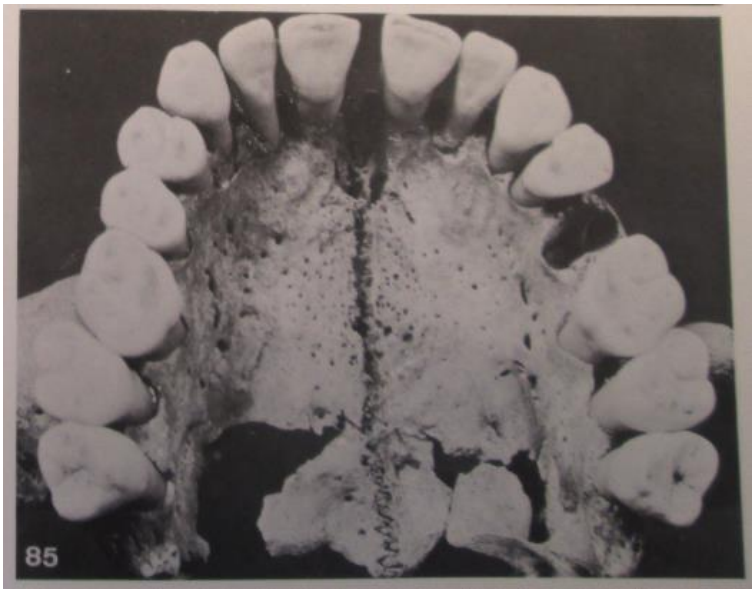


Fig. 3.1: Example of pitting of oral palatine surface from Møller-Christensen (1978: 89).

3.1.2 Johannes Andersen and Keith Manchester

In the 1980s and 1990s, Andersen and Manchester (and others) published a series of papers outlining rigorous investigations into the clinical and pathological nature of lesions identified in individuals with leprosy. Both authors have a medical background, with Johannes Andersen (1923-2005) working initially as an orthopaedic surgeon on leprosy patients in India and Africa (Bennike, 2012), and Keith Manchester (b. 1938) working as a General Practitioner in Bradford, UK (Roberts, 2012). They were the first to consider how radiological indicators of leprosy could be used to inform what lesions might be observed in archaeological remains, in doing so linking radiographic features observed in live patients with macroscopic lesions observed in palaeopathological material - shedding light on the underlying aetiology of lesions.

3.1.2.1 Early Papers (1981-1989)

Manchester (1981) described a skeleton displaying cranial indicators of leprosy from an assemblage in Eccles, Kent excavated in 1970-72. He provided a detailed list of the cranial and post-cranial lesions he considered characteristic of leprosy. Following Møller-Christensen (1978), Manchester recorded erosion of the anterior nasal spine, atrophy of the alveolar process of maxilla, osteitis of the nasal and oral surfaces of palate, cribra orbitalia, and bilateral periosteal new bone formation (PNBF) of tibiae and fibulae. While the lesions were listed, they were not described in any detail. Uncertainties arise when Manchester (1981) used the three-point scale proposed by Møller-Christensen (1978) to interpret the lesions. The language adopted incorrectly suggests that the definitions for each grade of the scale are generic and can be applied universally; Møller-Christensen (1978: 30) describes a II° lesion of the anterior nasal spine as 'advanced anterior nasal spine (ANS) atrophy, although a distinct but very small ANS remains', while defining II° pitting of the oral surface of the hard palate as, 'more advanced stages of the changes and perforations' (Møller-Christensen, 1978: 32). The definition of a 'II°' lesion varies in Møller-Christensen (1978), which is unclear from reading Manchester (1981), who suggests that the three-degree scale has generic definitions for all lesions. This displays how the details of the source material can become conflated despite solid referencing and full disclosure of lesions under study.

From 1987 to 1994, Andersen and Manchester used clinical observations to introduce new lesions associated with leprosy (Table 3.2). In 1987, they introduced 'volar grooving' of the distal end of the proximal hand phalanges as a secondary effect of claw-hand deformity resulting from leprogenic paralysis of the ulnar nerve. They argue that sustained hyperextension and hyperflexion at the metacarpophalangeal and interphalangeal joints respectively, with subsequent pressure on the distal end of the proximal phalanx, results in shallow half-moon-shaped grooves on the 'volar' surface. Grooves may affect a single phalanx or multiple phalanges, and occur as bilateral or unilateral lesions, depending on nature of claw-hand deformity in the individual. While not pathognomonic of leprosy, volar grooving may be a useful indicator of leprosy due to the chronic paralysis inferred, especially when found with other leprosy lesions. Andersen and Manchester (1987) made direct comparisons of radiographs from living individuals with leprosy with skeletal individuals. The number of clinical radiographs and skeletal cases observed was not reported but Andersen and Manchester (1987: 79) state that proximal phalangeal volar grooving is 'not known to be associated' with claw-hand deformity of any other aetiology. Later studies (e.g. see Lewis et al., 1995) corrected the anatomical terminology used to describe these lesions, which are now known as 'palmar' grooves.

In 1988, Andersen and Manchester added dorsal-tarsal exostoses to the diagnostic criteria. They argued that these lesions occurred because of collapse of the arch of the foot due to neuropathic paralysis of posterior tibial nerve in leprosy, using observations in live patients and clinical radiographs as a foundation for researching this in skeletal material. They described the dry bone manifestations in an early medieval skeleton from Cannington. The posterior tibial nerve supplies the motor component of all muscles that maintain longitudinal arches, with the exception of *Peroneus longus (*Andersen and Manchester, 1988). The navicular bone is the keystone of the arch, with paralysis of the surrounding supporting soft tissues and nerves resulting in volar displacement of the bone. This is a dynamic and progressive process that creates increased ligamentous stress at attachment sites. The development bony exostoses at these attachment sites is a chronic process, with gradual displacement of the navicular through continued weight-bearing on the foot, and loss of deep pain sensation due to the neuropathy. Andersen and Manchester (1988) also noted plantar ulceration that develops on the inferior aspect of the calcaneus and the first and fifth metatarsophalangeal joints if integrity of arches is maintained.

The exostoses observed by Andersen and Manchester (1988) presented as irregular, smooth ridges of bone extending transversely from the dorsal surfaces of the tarsal bones, with the navicular and talus bones being the most frequently affected. The lesions were located away from articular surfaces but could be observed with concurrent osteoarthritis. Andersen and Manchester (1988) note that exostoses on adjacent bones can fuse (ankylose), however integrity of articular surfaces is maintained. The exostoses are more radiolucent than the parent bones on radiograph.

The single individual observed in this case is from a larger assemblage of undisclosed size, so the overall frequency of dorsal-tarsal exostoses within the assemblage is unclear. This means it is also impossible to gauge whether dorsal-tarsal exostoses are only associated with leprosy (i.e. did they also occur in individuals not displaying other leprosy lesions), although the aetiology proposed by Andersen and Manchester (1988) is specific, suggesting that they believe dorsal-tarsal exostoses are unlikely to be caused by anything else. Detailed descriptions of the lesions and the proposed underlying aetiology are provided, however no direct reference is made to previous research into leprogenic neuropathy and disease progression in clinical cases to support these claims.

3.1.2.2 Later Papers (1992-1994)

Perhaps the most influential of their papers, in 1992 Andersen and Manchester presented a thorough analysis of the cranial effects of leprosy in archaeological remains (Table 3.2), with reference also to clinical literature and radiographs.

This is the first paper to propose that the cranial lesions due to leprosy in palaeopathological cases be referred to as 'Rhino-Maxillary Syndrome' (RMS), rather than *facies leprosa* (Møller-Christensen; 1961, 1978) or 'rhinomaxillary change' (Andersen, 1969). This was to adequately distinguish the bony changes caused by leprosy from the soft tissue lesions. The term 'syndrome' was proposed to account for the variability of lesions displayed between individuals, and the different underlying causes and progression of these lesions (Andersen and Manchester, 1992: 122). The primary lesions considered were absorption of the anterior nasal spine, rounding of the nasal aperture, absorption of the anterior maxillary alveolus, and inflammatory pitting of the oral and nasal palatine surfaces (Fig. 3.2). The aim of the paper was to consider the complicated aetiology of the lesions that comprise RMS, and not to simply to describe them. In addition to the previously described suite of lesions affecting the face, Andersen and Manchester (1992) added discussion of the intranasal structures (e.g. the vomer) and describe the progressive bone changes and pathogenesis of RMS with reference to clinical research. They considered the dry bone manifestation of the lesions using leprosy skeletons from Naestved in Denmark, and Chichester and Norton Priory, England. Andersen and Manchester (1992) refer to Møller-Christensen (1978) when considering how the lesions should be graded, but comment that the criteria has little use for assessing the duration of leprosy in an individual.

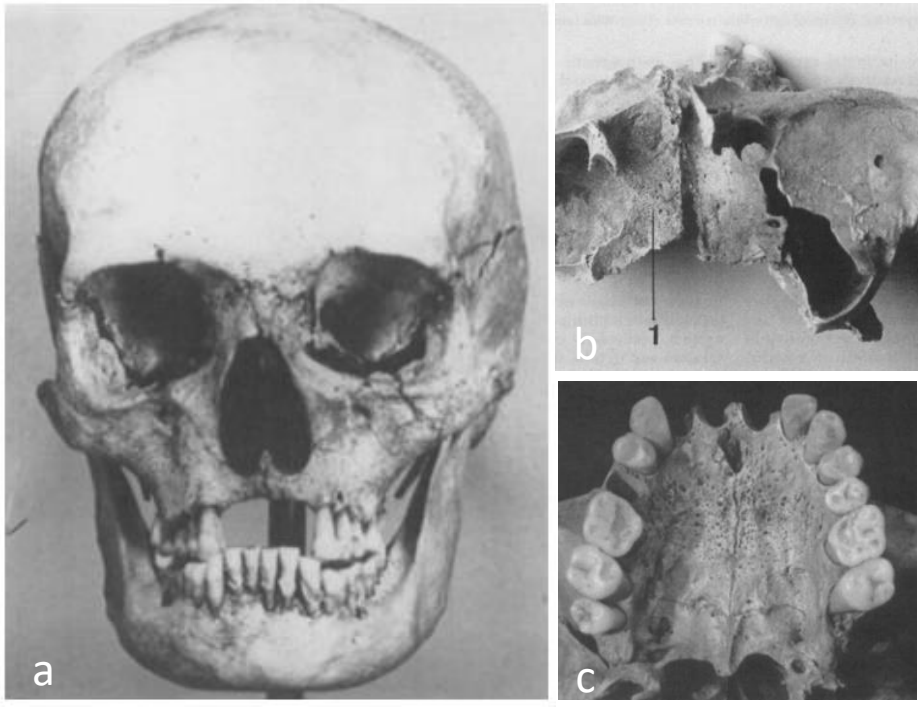


Fig. 3.2: An example of Rhinomaxillary syndrome from Andersen and Manchester (1992: 123, 125, 127); a: absorption of anterior nasal spine, margins of nasal aperture and maxillary alveolus; b: pitting of nasal palatine process; c: pitting of oral palatine process.

Also in 1992, Andersen, Manchester and Ali described diaphyseal remodelling of the metatarsals, metacarpals, and phalanges in leprosy (Fig. 3.3). They build on the observations of 'concentric atrophy' observed by Møller-Christensen at Naestved by incorporating radiographic observation of patients from a hospital in Perulia, India. The remodelling observed was either concentric, or mediolateral, with the former leading to the 'candy sucked' or hourglass morphology of the affected bone, and the latter leading to knife-edge deformity where absorption is only on the mediolateral aspects of the bone, with the anteroposterior aspects unaffected and retaining their original diameter. The original cortical thickness of the bone is maintained, differentiating concentric remodelling from osteopenia. Complete obliteration of medullary cavity eventually occurs. Anderson et al. (1992) suggest that this is the result of concurrent periosteal osteoclastic and endosteal osteoblastic activity, where osteoclasts continually absorb periosteal cortical bone while osteoblasts simultaneously deposit endosteal cortical bone. Only the phalanges, metatarsals, and (less commonly) metacarpals are affected by this kind of remodelling. They argue that differences in the arterio-dilation capabilities of the endosteal and extracortical blood supply as a result of irreversible damage to the nerves caused by *M. leprae* may lead to an imbalance of oxygen tension, with extracortical tissues exposed to high oxygen tension and endosteal tissues exposed to low oxygen tension. This favours osteoclastic and osteoblastic activity respectively - leading to diaphyseal remodelling with retention of cortical thickness (Marks, Jr., 1979). They note diaphyseal remodelling may also occur with coincident acroosteoloysis, wherein the proximal phalanx is absorbed (Botou et al., 2017).

Incorporating palaeopathological and radiographic data highlights the benefit of a multifactorial approach and demonstrates how original observations can be built upon by incorporating novel methods of observation when reviewing skeletal material. Andersen, et al. (1992) analysed dry bone changes in 198 feet from Naestved (17 showing phalangeal remodelling, 30 metatarsal remodelling) and 147 hands (7 showing metacarpal remodelling), and the clinical radiographs of 83 feet from Perulia (38 showing phalangeal remodelling, 53 metatarsal changes). It is unclear how complete the hands and feet from Naestved were - missing skeletal elements may explain the disparity between the frequency of remodelling observed in the palaeopathological and radiographic material. Also, individuals observed radiographically were known leprosy sufferers, allowing for a more targeted study than was possible for the Naestved individuals. Further analysis of radiographic material of known leprosy suffers may provide useful data for rates of diaphyseal remodelling in leprosy that can be used to inform palaeopathological studies going forward.

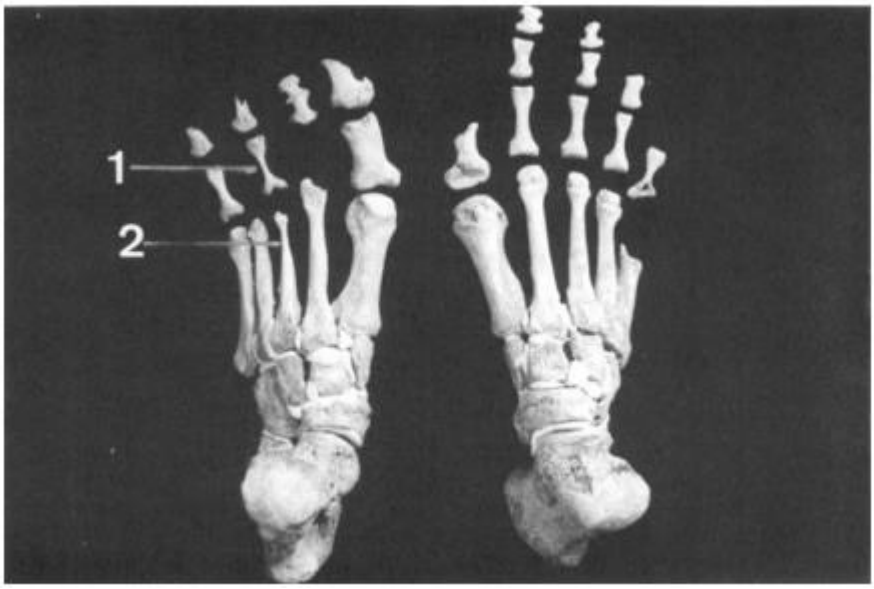


Fig. 3.3: Diaphyseal remodelling in Andersen et al. (1992: 212).

Andersen, Manchester and Roberts (1994) described septic bones changes in leprosy, again comparing the dry bone changes seen in archaeological individuals with radiographs of live patients to inform palaeopathological diagnosis. They argue that the changes to the extremities should be used to provide a 'tentative diagnosis' of leprosy in the absence of RMS.

Tuberculoid and lepromatous leprosy are immunologically stable at both ends of the spectrum, with unstable borderline variants that eventually gravitate to either end of these stable states. However, concurrent non-specific infection or pregnancy may lead to worsening of the disease, with increased immunological stress favouring the development of lepromatous leprosy (Andersen et al., 1994). Although not the direct cause of soft tissue and bone sepsis, the nature of physical deformity in the limbs and joints influences the site and progression of sepsis. The pattern of neuropathy during the course of infection by the *M. leprae* bacilli differs in the lepromatous and tuberculoid forms, with sensory neuropathy developing late and early respectively. The sympathetic component of autonomic nerve damage is permanent dilation of arterioles, leading to peripheral hyperaemia. The loss of sensitivity allows minor unperceived trauma to progress to chronic insensitive ulceration. Repeated trauma leads to damaged capillaries and increasing haemorrhage, resulting in aseptic necrosis of tissue. This favours invasion by bacterial pyogenic infection (Andersen et al., 1994). Andersen and colleagues (1994) argue that tuberculoid leprosy presents as isolated skin lesions with asymmetrical distribution of nerve damage leading to asymmetrical infection, whereas in the lepromatous form, changes would be more widespread.

The study focussed on septic changes to the appendicular skeleton (Fig. 3.4), discussing how the patterns of neuropathy influence the secondary effects that promote the invasion of pyogenic

bacteria. Andersen et al. (1994) divide the bony lesions of the extremities in leprosy – 1) non-pyogenic lesions that develop due to direct involvement of *M. leprae* bacilli, and 2) Pyogenic lesions of bones and joints due to secondary infection by environmental pathogens because of deep tissue anaesthesia and ulceration. They suggest that direct non-pyogenic involvement of *M. leprae* bacilli present as lytic foci of the bone cortex or medulla on long bones, with circumscribed erosion of the cortical surface and possible periosteal new bone formation around the margins. Further to this, they suggest that extensive sheaths of lepromatous granulomata may cause multiple irregular erosions with marginal periosteal new bone formation (particularly on the metatarsals, metacarpals, and phalanges). They state that medullary lesions are subchondral (located on metacarpophalangeal and proximal interphalangeal joints specifically), and present as lytic foci or cysts (Andersen et al., 1994: 25).

Andersen et al. (1994) suggest that the pyogenic lesions in leprosy are manifest in the spread of marked 'periostitis', with the appearance of distinct pitting of the cortical surface, with subsequent deposition of extracortical woven bone that later develops into a new cortical surface. As bacteria progress deeper into the bone, a 'true' bone abscess may develop that presents as a cystic cavity with a smooth or ragged surface. Lesions may result in pyogenic osteomyelitis, at which stage is non-specific and indistinguishable from osteomyelitis of another aetiology. These lesions may also be observed in the long bones. Andersen et al. (1994) suggest that the pyogenic bone and joint lesions of leprosy are restricted to the hands and feet, contradicting earlier statements that swelling of nasal mucosal tissue due to proliferation of *M. leprae* bacilli may result in ulceration, and in turn favour invasion of pyogenic bacteria (Andersen and Manchester 1992). It is unclear what research Andersen et al. (1994) are basing these conclusions on.

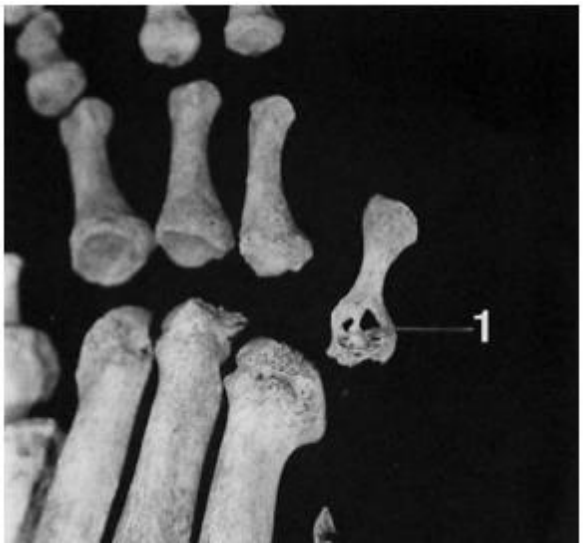


Fig. 3.4: Example of septic bone changes in leprosy from Andersen et al. (1994: 25), showing lytic lesion on proximal end of 5th proximal phalanx.

Table 3.2: Lesions and terms introduced by Andersen and Manchester (with others).

Paper	Lesion/term Introduced	Clinical Basis
Andersen and Manchester, 1987	Palmar grooving of distal end of proximal hand phalanges	**Yes**
Andersen and Manchester, 1988	Dorsal-tarsal exostoses	**Partial**
Andersen and Manchester, 1992	'Rhino-Maxillary Syndrome' – absorption of anterior nasal spine, absorption of anterior maxillary alveolus, rounding of the nasal aperture, oral/nasal pitting	**Yes**
Andersen, Manchester and Ali, 1992	Concentric diaphyseal remodelling	**Yes**
Andersen, Manchester and Roberts, 1994	Non-pyogenic and pyogenic infection.	**Yes**

3.1.3 Subsequent Studies Introducing New Lesions

3.1.3.1 Lewis, Roberts and Manchester, 1995

In this paper, Lewis et al. (1995) introduce several lesions to the long bones in leprosy resulting from inflammation and disturbance of the periosteum (Table 3.3). This disturbance may result from either localised contact by infected soft tissues, or via hematogenous spread of leprosy bacilli from a distant site (Lewis et al., 1995).

Lewis et al. (1995) analysed the remains of 355 individuals from the medieval cemetery of the Hospital of St James and St Mary Magdalene in Chichester. Leprosy was diagnosed on the presence of features of rhino-maxillary syndrome as in Møller-Christensen (1953), Andersen and Manchester (1987, 1988, 1992), and Andersen, et al. (1992). A total of 50 (14%) of the 355 individuals were diagnosed as having leprosy. Inflammatory bone changes (subperiosteal new bone formation) to the radii, ulnae, tibiae, fibulae, femora, metacarpals and metatarsals were recorded, with 38 of the 50 individuals determined to have evidence of leprous change (76%) displaying inflammatory bone change in some form. In addition, 60 (19%) of the remaining 305 individuals not displaying lesions characteristic of leprosy also displayed some form of inflammatory bone change. Of all inflammatory bone change observed in these 355 individuals, lesions to the tibiae were by far the most common, with 76% and 61% of the leprous and non-leprous individuals displaying these

lesions respectively. Inflammatory bone changes are noted clinically, however Lewis et al. (1995) note that clinical observations are infrequent due to the more subtle lesions being hard to identify on radiograph. Indeed, the frequency of bone change noted in the skeletal population suggests that incidences of inflammatory bone change would be much higher in a clinical context than literature would suggest (Lewis et al., 1995).

Lewis et al. (1995) also introduced leprogenic ossification of the crural intraosseous membrane between the long bones, as evidenced by sections of distinct ossification protruding from the cortical surface along the coronal plane on the lateral and medial aspects of the tibia and fibula respectively. Ossification of this kind in leprosy sufferers is supported by reference to clinical literature by Lewis et al. (1995), observed in clinical contexts as radio-opaque masses between these bones in radiographs. A suggested aetiology of this is that foci of osteoid may appear in these regions due to localised trauma and infection that results in myositis (inflammation of the muscles) and ossifying fasciitis (Resnick and Niwayama, 1988; Lewis et al., 1995).

3.1.3.2 Boocock, Roberts and Manchester (1995)

In this paper, Boocock et al. (1995) tested the hypothesis that maxillary sinusitis was more frequent in individuals with leprosy than those without. Maxillary sinusitis is understood to be the bacterial inflammation of the soft tissues within the sinus via upper respiratory tract infection, or invasive dental infection (Chapnick and Bach, 1976), which if sustained may result in ulceration of the tissues, predisposing them to invasion by secondary pyogenic bacteria. If this process is sustained, bony reactions may occur if there is disturbance of the periosteum within the sinus.

Leprosy is known to invade and proliferate primarily in the low-temperature regions of the body, with the nasal mucosa one of them most commonly affected of these regions. The presence and spread of leprosy bacilli within the nasal mucosa and soft tissues of closely located sinuses has been proposed to lead to maxillary sinusitis following broadly the same disease process as noted above.

The sample comprised 306 individuals excavated from the medieval Hospital cemetery of St James and St Mary Magdalene, Chichester. Of the 306 individuals, a total of 133 were included in the final analysis, as they had at least one sinus preserved for examination. Of these individuals, 29 were described as leprous (16 lepromatous and 13 tuberculoid), with the remaining 104 individuals displaying no leprous lesions. Lepromatous leprosy was diagnosed ‘primarily’ on the presence of palaeopathological lesions as described in Andersen and Manchester (1992), and Manchester (1981) for lepromatous leprosy, and on the absence of rhino-maxillary syndrome with unilateral and localised lesions to the lower limbs for tuberculoid leprosy. No research is cited, or indication of the precise form of lesions provided, for the assessment of tuberculoid leprosy in this paper, however.

Only the non-leprous individuals were assessed for age. It would have been useful to also have the age distribution of 'leprous' individuals displaying maxillary sinusitis, and how that compared the distribution of the lesion in non-leprous individuals, and non-leprosarium cemeteries. Nonetheless, their final analysis shows that whether an individual is leprous or non-leprous does not affect the occurrence of bony changes indicative of maxillary sinusitis in the population, suggesting that maxillary sinusitis not a useful indicator of leprosy. Therefore, maxillary sinusitis only recorded in this thesis if it was severe, to gauge if more severe forms might occur along with specific leprosy lesions.

3.1.3.3 Boldsen 2001, 2005 and 2009

In these papers, the Danish physician Jesper Boldsen introduces statistical methods in which to gauge the likelihood that an individual may display lesions if affected by leprosy (specificity), and/or whether an individual has leprosy at all (sensitivity). The purpose of this is to provide a statistical model that may be more useful in determining how leprosy may have affected a population. This is an attempt to address the limitations that the frequency of skeletal lesions in a population presents in the view of the osteological paradox (see Wood et al., 1992; Soltysiak, 2015; Dewitte and Stojanowski, 2015). The paradox outlines that lesions displayed in skeletal populations do not necessarily reflect the true nature of illness and disease within that population given the time it takes for skeletal lesions to appear. Put simply, those displaying lesions may have been immunologically 'stronger' than those that do not, as they survived long enough for lesions to appear. These tests are proposed to alleviate these issues by accounting for specificity and sensitivity of leprous lesions at population level.

Boldsen introduces several new lesions that he considers diagnostic of leprosy in addition to rhinomaxillary syndrome - subperiosteal exostoses on the fibula, porous hyperostosis of the fibula, and periosteal changes to the fifth metatarsal. These lesions do not appear to be founded on previous clinical or palaeopathological research, with no evidence provided in support of their inclusion in this study. It is therefore unclear how much weight is to be afforded these lesions. Also, while Boldsen does provide information on his scoring scheme in the annex of his 2005 paper, including what the lesions should look like, it remains unclear how many lesions need to be present and what combinations to consistently diagnose or assess leprosy in skeletal remains.

There are some broader methodological issues present in these papers. For example, Boldsen (2001, 2005, 2009) dismisses established methods of ageing and sexing in lieu of an undisclosed method. This is concerning for the results, as Boldsen (2001: 383) states that as age and leprosy showed no particular affinity, skeletons were 'aged subjectively', but then states that age did in fact correlate with severity of 'leprotic' lesions (Boldsen, 2001: 386). By not adhering to standard

methods, or disclosing those actually used, it is impossible to discern and replicate Boldsen's study in full, in doing so invalidating the link between age and leprosy in the study. Boldsen (2001: 383) does state 'primarily following' the criteria described by the Workshop of European Anthropologists (1980), but it is not stated exactly how.

Boldsen's (2001) argument is based on the assertion that leprosy has evolved and changed over time, as have the socio-economic conditions of humans; therefore the skeletal manifestations of leprosy will have changed. Conversely, Phrengle et al. (2021) show that while several strains of *M. leprae* exist and have evolved in parallel from a common ancestor over the last 2500 years, this only aids in determining the geographical origin of a particular strain, and genetic diversity between strains is limited (Britton and Lockwood, 2004). The genetic diversity and particular strain contracted also does not affect the severity and expression of the disease in an individual, as it is the immune response of the individual that dictates this (Britton and Lockwood, 2004; Inskip et al., 2015). Socio-economic factors are not the only aspects to consider in disease transmission and expression, as the genetics of the immune system also varies between individuals (Frank, 2002), with genetic variation a key factor in the immune response to leprosy (Mi et al., 2020). Krause-Kyora et al. (2018) also identified a statistically significant association of the presence of *M. leprae aDNA* and human leukocyte antigen allele DRB1*15:01, a strong indicator of susceptibility to lepromatous leprosy, in Medieval European populations. The link between genetics, socio-economic factors and disease transmission is complex however, with recent research in light of the Covid-19 pandemic highlighting the need to incorporate social determinants of health into disease modelling (Galanis and Hanieh, 2021). This means that skeletal manifestations of leprosy have probably always been variable, but primarily due to immunological variation between individuals (which may be driven by socio-economics factors). It therefore unlikely that evolution of different strains of leprosy are what causes variation in lesion expression in the case of leprosy.

Table 3.3: Lesions introduced in subsequent research.

Paper	Lesion(s)	Clinical Basis
Lewis et al. 1995a	'Periostitis' on the tibiae, fibulae, ulnae, and radii	**Yes**
	Ossified interosseous membrane	**Yes**
Boocock et al., 1995	Maxillary sinusitis	**Yes**
Boldsen, 2001	Subperiosteal exostoses on fibula;	**No**
	Porous hyperostosis of the fibula;	**No**
	Periosteal changes to the fifth metatarsal	**No**

3.1.3.4 Leprogenic Odontodysplasia

Leprogenic odontodysplasia (LOD) is the term adopted to describe the malformed roots of upper permanent incisors in leprous individuals in palaeopathological assemblages. First described by the Dutch dentist, Knud Danielsen, in 1968 (see Danielsen, 1968), from observations on the same Naestved individuals. LOD is described as a sharp concentric constriction of root of the central maxillary incisor starting halfway between the neck and the tip of the root. Danielsen (1968) described one individual (aged 8-9 years), with follow up work in 1970 (see Danielsen, 1970), yielding a further three observations (all aged between 10-11 years). The co-occurrence of stunted roots with lesions indicating rhinomaxillary syndrome led Danielsen to conclude that they were the result of lepromatous leprosy in childhood (Danielsen, 1970; Matos and Santos, 2013). The aetiology of LOD remains poorly understood (Matos and Santos, 2013), and since Danielsen's four observations, only a handful of individuals have been presented in the palaeopathology literature, over 40 years later (Kjellstrom, 2012; Roffey and Tucker, 2012; Matos, 2011; Matos and Santos, 2013). There have yet to be any clinical observations (Lewis, 2017), and there have not been any clinical investigations. Matos & Santos (2013) note a single tooth found in a juvenile skeleton from an assemblage of 1200 skeletons. This could be due to the nature of the condition predisposing the tooth to loss either ante- or post-mortem. Matos & Santos (2013) found the deformity with other signs of RMS, notably the rounded margins of the nasal aperture, absent anterior nasal spine, and absorption of much of the central alveolar process of the maxilla, with only the very upper portions of the central dental cavities surviving.

The infrequency of LOD in the palaeopathology literature combined with the absence of clinical observations weakens the claim that malformed roots of this nature are truly leprogenic, with the

name directly suggesting that this malformation is caused by leprosy. Root malformation of this kind may be simply a non-metric trait (Roberts, 1986; Cunha et al., 2012; Lewis 2017), or mimicked by other diseases such as Downs and Steven-Johnson syndrome (Lewis, 2017), or trauma, or just happen to occur sometimes in individuals that also happen to have leprosy. If a link between leprosy could be proven in a modern clinical environment, LOD may prove useful in identifying the age at which an individual contracted leprosy, given the age at which the root develops initially (Matos and Santos, 2013). Matos and Santos (2013) indicate that single rooted teeth are prone to antemortem loss even where no alveolar resorption has occurred in non-leprous individuals. So the possibility that LOD is in fact the result of a more broad mal-developmental stimuli that predisposed an individual root malformation and developing leprosy within the population cannot be ruled out, and further research is required. Roffey and Tucker (2012) observed root malformation in a non-adult individual (SK8) at Winchester. Therefore, LOD was researched in this thesis.

3.1.3.5 Active vs Healed Lesions in Leprosy

Ortner (2003) noted limited reference to active lesions related to leprosy in the palaeopathological record. This is despite phases of distinct active infection in clinical cases, and evidence of osteoclastic action due to a reduction of bone in affected areas, presenting as pathological pitting, with distinct and sharp margins around the pits. Ortner suggested that this is a necessary precursor to a subsequent phase of apparent osteoblastic activity that results in the smooth appearance of healed lesions, particularly in regions associated with rhinomaxillary syndrome lesions. He proposes that active phases are less apparent in archaeological material due to the relative brevity of these episodes, and therefore the lower chance that an individual would die in this state when compared to the chronic nature of smooth lesions associated with healing (Weston, 2008, 2011). There may still be an accumulation of evidence, however, indicative of leprosy reactions (see section 2.3.2).

Lesions were recorded as active or healed (where applicable) in this project to further explore relative rates of active/healed lesions. It follows that active lesions observed in any of the locations where leprosy lesions might occur should be indicative of an active episode of inflammation due to leprosy (should the overall distribution of lesions across the skeleton indicate leprosy). These may be indicative of active episodes of leprosy reactions.

3.1.3.6 Summary

The above details how the key lesions used to assess leprosy in the archaeological record were determined. The comparison of evidence from modern-day leprosy patients to medieval skeletal remains were shown to be useful, particularly for rhinomaxillary and postcranial lesions as determined by Andersen and Manchester (and others). However, a potential gap is that there were

no healthy comparison samples used in these studies, so natural morphological variation in these regions may not be fully appreciated, which is potentially an issue where the evidence for leprosy is less severe.

3.2 Diagnosis of Leprosy in Current Palaeopathological Studies

Leprosy continues to be reported in archaeological material, with most papers focussed on individual 'first' cases. However, the introduction of new lesions for use in appraising leprosy has been scant in recent years, with modern research relying on the contributions of Møller-Christensen and Andersen and Manchester to diagnose leprosy. Concern regarding diagnostic rigour in palaeopathology generally was highlighted as a widespread issue by Zuckerman et al., (2016). The variation of consistency and rigour noted there has permeated into recent studies concerning leprosy (Blau and Yagodin, 2005; Rubini and Zaio, 2009; Roffey and Tucker, 2012; Antunes-Ferriera, 2013; Crespo et al., 2017), which routinely cite the pioneering research without always giving full consideration of the source material, or how terminology and descriptions should be applied to provide consistency. This inconsistency in methodological approach and rigour masks the complexity and variation of leprosy as a disease, and how it presents morphologically in skeletal remains, and hampers the contribution that macroscopic assessment of skeletal remains can make in bioarchaeological investigations. This is particularly evident with the secondary inflammatory bone changes in leprosy, which have been shown to be distinctly more variable, complex, and potentially indicative of leprosy (Lewis et al., 1995) than recent research would suggest. Where new lesions have been introduced, there is no evident basis (clinical or otherwise) that the lesions are leprogenic, and have not been presented as part of a usable and replicable criteria (see Boldsen, 2001; 2005; 2009). This is concurrent with the rise of the use of ancient DNA (aDNA) to confirm the presence of *M. leprae*, with the implication that the presence of the aDNA is enough to confirm a diagnosis of leprosy without all pathognomonic skeletal lesions being present (Cole et al., 2022; Spekker et al., 2022).

Finally, while pioneering in terms of the lesions to consider, the research by Møller-Christensen, and subsequently Andersen and Manchester, did not provide rigid and replicable criteria to consistently gauge to what extent the number of lesions we see and in which locations are attributable to leprosy, beyond the five rhinomaxillary syndrome lesions that Andersen and Manchester (1992) consider to be pathognomonic. This is particularly problematic in cases where there are fewer than five rhinomaxillary syndrome lesions, or only postcranial lesions, or no skull is preserved, as is often the case. In other words, previous criteria do not disclose how many lesions need to be present and in what combinations to consistently assess leprosy in skeletal remains, and in turn how sure we can be that the skeletal lesions we see were caused by leprosy. This is the principal methodological

issue that this research aims to address, and leads us to the Modified Istanbul Protocol, which has been redeveloped in this research into a method called 'Lepro-C'.

3.2.1 Modified Istanbul Protocol and Lepro-C

The Modified Istanbul Protocol (MIP) was devised by Appleby et al. in 2015, and was developed in response to the proliferation of loose diagnostic terms such as 'probable' and 'possible' when assessing disease in skeletal individuals. The primary issue being the absence of clear definitions and ambiguous use of these terms. The method has not been widely applied to human remains (Mills, 2017), however MIP is particularly relevant for an inherently variable disease such as leprosy, with previous research papers concerning leprosy in skeletal remains containing some of the general issues presented by Appleby et al. (2015) and Zuckerman et al. (2016)(see Chapter 5). While MIP has been noted in more recent papers, it remains something of an afterthought and has not been applied as actively (or with the precedence) it should have in the differential diagnosis process (see Kohler et al. 2017: 13, for example).

The Modified Istanbul Protocol presents clear diagnostic categories with clear definitions. However, those provided by Appleby et al. (2015: 20) suggest that differential diagnosis should be determined for each lesion individually, and then the overall distribution of lesions used to assign a final differential diagnosis. This approach seems 'back-to-front'. The overall distribution of lesions ought to be given precedence in differential diagnosis from the outset, due to the characteristic locations of the skeleton affected by leprosy. Any outlying lesions not expected for leprosy can be used to assess potential co-morbidity or unforeseen variation of lesion expression in individuals displaying leprosy lesions. Therefore, MIP has been adapted into 'Lepro-C' (see Chapter 4 for a full breakdown of the criteria). The Lepro-C categories adopted in this research follow the recommendation of Matthias et al. (2016), with the wording changed to make it relevant to leprosy, which drops the 'typical of' category as the definition is too similar that of 'highly consistent', and retention of this category could potentially lead to issues similar to that of loosely defined terms such as 'probable' and 'possible' that MIP attempts to dispel.

In short, Lepro-C aims to rigidly define the levels of certainty for diagnosis of leprosy in skeletal remains, and provide replicable criteria to assess this, so that a firmer foundation for results and conclusions of research can be made going forward.

3.2.2 M. leprae Ancient DNA and Leprosy

The consideration of aDNA in archaeological investigations into leprosy is gaining momentum (see Inskip et al., 2015; Roffey et al., 2017; Filipek et al., 2022; Cole et al., 2022 for some examples), with

the biomolecular study of disease in palaeopathology generally experiencing significant development in the last 25 years (Roberts, 2020: 179). Caution is urged when considering leprosy aDNA and linking it to macroscopic lesions. As while the presence of aDNA confirms the presence of *M. leprae*, the pathogen, in the population and in the individual, it does not necessarily follow that the lesions present are due to leprosy, the medical condition that can develop due to *M. leprae* infection, as isolation of the pathogen does not definitely prove that it caused the lesions seen (Roberts and Brickley, 2018: 423). This means observed lesions could be caused by other means even if *M. leprae* aDNA is present, particularly if the skeletal evidence for leprosy is limited overall and the lesions are non-specific (Roberts, 2020: 180). Nor does the absence of aDNA mean that the lesions caused were not caused by leprosy if the skeletal evidence is diagnostic (Spekker et al., 2022). This applies to individuals from leprosarium or non-leprosarium cemeteries. The distinction between carrying the bacterium *M. leprae* and having the medical condition of leprosy is important, as the former does not necessarily lead to the latter. Modern clinical studies into leprosy in endemic areas show that individuals can have a subclinical *M. leprae* infection, without ever developing leprosy. Instead, they may shed the bacteria until their immune system destroys it (Goulart et al., 2015), with this being suggested as a key and underappreciated factor in the spread of leprosy in endemic regions (Araujo et al., 2016). Therefore, the replicable Lepro-C criteria devised in this research are important as it will allow subsequent studies to provide the appropriate macroscopic context (and of the appropriate resolution) on a consistent basis to further inform discussions into aDNA and biochemical markers in those displaying leprosy lesions. aDNA studies into leprosy also tend to focus on individuals already displaying skeletal signs of leprosy (see Mendum et al., 2014; Inskip et al., 2015; Donoghue, 2017; Krause-Kyora et al., 2018; Filipek et al., 2022; Cole et al, 2022). Spekker et al. (2022) show that individuals can display convincing skeletal evidence of leprosy but not have *M. leprae* aDNA present, so it would be beneficial to also test whether *M. leprae* aDNA occurs in individuals in leprosarium cemeteries that do not display skeletal evidence of leprosy. This would allow wider discussion on the possible epidemiological spread and transmission of the bacterium historically, and the nature of carrying *M. leprae* aDNA and how that may relate to displaying macroscopic leprosy lesions (or not).

3.2.3 M. lepromatosis Ancient DNA and Leprosy

Mycobacterium lepromatosis aDNA has yet to be identified in human remains in the archaeological record. It is however being screened for in recent aDNA investigations to leprosy in humans from medieval England (see Cole et al., 2022). M. lepromatosis has been identified in modern-day British red squirrels (Cole et al., 2022), with a zoonotic transmission of M. leprae from humans to red squirrels suggested by Donoghue (2019). Proposed transmission routes in the Middle Ages are the

fur trade, or keeping of them as pets (Donoghue, 2019). It perhaps then follows that the presence of M. lepromatosis may have been similarly transmitted from humans to squirrels in the Middle Ages, suggesting it was present in humans at that time. The divergence of M. leprae from M. lepromatosis approx. 13 million years ago (Singh et al., 2015: 4459), and the proposed parasitic evolution of leprosy bacilli in early hominins, and subsequently humans (Han and Silva, 2014), at least suggest it is only a matter of time until it is identified in archaeological human remains.

For possible lesions on bone that might be caused by M. lepromatosis, given that in modern clinical contexts M. lepromatosis primarily causes lepromatous leprosy (see Deps et al., 2021), it is reasonable to suggest that rhinomaxillary and postcranial lesions would occur similar to M. leprae.

3.3 Differential Diagnosis for Leprosy Lesions

The following details the possible differential diagnoses for the individual lesions under consideration in this research. Each individual lesion displayed by an individual may have several possible differential diagnoses when considered in isolation, however the overall combination of lesions is of paramount importance when assessing leprosy in skeletal remains. This is particularly the case for rhinomaxillary syndrome lesions, as the likelihood of lesions being caused by leprosy increases when more rhinomaxillary lesions are displayed in combination, more so when also found with absorptive and proliferative postcranial lesions, although comorbidities may still occur. This principle is the foundation of Lepro-C (detailed in Chapter 4). It is nonetheless important to be mindful of differential diagnoses for these lesions, as there will be cases where the overall evidence of leprosy displayed by an individual is limited, or they may display postcranial lesions only, where the specificity to leprosy is potentially not as clear.

3.3.1 Facial lesions

3.3.1.1 Rhinomaxillary Syndrome (RMS)

3.3.1.1.1 Lesions to the Nasal Aperture

Several conditions may affect the nasal aperture, including syphilis and yaws (Rubini and Zaio, 2009), tuberculosis (Ortner, 2003), leishmaniasis – a zoonotic disease endemic to the Mediterranean (Ready, 2017), and malignant neoplasms (Cook, 2002; Ragsdale et al., 2018).

The lesions caused by these conditions tend to be more aggressive and destructive in appearance in comparison to the inflammatory pitting or smooth-edged, regular and symmetrical remodelling seen in leprosy. While syphilis may result in destruction of the nasal bones (Hackett, 1975), this can be irregular and accompanied by significant pitting and sclerosis (Ortner, 2003). The nasal aperture

in tuberculosis tends to present with marginal fine pitting (Ortner, 2003) rather than smooth rounding often observed in remodelling of the nasal aperture in leprosy (Andersen and Manchester, 1992), although pitting can occur in the margins in leprosy when the lesion is less advanced, exposing the nutrient channels. Neoplastic lesions also tend to be more unilateral or asymmetrical (Ortner, 2003).

3.3.1.1.2 Absorption of Anterior Maxillary Alveolar Bone

A characteristic feature of resorption of the alveolar bone in leprosy is that it is generally confined to the maxillary incisors, due to neuropathy of the maxillary branch of the trigeminal nerve, although it can extend further in advanced cases (Andersen and Manchester, 1992). It is rare to find normal antemortem tooth loss of all anterior incisors, but this results in horizontal alveolar absorption, rather than the half-moon pattern seen in leprosy. Actinomycosis, a bacterial infection that can affect the maxilla, is more pronounced on mandible (Ortner, 2003). Syphilis may also affect the maxillary alveolus, but destruction may extend further than central maxillary incisors, is irregular and often lytic in appearance (Fig. 3.5), and accompanied by sclerosis of remaining bones (Ortner, 2003; Walker et al, 2015).

3.3.1.1.3 Pitting of Oral Palatine Process (PPMO)

Treponemal infection can result in PPMO (Manchester, 1999), however this may be more markedly destructive than the inflammatory pitting observed in leprosy (Ortner, 2003, Rubini and Zaio, 2009), and can lead to the complete destruction of the PPMO. Perforation of the hard palate may also occur in leprosy (Lunt, 2013). In leprosy, the inflammatory pitting is concentrated along the palatine suture (Andersen and Manchester, 1992).

3.3.1.1.4 Pitting of Nasal Palatine Process (PPMN)

Aspergillosis can cause inflammatory granulomatous lesions in nasal passages, however it characteristically affects only the paranasal sinuses, orbit, and anterior cranial fossa (Rubini and Zaio, 2009). Mucormycosis, a rare fungal infection, can also cause lesions of the paranasal sinuses, but is restricted to this region (Ortner, 2003). Sarcoidosis, an infection of unclear aetiology (Rubini and Zaio, 2009) can cause PPMN, and can, very rarely, erode the anterior nasal spine (Ortner, 2003)(it can also cause lytic lesions to hand and foot phalanges). Lupus vulgaris is a chronic tubercular infection of the skin, characterised by yellow swelling, ulceration, and abscesses (Rubini and Zaio, 2009), which can lead to destruction of the nasal bones. However, the anterior alveolar process is rarely affected (Møller-Christensen, 1967). Rhinitis can cause generalised inflammation

and pitting (Ortner, 2003), whereas in leprosy inflammatory pitting is concentrated along the palatine suture.

3.3.1.1.5 Absorption of Anterior Nasal Spine (ANS)

The anterior nasal spine can be absorbed by treponemal diseases (Rogers and Waldron, 1989; Cook, 2002). The nasal spine can also be absorbed by sarcoidosis and lupus vulgaris, as noted above. It can also be damaged as a result of direct trauma (Kucuk, 2014).

Cook (2002) questioned how pathognomonic the rhinomaxillary syndrome lesion is for leprosy, and presented five cases of non-leprosy in skeletal remains from North America that mimic RMS. These individuals were; 11-C36-56 (Illinois, Late Archaic); FMNH 46684 (Arizona Pueblo III); TUI-7K (Illinois Middle Woodland); Basketmaker mummy (New Mexico); FMNH 42678 (Arizona Pueblo III). So, as these potential differential diagnoses exist for individual RMS lesions and there was a risk that it may be mimicked by other diseases, postcranial evidence should be taken into consideration when considering *diagnostic* cases when recording the skeletal material. If the lesions are mild, it may be difficult to distinguish leprosy from syphilis (Ortner, 2003; Walker, et al. 2015). Cleft palate is also a differential diagnosis for RMS (Ortner, 2003).

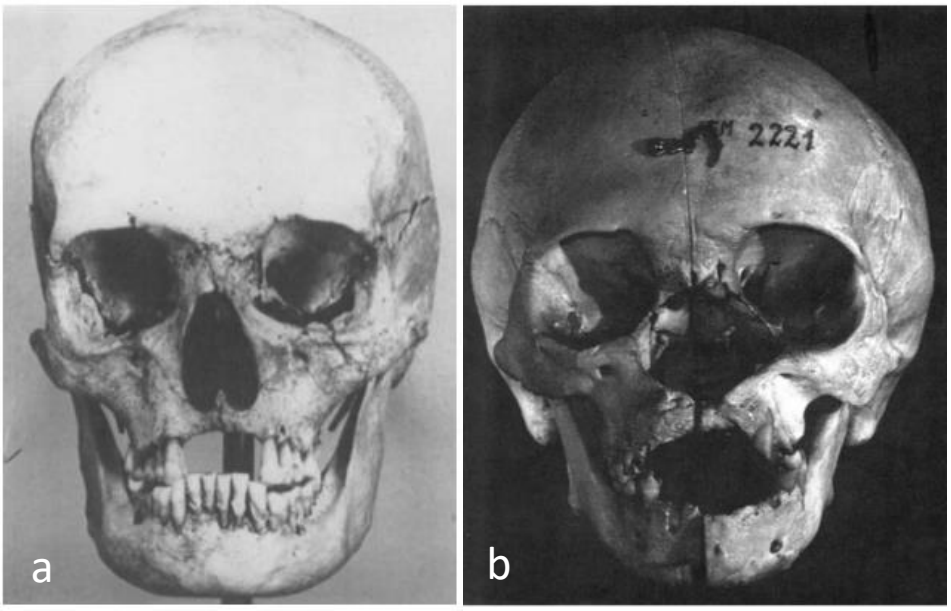


Fig. 3.5: Rhinomaxillary syndrome in leprosy (a), compared with destructive lesions to the rhinomaxillary region in tertiary syphilis (b). This is an example of a possible differential diagnosis of the absorptive lesions seen in the rhinomaxillary syndrome, note however that the lesions in (b) are more destructive and extensive, with evidence of sclerotic healing, differentiating it from the leprosy seen in (a). Images: (a) from Andersen and Manchester (1992: 123), (b) from Ortner (2003: 386).

3.3.1.2 Leprogenic Odontodysplasia (LOD)

A possible differential diagnosis for shortened/blunt central maxillary incisor roots observed in leprous individuals could be 'short root anomaly' (Fig. 3.6), first identified clinically by Volmer Lind (1972), in a Swedish population. While short root anomaly remains poorly understood, frequently misdiagnosed, and of unknown aetiology (Puranik et al., 2015), where observed it primarily affects the central maxillary incisors (Lind, 1972). The prevalence in modern day white European populations is 2.4-2.7% (Apajalahti et al., 1999). It is difficult to assess prevalence of LOD in skeletal populations, as RMS to a significant enough degree to diagnose leprosy may preclude the survival of central maxillary incisors (Matos and Santos, 2013). Leprogenic odontodysplasia is somewhat controversial, as it has not been noted often in the archaeology record. It has an unclear aetiology, meaning its links to leprosy are tenuous (Matos and Santos, 2013).

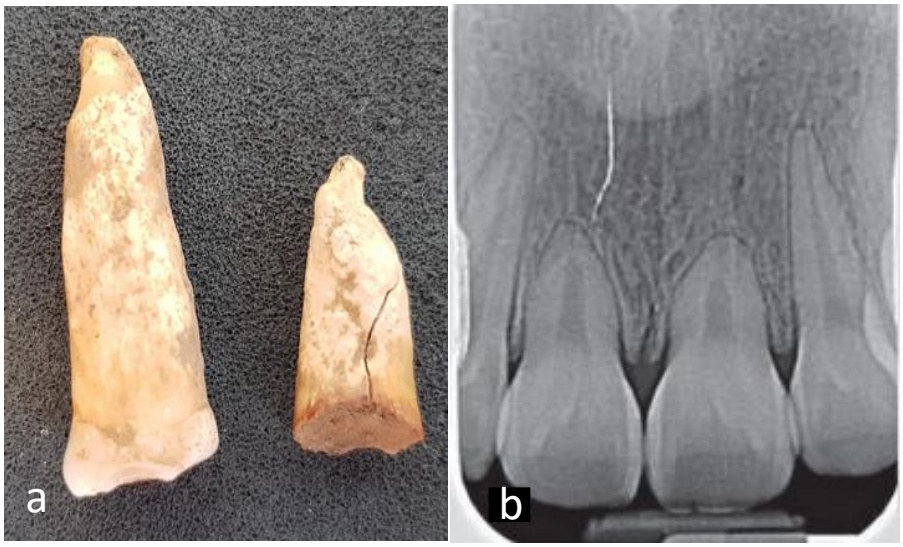


Fig. 3.6: Leprogenic odontodysplasia in leprosy (a), and short root anomaly (b). Image (b) from Puranik et al. (2015: 67).

3.3.2 Postcranial lesions

3.3.2.1 Palmar Grooving of Distal Proximal Phalanx

Palmar grooving of the distal proximal phalanx may potentially be caused by any neuropathy that could induce sustained flexion (i.e. claw-hand deformity) in the proximal and distal interphalangeal joints. Direct nerve damage as the result of trauma can also cause claw-hand deformity (Fufa et al., 2014).

Commonly cited causes of claw-hand deformity include:

3.3.2.1.1 Systemic Sclerosis

Systemic sclerosis is an autoimmune disease that affects vasculature throughout the body, and universally affects the hands (Young et al., 2016), with secondary inflammatory arthritis and joint contractures (Young et al., 2016). It manifests as symmetrical, poly-articular synovitis of the metacarpophalangeal (MCP) and proximal interphalangeal joints (PIP) in a pattern akin to rheumatoid arthritis (see below). This can lead to erosive lesions on articular surfaces (although they may be more discrete than those observed in rheumatoid arthritis (RA)), and joint contracture of the affected digits (Young et al., 2016), particularly of the PIP joint (Bogoch and Gross, 2005). Joint contractures may occur on any number of digits and be either bi- or unilateral (Balint et al., 2014), therefore distinguishing systemic sclerosis from leprosy on the presence of palmar grooving alone would be difficult, emphasising the need to account for patterns of lesion distribution across the skeleton.

3.3.2.1.2 Rheumatoid Arthritis

Rheumatoid arthritis (RA) is an autoimmune disease which can cause phalangeal contractures similar to that observed in leprosy (Laine et al., 1957; Pfinsgraff et al., 1986; Chalom et al., 1997). The clinical presentation of RA varies clinically (Grassi et al., 1998), however it is characterised in early stages by symmetrical polyarthritis in the MCP and PIP joints of the hands, and the metatarsophalangeal joints of the foot. RA may eventually affect any joint, although the distal interphalangeal (DIP), sacroiliac, and lumbar spine are rarely involved, differentiating it to other arthropathies (Grassi et al., 1998). Contracture of the PIP joint is a common outcome, and may affect any of the digits (Ugurlu and Ozdogan, 2015). Differentiating lesions resulting from RA induced contracture from those induced by leprosy is complicated by the fact that leprosy can mimic RA (see section on arthritis below). However, as RA is autoimmune, and therefore due to overreactive immunity to the point the body attacks itself (Smolen et al., 2016), then the presence of erosive arthropathy akin to RA in conjunction with other lepromatous leprosy (LL) lesions may perhaps be strongly indicative of leprosy induced inflammatory arthritis, as LL is the result of low reactive immunity. This suggests that co-morbidity of true RA and LL would be unlikely, as the immunological routes to either condition are perhaps too incongruent to occur simultaneously. Rapidly fluctuating immune states of the individual cannot be discounted, however (Crespo et al., 2019).

3.3.2.1.3 Volkmann's Contracture

Volkmann's contractures (VC) are ischemic (reduced blood supply) contractures of the muscles of the forearm and hands (Smith et al., 1984). Volkmann's contracture is most often the result of direct

trauma, such as burn injuries (Ahn and Maitz, 2010) or bone fractures. Supracondylar fractures of the humerus (Pettitt and McArthur, 2012), can cause the muscles affected by the ischemia to contract up to one-sixth of its usual length, creating further blood flow issues (Holden, 1975). This means that evidence of fracture, if found with grooving, may help differentiate VC from leprosy, although they may occur simultaneously. However, individuals with leprosy with badly affected feet are more susceptible to falls (Da Cruz Junior et al., 2024), so this could lead to increased trauma observed on the hands.

3.3.2.1.4 Dupuytren's contracture

Dupuytren's contracture results from a disease of the palmar fascia, characterised by progressive thickening of connective tissues in the region causing flexion contracture of one or more fingers, primarily affecting the PIP and MCP joints (Lackie, 2010; Stanbury et al., 2011). Diseased palmar fascia may extend to the digits, culminating in reduced function and range of motion of the affected digits (Bergovec et al., 2018). Diabetic neuropathy may also induce Dupuytren's contracture (Kapoor and Sibbitt, 1989; Biehler-Gomes et al., 2019).

3.3.2.1.5 Congenital flexion contracture (Camptodactyly)

Camptodactyly is a non-traumatic congenital flexion contracture of the PIP joint, found in all of the 'arthrogryposes' – a catch-all term for congenital joint contracture (Wall et al., 2018). Rayan and Upton (2014: 452) directly discuss 'palmar flattening of the proximal phalangeal condyles' and the development of a 'groove in the neck of the proximal phalanx' in cases of camptodactlyly. This condition most often affects the fifth phalanx (Rayan and Upton, 2014), and affects 1% of the population (Dautel, 2003; Netscher et al., 2015). Radiographic data utilised by Woo Hong et al. (2019) suggests that it affects more males than females (58 males to 22 females displaying camptodactyly), with the average age of onset just 12 months of age (with the oldest individual at 36 months). Lesions to the hands are rare in childhood cases of leprosy

3.3.2.1.6 Summary

With the exception of Andersen and Manchester (1987: 79), who briefly mention 'Dypuytren's' (*sic*), and those papers considering camptodactyly noted above, the clinical literature does not discuss the occurrence of palmar grooving in these conditions directly. However, the potential presence of grooving is inferred by the similar method of action (induced hypo or hyperflexion) these conditions have on the nerves and musculature, and the subsequent pressures on the bone at these joints. Given the limited response to pressure of any aetiology for bone, it may not be possible to distinguish grooving caused by leprosy from that of any other aetiology if grooving is the only lesion displayed. Andersen and Manchester (1987) suggested that grooving caused by leprosy may not be

morphologically consistent from case to case, depending on whether there is any medial or lateral deviation of the proximal middle phalanx as it applies pressure against the palmar surface of the distal proximal phalanx.

A similar condition may also produce grooving; 'swan-neck' deformity', where there is hyperextension of the proximal interphalangeal joint and flexion of the distal interphalangeal joint (McKeon and Lee, 2015). Swan-neck deformity has been observed both in leprosy (Gunawan et al, 2017; 2021), and in rheumatoid arthritis (Van der Geisen et al., 2009; Van der Geisen, 2010; Gunawan et al., 2017). Swan-neck deformity may potentially result in grooving/pressure lesion in dorsal surface of distal proximal phalanx, and grooving on palmar distal middle phalanx instead, should flexion be sustained and of serious enough extent.

3.3.2.2 Arthropathy

Articular or periarticular lesions, particularly those to the phalanges and metacarpals/metatarsals that might be observed in leprosy, including dactylitis, have several potential differential diagnoses.

3.3.2.2.1 Inflammatory Arthropathy

Erosive osteoarthritis (EO) is confined to the hands (Mays et al., 2017), and generally presents asymmetrically on the appendicular skeleton, primarily with central and juxta-articular erosions (Waldron, 2008) resulting in distinct 'gull-wing' or 'saw-tooth' marginal osteophyte formation (Martel et al., 1980), with possible ankylosis (Greenspan, 2003). Juxta-articular lytic lesions in the hand phalanges can be observed in leprosy, although they lack the characteristic osteophyte formation of EO (Dave et al., 2004), where lytic lesions on the left 5th and right 1st proximal phalanx are observed, which would differentiate the two conditions.

Gout is a metabolic disorder where calcium and urate crytals accumulate in granulomatous masses (Rothschild and Heathcote, 1995). This can lead to osseous erosions in epiphyses, metaphyses and articular surfaces (Resnick and Niwayama, 1988; Rothschild and Martin, 1993), particularly the distal and proximal aspects of the metacarpals, metatarsals, and phalanges (Rothschild and Heathcote, 1995). The erosive lesions have sclerotic margins with reactive bone formation (Resnick and Niwayama, 1988). They are characterised by a distinctive 'Martel's hook', wherein a layer of outer cortical bone survives and 'overhangs' the peri-articular lesion.

3.3.2.2.2 Septic Arthritis (SA)

Septic arthritis can also occur in leprosy and may present as dactylitis in the hands and feet due to primary granuloma, or destructive articular lesions due to invasive pyogenic infection (Andersen et

al., 1994). Differential diagnosis for the infectious agents that might cause this are streptococcus and staphylococcus, tuberculosis (and other mycobacteria), venereal syphilis, brucellosis and sarcoidosis (Hamard et al., 2020). These can all manifest as periarticular destructive lesions.

3.3.2.2.3 Tuberculosis

Tuberculosis must also be considered for lytic lesions in epiphyses/metaphyses of these bones where there is little or no reactive bone formation and limited other evidence for leprosy, given the potential haematogenous spread of tuberculous foci to these regions (Ortner, 2003), and the continued presence of haematopoietic marrow in these regions into adulthood (Kricun, 1985). The distribution of haematopoetic marrow must also be considered when assessing leprosy between children and adults due the haematogenous spread of bacilli (Talhari et al., 2015) and the higher level of hematopoetic marrow observed in children. Co-infection of TB and leprosy can occur, and is documented in the clinical literature (Mangum et al., 2018). There is not a consensus on the prognosis for co-infection, however (Mangum et al., 2018). The immune function of the individual will most likely cause distinct variability in host response, as ever.

3.3.2.2.4 Summary

The form of joint lesions will hold major clues to the underlying mechanism, so careful attention must be paid to which joint lesions consistently co-occur with leprosy lesions (if any). Lesions mimicking RA may be most indicative of leprosy where arthropathy occurs, as synovitis with secondary pannus formation leads to osteoclastic destruction of (peri)articular surfaces in RA (Lories and Baeten, 2009; Mays et al., 2017). Therefore, penetration of the synovium by leprosy bacilli may stimulate a similar response, particularly given the patterns of joint inflammation mimicking RA noted in clinical literature for leprosy (Mandal, et al., 2008; Chauhan et al., 2010, Andres et al., 2012, Fernandes et al., 2014, El Gendy et al., 2016). This may be most apparent in long bone joints. However, if leprosy bacilli were to stimulate septic arthritis, then ankyloses and extensive destruction with reactive bone formation may also be observed (Ortner, 2003). Elbows, knees and ankles are commonly noted as being affected in modern clinical literature (Chauhan et al., 2010).

Co-morbidity of arthritis and leprosy is feasible (Salvi and Chopra, 2013), so the precise form and location of joint lesions, and whether they consistently co-occur with leprosy lesions may inform whether lesions are related or coincidental.

3.3.2.3 Cubital Tunnel Syndrome

3.3.2.3.1 Lesions to the Proximal Ulna and Distal Humerus

Ulnar nerve compression, particularly where it runs through the cubital tunnel of the elbow, may lead to marked inflammation of soft tissues (Donaghy, 2003). Lesions may occur on the distal humerus, where the nerve, or other inflamed local soft tissues, could disturb the periosteum in the event of concentric enlargement as noted in leprosy (Payne et al., 2015). Inflammatory lesions may also arise on the proximal ulna, as while the ulnar nerve is not in direct contact with bone at this site, inflammation of surrounding soft tissues may lead to periosteal disturbance. Additionally, expansion of the nerve may cause a pressure lesion by pressing soft tissues against the periosteum (Ragsdale et al., 2018). There may be subperiosteal new bone formation in response to inflammation (Weston, 2008, 2011). Again, this will depend on whether the inflammation instigates a blastic or lytic response (or any response at all). Trauma not related to leprosy could also potentially cause lesions to this area due to the high potential for trauma to this region in everyday activity (Reed and Reed, 2012). The occurrence of ulnar nerve compression at the elbow may also be idiopathic (Pisquiy et al., 2019). In modern populations, cubital tunnel syndrome occurs mainly due to chronically repetitive occupational tasks, such as typing at a keyboard, truck driving, pushing heavy carts, use of tools such as hammers and pneumatic drills etc. (Garland et al., 1996; Pisquiy et al., 2019). The outcomes of modern-day work may be transcribed to a labour-intensive medieval setting, as the underlying anatomy of humans has not changed, and the mechanical demands may be comparable (Brass, 2004). So occupational hazards must be considered, however in this study this would have to be weighed against the leprosarium context of the assemblages when looking for evidence of cubital tunnel syndrome. In general, cubital tunnel syndrome is the second most common compression neuropathy after carpal tunnel syndrome (Palmer and Hughes, 2010), and the ulnar nerve is the nerve most commonly affected by leprosy neuritis (Payne et al., 2015; Leite et al., 2023).

3.3.2.4 Lesions of the Hands and Feet

Absorptive lesions in the bones of the hands and feet are a key indicator of leprosy, however the lesions may be mimicked by the following:

3.3.2.4.1 Diabetes

Diabetic neuropathy, a nerve ischemia affecting nerve function because of *diabetes mellitus*, can induce similar clinical manifestations (Biehler-Gomez et al., 2019) to that seen in leprosy (Fig. 3.7), particularly anaesthesia of distal appendages and the ensuing risk of secondary pyogenic infection

(Biehler-Gomez et al., 2019). The foot is particularly vulnerable to diabetic neuropathy, with neuropathic arthropathy common (Arkilla and Gautier, 2003; Biehler-Gomes et al., 2019). This can further result in deformity of foot arch and create 'calluses over time' (Biehler-Gomes et al., 2019: 1226) on heads of the metatarsals. Diabetic ischemia can also induce osteolysis of the distal metatarsals and proximal phalanges (Belcastro et al., 2005), matching the tapering morphology of absorption observed in leprosy. Absorption of the distal phalanges mimicking acroosteolysis can also occur (Biehler-Gomez, 2019). Belcastro et al. (2005) note that diabetic osteopathy is limited to foot bones. Diagnosing diabetes on skeletal evidence alone, however, may be impossible due to non-specificity of lesions (Dupras et al., 2010). Despite the similarities of the lesions caused by diabetic neuropathy, it is unlikely that someone in the late medieval period would have survived with diabetes long enough to develop lesions that mimic leprosy, as the people that developed diabetes prior to the discovery of insulin in 1921 has short life expectancies (Brostoff et al., 2007). Therefore, lesions of this pattern are more likely caused by leprosy individuals from this period.

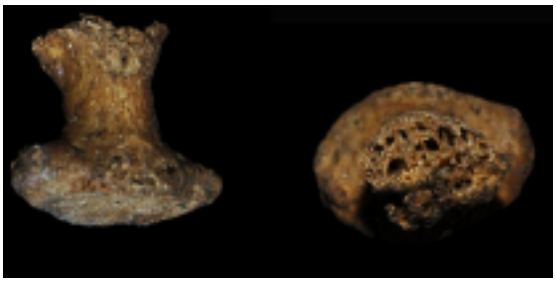


Fig. 3.7: Example of lytic lesions to the distal phalanx of the foot as a result of diabetes, mimicking the acroosteolysis that can occur in leprosy. Image from Biehler-Gomes (2019: 1233).

3.3.2.4.2 Raynaud's Phenomenon

Raynaud's phenomenon arises where proper dilation of arteries in distal phalanges is prohibited, which can result in osteolysis (Varju et al., 2017). In severe cases can result in gangrene and self-amputation (Huang et al., 2019). Raynaud's phenomenon is a clinical manifestation an underlying condition, such as systemic sclerosis (Young et al., 2016; Varju et al., 2017), or Sjogren's syndrome (Huang et al., 2019), rather than an illness in itself. Therefore, Raynaud's phenomenon could be a sequelae to leprous neuropathy.

3.3.2.4.3 Frostbite

Tissue injury due to cold exposure can result in necrosis and amputation of affected tissues (Khan et al., 2019). Can occur in a multitude of environments, urban or otherwise, where individuals experienced prolonged exposure to cold weather (Petrone et al., 2003; Hutchinson et al., 2018; Khan et al., 2019). The necrosis and amputation would result in a distinct transverse lesion at the

end of the remaining bone, with the width of the surviving bone retained, distinguishing it from the tapered and 'candy sucked' lesions of metacarpal and metatarsal leprosy lesions.

3.3.2.4.4 Madura foot

Madura foot results from the contraction of actinomycetomas; a group of bacterial infections that may enter the body following trauma (Ziljstra et al., 2016). These lesions occur most commonly in patients that walk barefoot in rural communities (Zampella et al., 2017), and manifests as swollen subcutaneous nodules, and can lead to osteomyelitis if bacteria penetrates bone (Pickert and Nguyen, 2012)(Fig. 3.8). However, Tomimori-Yamashita et al., (2001) radiologically observe extensive osteolytic lesions (with sclerotic margins) on all aspects of the metacarpals due to actinomycetoma infection. Kassimi et al. (2013) observe anterior tarsal and medio-tarsal osteolysis in a clinical case. These bacteria originate in tropical and sub-tropical climes (El Muttardi et al., 2010), so the likelihood of these bacteria being present in a leprosaria assemblage from Medieval England would have to be considered. Where observed, bacteria seem to manifest unilaterally (Pickert and Nguyen, 2012). Extensive reactive bone formation in response to infection would be difficult to ascribe to a specific disease/infection where there is no apparent global deformation of foot architecture (e.g., foot drop), which would have to be present to suggest a neuropathic element to narrow diagnoses down further.

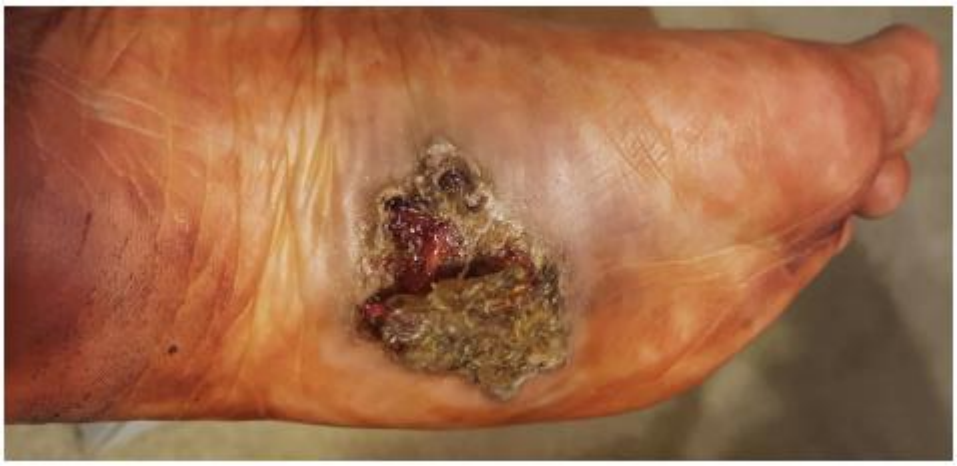


Fig. 3.8: Plantar ulceration due to madura foot, mimicking the plantar ulceration that can occur in leprosy. Image from Zampella et al. (2017: 130).

3.3.3 Non-specific lesions

3.3.3.1 Tibia and Fibula Lesions

Tibia and fibula lesions are common in leprosy, but lesions on these bones they may be caused by several means.

3.3.3.1.1 Periosteal New Bone Formation (PNBF)

PNBF can be caused by anything that breaks, tears, or touches the periosteum, stimulating an osteoblastic response (Weston 2008, 2011). The elevation of the periosteum from the cortical surface is not essential for a reaction (Weston 2008, Weston 2010, Ragsdale et al., 2018). It is inherently non-specific, however, the location and form of PNBF on the tibiae and fibulae may still be useful, particularly when associated with rhinomaxillary lesions. This is due to the progression of leprosy bacilli up connective tissues of foot and leg, and the chronic nature of the disease where patients experience repeated leprosy reactions. This means that there is potential for extensive, and potentially morphologically variable, PNBF in leprosy. Non-gummatous reactive bone on distal tibia may be difficult to impossible to distinguish from conditions other than leprosy where lesions elsewhere are limited (Ortner, 2003).

3.3.3.2 Secondary Pyogenic Infection

Evidence of pyogenic infection alone would not be enough to indicate leprosy. As osteomyelitis, while identifiable by the presence of involucrum, sequstrum and cloacae (Ortner, 2003) would be difficult to ascribe to specific disease (Lew and Waldvogel, 2004; Hogan et al., 2013) if not found with more specific leprosy lesions, and is most often caused by strep or staph infection secondary to trauma (Ortner, 2003). However, osteomyelitis may also be caused by vascular insufficiency, or haematogenous spread of infection from elsewhere (Lew and Waldvogel, 2004). Location may help however, particularly if found in tarsals and metatarsals, distal tibiae, carpals, metacarpals. It may not be possible to distinguish between secondary osteomyelitis due to leprosy and primary osteomyelitis from another infection if further evidence for leprosy elsewhere on the skeleton is limited (Lew and Waldvogel, 2004).

Secondary ulceration of cutaneous lesions may lead to extensive periostitis where bone is close to the skin, for example on the anterior tibia (Boel and Ortner, 2013). These may present as smooth raised lesions with sharply defined demarcations on the bone surface, indicating the site of the cutaneous ulcer, with extensive reactive new bone surrounding this in response to inflammation and periosteal disturbance (Ortner, 2003, Boel and Ortner, 2013). This could result in extensive destruction or ankyloses of several bones when in close proximity, such as tarsals and metatarsals

(Boel and Ortner, 2013). Again, ascribing evidence of secondary ulceration of cutaneous lesions would be difficult in the absence of further skeletal evidence for leprosy.

3.3.3.3 Enlarged Nutrient Foramina (ENF), and New Bone Around Foramina

ENF have been suggested as a possible outcome of leprosy as a sequelae to neuropathy and hypertrophy of nerves, and concentric remodelling in the phalanges (Moonot et al., 2005). Thappa et al. (1992) observed ENF in 5.3% of individuals in a radiographic study of 76 modern leprosy patients. ENF is not a phenomenon limited to leprosy. Fink et al. (1983) observed phalangeal ENF in patients with Gaucher's disease (an inherited metabolic disorder that induces abnormal enzyme production (Nagral, 2014)), and thalassemia (Kattamis et al., 2022)). The precise nature of ENF in leprosy is difficult to determine, as papers that cover ENF simply mention that the foramina are enlarged, with no comparison to 'normal' foramina (see also Ankad and Halawar, 2015), so distinguishing it as a true pathology over simple individual variation is yet to be explored.

Similarly, hypertrophy of nerves and vessels around nutrient foramina may disturb the periosteum and lead to PNBF in and around nutrient foramina.

3.3.3.4 Non-specific Lesions of the Lower Extremities

Collapse of the longitudinal arch of the foot is a common sequelae of leprous neuropathy (Andersen and Manchester, 1987), and can lead to exostoses (bony projections) on the dorsal aspect of the navicular bone, and bones adjacent to it. This is due to the volar displacement of the navicular bone increasing ligamentous stress, stimulating an osteoblastic response. The most common aetiology of neuropathy induced flat foot aside from leprosy is *diabetes mellitus* (Mann, 1983). The non-specific bony indicators of diabetes induced neuropathy in the foot (osteolysis, deformity and inflammatory reactive bone due to secondary infection resulting from ulceration) are comparable to that of leprosy (Rothschild and Benham, 2005; Biehler-Gomes et al., 2019), and can also result in exostoses (Nguyen, et al., 1991). Chronic cases of foot drop may also lead to tarsal disintegration, which in leprosy is characterised by the fragmentation of one or more tarsal bones (Harverson and Warren, 1979), and may manifest similarly in non-leprous foot drop. For leprosy patients, this is mainly caused by biomechanical factors due to neuropathy of muscles that sustain the foot arch (Kulkarni and Mehta, 1983), however secondary sepsis leading to disintegration (with possible ankylosis and/or aggressive reactive bone formation) of foot bones is also a factor (Harverson and Warren, 1979). This means in advanced cases, tarsal disintegration may be indistinguishable from that caused by other means, such as *diabetes mellitus*, where other evidence for leprosy in the skeleton is limited.

Aside from neuropathy, acquired flat foot may also result from arthritis (inflammatory or degenerative) that affects the ankle joint, talonavicular joint or tarsometatarsal joint, or from direct trauma to the posterior or anterior tendons (Mann, 1983), and may feasibly result in dorsal exostoses.

Charcot's arthropathy is most commonly observed in the foot, particularly in diabetic osteopathy (Frykberg et al., 2012). Charcot's joints result from neuropathy that inhibits soft-tissue support of weight bearing structures, leading to joint and bone destruction due to increased osteoclastic activity and uncontrolled inflammation (Jeffcoate et al., 2015). The inflammatory pathways that lead to Charcot's arthropathy preferentially differentiate osteoclasts, leading to marked osteolysis (Yasuda et al, 1998; Petrova and Edmonds, 2013). This can be observed clinically in the joints of the hand, foot, ankle, knees and wrists in leprosy in up to 10% of patients (Messner et al., 1997; Chauhan et al., 2010). Joint dislocations, pathological fractures and subsequent deformities may also be present (Chauhan et al., 2010).

3.3.4 Differential Diagnosis for Leprosy in Non-adults

The differential diagnoses for leprosy lesions that may develop in non-adults are essentially the same as those that may be seen in adults. However, there are some key differences in the expression of leprosy in non-adults. For example, foot lesions tend to be less common (Lewis, 2017), with no cases of dorsal tarsal exostoses or navicular squeezing noted in archaeological contexts for child cases of motor neuropathy (Andersen and Manchester, 1987). This may be due to the development of those bones as a child grows, or due to preservation issues. Additionally, evidence for leprosy overall tends to be stronger in older non-adults (see Lewis, 2017), perhaps representative of the chronic course of the lepromatous form of the disease, with the most advanced facial changes taking up to 17 years to develop (Reichart, 1976). Additionally, lesions to the carpals and metacarpals may only be detectable radiologically (Lewis, 2017), which would have to be taken into account when considering differential diagnosis and the presence of lesions in non-adult skeletal remains.

Chapter 4: Materials and Methods

The following chapter details the materials and methods adopted in this research. It first outlines the study samples of Chichester and Winchester, including the archaeological background and previous skeletal evidence for leprosy present at both of the sites. It then details the methods used to age and sex the individuals in the assemblages, followed by the introduction of Lepro-C – the method devised in this thesis to assess leprosy going forward. It ends by detailing the statistical methods adopted to analyse the results.

4.1. The Study Sample

The Leprosy Criteria (Lepro-C) was tested by assessing two skeletal assemblages: St James and Mary Magdalen, Chichester, and St Mary Magdalen, Winchester, comprising 131 and 121 total individuals, respectively. These assemblages have been reported to have high rates of leprosy diagnosed previously using established macroscopic and radiographic methods (Magilton et al., 2008; Roffey and Tucker, 2012), so were ideal to test the Lepro-C criteria on. Males, females, and non-adults have also been previously identified at both sites, so there are also important demographic elements to the cemeteries also. A third assemblage, Timberhill, in Norwich was planned for inclusion but had to be omitted due to restrictions from the COVID-19 pandemic, and the ongoing impact that these delays and restrictions had on the data collection phase of the project in 2020 and 2021. Lepro-C was also tested against primary papers from the literature (Chapter 6). These two approaches tested Lepro-C and its use as part of the methodology of a project from the outset, and its use retrospectively on previous studies.

The following describes the two skeletal assemblages under consideration in this research, placing the sites in their archaeological context, and the previously noted rates of leprosy in the skeletal remains.

4.1.1 St James and Mary Magdalen, Chichester

4.1.1.1 Archaeological Context

The original records of the hospital do not survive (Magilton, 2008: 57), so the chronology of the site has been determined from references from other sources, such as wills, or from transcripts of the records (Magilton, 2008: 57). The leprosarium was first recorded in Bishop Seffrid II's confirmation charter in AD 1187, which indicates it was founded prior to AD 1118 for eight leprosy patients (Lee and Magilton, 1989). Page (1907) suggested that the leprosarium was run by a Master

with assistance from the senior inmate, with new patients admitted via agreement of a committee comprised of the master and most of the current patients. Bishop Seffrid II's amendment to the charter indicates that eight linen shirts were granted at Christmas, with an offer of 15 days relaxation of penance to patrons, as an incentive to increase almsgiving (Magilton et al., 2008). In the 12th century there is also the first evidence of the burial of a non-leprous individual at the at the site, from evidence of a dispute between the rector of Itchenor (a Parish South-West of Chichester) and his parishioners about insufficient payments for a burial (Magilton, 2008: 58). This is significant given the 12-14th century phase of the site covered by the Area A excavations (see below), as this shows that people not suffering from leprosy were also being buried at the site in some instances in these centuries. It cannot be known from this reference just how many non-leprous individuals were being buried at the site at this time, or how regularly, however.

Not much is known of the hospital in the 13th century (see Magilton, 2008: 58), although a list of masters of the leprosarium began in 1244 (Magilton, 2008: 58). It is from the 14th century that documentary sources become more numerous (Magilton, 2008: 58). This is mainly in the form of wills, with them suggesting that the hospital may have changed to a more general hospital by this stage. For example, in 1373, William de Lynne, Bishop of Worcester, left 20s to the 'lepers' of Lodsdown and the 'poor' of the hospital of St James and Mary Magdalen, Chichester (Magilton, 2008: 58). This implies that the hospital was no longer a specific leprosarium by this point, and it interesting given that the highest concentration of the skeletal evidence of leprosy is found in the 12-14th century phases of the cemetery in Area A, with the evidence sharply tailing off in the later phases of the site in Area B. The effect of the Black Death from 1348 onwards on the hospital is inconclusive in terms of direct effects on patients, but Magilton (2008: 59) suggests that an effect of the plague may have been a growing demand for places from widowers. So, the after-effects of the plague may have sped up the transition of the hospital to an almshouse, given the apparent overall decline of leprosy at this time occurring concurrently, and an increased demand on places from widowers, although the causes of leprosy decline in Medieval England are debated (Crespo, 2019).

Women were admitted from the 15th century (Magilton, 2008). While initially for 8 inmates, this number increased as a 1594 list of hospital inhabitants showed that there were 5 men and 6 women as inmates (Magilton, 2008). Inmates lived under a quasi-monastic rule, with brothers approaching death required to give 6d to each of the other inmates to pay for a meal on the day of his burial (Magilton, 2008). The final direct reference to leprosy patients at the leprosarium was in a will from AD 1418, however the institution itself functioned until the end of the 17th century, with the old building in ruins by 1705 (Magilton, 2008). In the later phase of the site, the facility possibly

functioned as an almshouse (Magilton et al., 2008). Revisionist research shows that social patterns of patronage had a significant influence on the nature of these institutions (see Rawcliffe, 2007), as landed endowments on leprosaria were not generous, so had to rely on other money-making activities to survive (Marcombe, 2003: 32). Therefore, changes in disease distribution across the site may reflect changing social trends on the part of those willing to donate to these institutions, and the kinds of ailments they were inclined to support, rather than reflecting the true prevalence of the disease in the community.

4.1.1.2 Skeletal Evidence for Leprosy

The cemetery associated with the medieval phase of the St James and Mary Magdalen hospital in Chichester (Fig. 4.1) was initially discovered in 1947 prior to the construction of a housing estate (Lee and Magilton, 1989). Several skeletons were initially examined for leprosy, but no traces were found (Lee and Magilton, 1989). The cemetery was later excavated in 1986-87, and in 1993, by the Chichester District Archaeological Unit prior to further building at the site (Lee and Magilton, 1989; Magilton et al., 2008). A total of 330 graves were excavated, revealing a total of 384 individuals (Ortner, 2008: 199). Of these, 74 individuals (19.2%) displayed 'leprous change' (Lee and Manchester, 2008: 209). Of these, Lee and Manchester (2008: 211) note that 72 (18.8%) individuals displayed 'definite' signs of rhinomaxillary syndrome. 'Bony changes' to the hands, feet and lower legs were also present in 49 (12.8%) individuals in this assemblage (Lee and Manchester, 2008). Lee and Magilton (2008: 266) also note in Area A at Chichester that 'known or probable lepers' were most commonly 'young men', with rates decreasing with age, despite the overall adult age distribution for males being relatively evenly spread. Further research on these individuals was conducted on inflammatory changes associated with leprosy by Lewis et al. (1995), revealing further evidence of leprosy in the assemblage, particularly ossification of the interosseous membrane of the tibia and fibula related to the spread of the bacterium up the ligaments of the lower legs via the foot.

The cemetery was divided into two sections, Area A and Area B, in the earlier western and later eastern portions of the cemetery respectively. Individuals from Area A were those assessed for leprosy in this project, as Area A is broadly dated to the 12-14th centuries when the site functioned as a leprosarium (Magilton, 2008). Area A in this study is comprised of 131 individuals, predominantly adult males (65.6%), with just 2 non-adults. Lee and Manchester (2008: 209) observed that the highest concentrations of leprosy were in Area A, with 56 individuals (42.7%) in that study displaying 'definite leprous change'. This is in contrast with area B, where only 18 of the remaining 253 individuals (7.1%) displayed 'definite leprous change'. Area B relates to the later phases of the site from the 15th century onwards, when the hospital primarily functioned as an

almshouse, explaining the low rates of leprosy in Area B compared to Area A. This is why Area A was targeted in this research, as it offered the best opportunity to test the Lepro-C criteria.

4.1.2 St Mary Magdalen, Winchester

4.1.2.1 Archaeological Context

Documented use of the St Mary Magdalen site as a leprosarium dates back to the mid-12th century, with surviving foundation structures of the building, and radiocarbon dating of some individuals, indicating an earlier foundation of the site in the 11th century (Roffey and Tucker, 2012), with three key phases of the development of the hospital between the 11th-15th centuries (Roffey and Tucker, 2012). The primary phase of the site from the 11th century consisted of timber structures and a small discrete cemetery to the north (Roffey, 2012). These timber structures were replaced later by a stone chapel and masonry hall in the mid-to-late 12th century, with the larger main southern cemetery being used from this time (Roffey, 2012). The hospital had been reformed with almshouses to care for infirm and poor individuals by the late 16th century (Roffey, 2012), suggesting that by this point it likely no longer functioned solely as a leprosarium (Roffey and Tucker 2012) – a pattern noted for leprosaria more broadly in the UK (Rawcliffe, 2007). After this, the site functioned as a troop barracks, and was in ruins by the 17th century (Roffey and Tucker, 2012).

The leprosarium was situated in the suburbs of medieval Winchester, some 1.6km east of the city centre (Roffey, 2010). The presence of male and female individuals displaying evidence for leprosy at the site indicates that both sexes were admitted. This was not unusual. Evidence of biological sex from leprosaria in the UK indicate a range of sex-specific or mixed-sex institutions (Roffey, 2012), although some interments may be patrons or hospital staff. Individuals were admitted from the urban area and surrounding environs of Winchester, with the patients living by a quasi-monastic rule overseen by a master (Roffey, 2012; Roffey and Tucker, 2012). Interestingly, Roffey and colleagues (2017) suggest that one individual, SK27, is a pilgrim from South-Central and Western Asia, using evidence for strain genotyping of *M. leprae*, cranial morphology and isotopic analyses on tooth enamel. This indicates the varied demography of Winchester at this time. Harley Manuscript 328 (cited in Doubleday and Page, 1903) suggests that the leprosarium was originally designed for 18 patients (9 of each sex). However, receipts concerning the inventory of the hospital and on-site occupants from around AD 1400 suggest the presence of a master, and reduction of patients to 14 (7 of each sex). Parish registers from AD 1342 also indicate the presence of two clerks (Doubleday and Page, 1903). The allowances made to patients suggest that the leprosarium was well funded (at least for a time) with patients provided five pence per week to spend on food and provisions, six shillings a year for clothing, and a 'flitch' of bacon (a lengthy steak cut from the side

of a pig) on the eves of Christmas, Ash Wednesday, Easter, and Pentecost (Doubleday and Page, 1903). Indeed, in 1333 Pope John XXII granted a faculty of £40 to the 'Wonsington' (now Wonston) Parish in Winchester, of which £25 19*s*. 4*d*. was to be paid yearly to the Hospital of St Mary Magdalen (Doubleday and Page, 1903). Roffey (2012: 218) notes that there may have been some social stratification in the hospital, with separate houses for individuals by 1400, reflected by the arrangement of the building at the site.

It is unclear whether the transition of the site to an almshouse catering for the old and infirm more broadly, with a concurrent reduction in leprosy patients, is due to an actual decrease in leprosy as a disease in England at this time (Roffey, 2012), or changing patterns of patronage (Demaitre, 2007; Rawcliffe, 2007).

4.1.2.2 Skeletal Evidence for Leprosy

Excavations of the St Mary Magdalen leprosarium and almshouse (Fig. 4.1) commenced in 2008 and were conducted by the Department of Archaeology at the University of Winchester (DAUW). The initial phase of excavations took place until 2011, revealing skeletal remains of 54 individuals from the northern cemetery (Roffey and Tucker, 2012). Excavations have continued since then, with the University of Winchester now holding 121 individuals from this site, comprising both adult males and females, and 35 non-adult individuals. The individuals from this assemblage are noted for their excellent surface preservation, overall completeness of individuals, and skeletal evidence of leprosy. Roffey and Tucker (2012) indicate that 86% of the 38 individuals from the 11th century northern cemetery on the site displayed evidence for leprosy, in both adult and non-adult individuals, with evidence of rhinomaxillary syndrome in 21 of 30 of these individuals with a preserved maxilla and nasal region (70%). Roffey and Tucker (2012) adopted the diagnostic criteria from Ortner (2008: 206). Roffey (2020: 547) notes that very few of the graves in the northern cemetery intercut, and were anthropomorphic in shape, which is normally only seen with monastic burials, such as those at the nearby abbey of St Mary's in Winchester. This indicates the quasi-monastic function of the leprosarium (Roffey, 2020: 548) before transitioning to an almshouse later, as the southern cemetery contains more intercut graves, suggesting that the quasi-monastic nature of the institution had changed (Roffey and Tucker, 2012). Several papers have been published on this site (see Roffey, 2012, 2017, 2020; Roffey and Marter, 2010a, 2010b, 2014; Roffey and Tucker; 2012 Roffey et al., 2017; Cole et al., 2022; Filipek et al., 2022). These mainly concern single individuals, a small subset of individuals, or were published before the full complement of individuals currently held at the University of Winchester had been excavated. A full monograph of the site is in development but has yet to be published (Dawson-Hobbis, *pers. comm.*). All the 121 individuals

from both the early northern and later southern cemeteries currently stored at the University of Winchester have been reassessed for leprosy in this research.

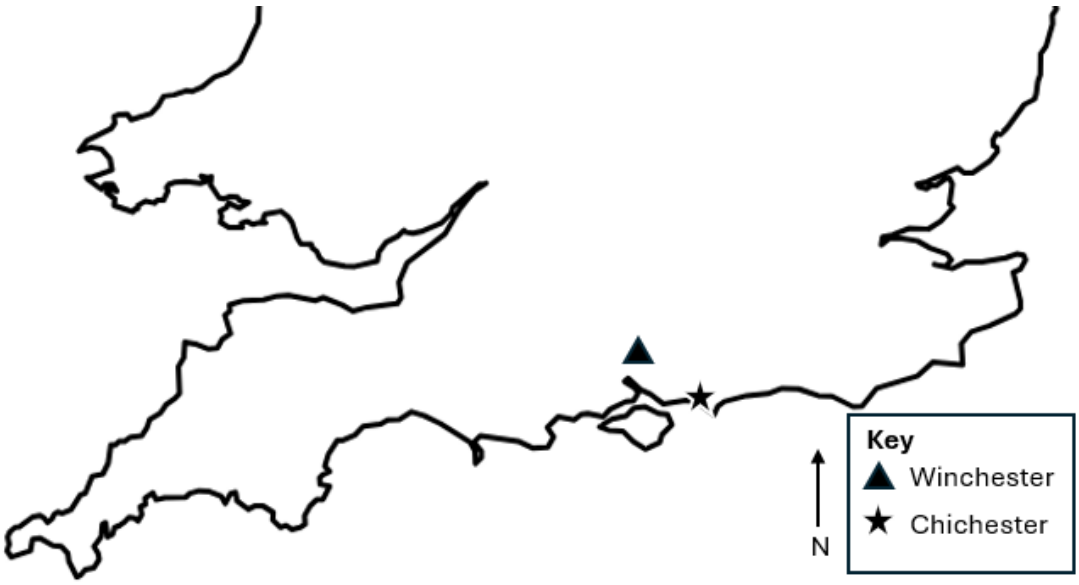


Fig. 4.1: Map of UK showing locations of Winchester and Chichester. Outline of UK © Crown copyright and database rights 2024 Ordnance Survey (AC0000851941).

4.2 Methods

The following details the methods used to analyse the skeletal assemblages. The demographic profile of the individuals was assessed first, followed by a detailed analysis of any lesions present that may be attributable to leprosy. The analysis of the skeletons was carried out blind and without reference to previous reports on individuals in the sample to avoid bias.

4.2.1 Determination of Biological Sex

Biological sex of adult individuals aged 17 years and older was assessed through observation of pelvic features following Phenice (1969), and Buikstra and Ubelaker (1994). Skull morphology was assessed following Buikstra and Ubelaker (1994) and Loth and Henneberg (1996). Morphology of the distal humerus was also used following Rogers (1999) and Falys et al. (2005). Individuals were recorded as male (M), female (F), or sex indeterminate (?). The biological sex of non-adult individuals (<17 years) was determined using the sciatic notch depth and mandible shape criteria outlined by Schutkowski (1993) and distal humerus criteria outlined by Falys et al. (2005). The traits used are listed in Table 4.1.

Table 4.1: List of traits used to determine biological sex in adults and non-adults.

Trait		Reference
Skull	Nuchal crest	Buikstra and Ubelaker (1994)
	Mandibular ramus flexure	
	Mastoid process	
	Supra-orbital margin	
	Supra-orbital ridge/glabella	
	Mandibular ramus flexure	Loth and Henneberg (1996)
Humerus	Olecranon fossa shape	Falys et al. (2005)
	Trochlea shape	
	Medial epicondyle shape	
Pelvis	Ventral arch	Phenice, 1969
	Greater sciatic notch	Buikstra and Ubelaker (1994)
Non-adult Traits	Sciatic notch shape	Schutkowski (1993)
	Mandible shape	

4.2.2 Determination of Age at Death

The morphology of pubic symphysis was used to primarily determine age at death (Meindl et al., 1985; Brooks and Suchey, 1990). However, a multifactorial approach has been shown to be the most accurate way of determining age at death (Lovejoy et al., 1985a). Therefore, age was also determined based on morphological changes to the auricular surface (Lovejoy et al., 1985b) and stages of dental wear (Brothwell, 1981). The sternal rib end was also used where possible, following Iscan et al. (1984). Adult age categories followed Falys and Lewis (2011) – 17-25, 26-35, 36-45, 46+ years. Non-adult individuals were aged primarily using the Atlas of Human Tooth Development and Eruption presented in AlQahtani et al. (2010), a method that develops non-adult dental aging presented by Moorrees et al. (1963a; 1963b), and stages of epiphyseal fusion after Schaefer et al. (2009). The age categories adopted for non-adults were 0-12 months, 6-10 years, 12-14 years, 13-15 years and 14-16 years. The traits used are detailed in Table 4.2

Table 4.2: List of traits used to determine age in adults and non-adults.

Trait		Reference
Dentition	Stages of dental wear	Brothwell (1981)
Ribs	Sternal end morphology	Iscan et al. (1984)
Pelvis	Surface of the pubic symphysis	Meindl et al. (1985); Brooks and Suchey (1990)
	Changes to the surface of the auricular surface	Lovejoy et al. (1985b)
Non-adult traits		
Dentition	Patterns of dental eruption	AlQahtani et al. (2010) adapted from Moorrees et al. (1963a; 1963b)
Postcranial	Stages of epiphyseal fusion	Schaefer et al. (2009)

4.2.3 Recording and Diagnosing Pathology

All leprosy pathology was described using terminology and lesions detailed in Lepro-C below. The recording form used is provided in Appendix B. Preservation was recorded following the MOLA Human Osteology Method Statement (Connell, 2012: 9)(Table 4.3). It was necessary to record the surface preservation so that poor preservation could be accounted for if no lesions were present. All individuals were recorded regardless of completeness.

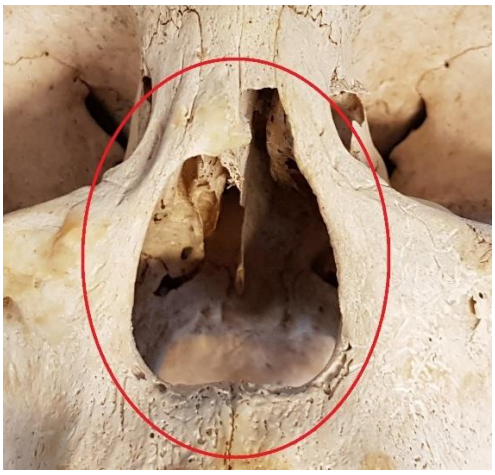
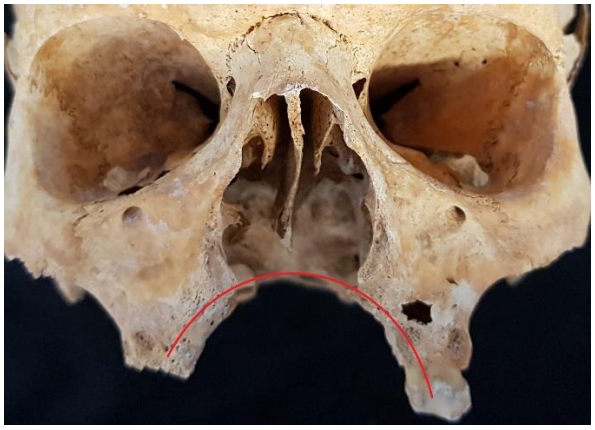
Table 4.3: Skeletal surface preservation grading system (reproduced from Connell, 2012: 9).

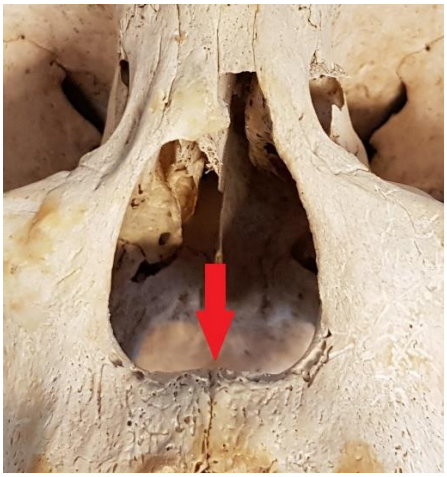
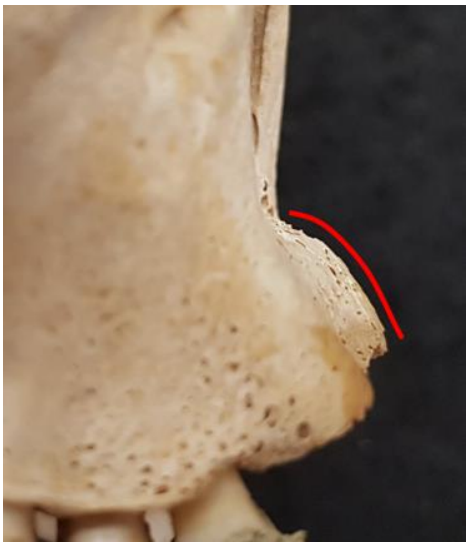
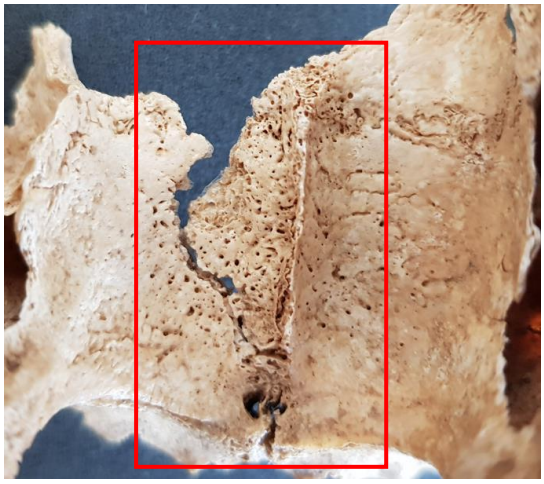
Grade	Description
1	bone surface in **good** condition with no erosion; fine surface detail such as coarse woven bone deposition would (if present) be clearly visible to the naked eye
2	bone surface in **moderate** condition; some post-mortem erosion on long bone shafts. Erosion of articular surfaces and some prominences
3	one surface in **poor** condition; extensive post-mortem erosion resulting in pitted cortical surfaces; articular surfaces missing or severely eroded

4.2.4 Diagnosis of Leprosy

Table 4.4, 4.5 and 4.6 illustrate the lesions used to assess leprosy in the skeletal assemblages. The lesions were analysed macroscopically, and were recorded as present/absent. Lesions were also recorded as active/healed, and whether they were unilateral/bilateral where appropriate. Lesions were recorded as present/absent, rather than graded, to ensure that Lepro-C remained simple and practical to use. This was done also because the presence of a combination of rhinomaxillary syndrome lesions and postcranial inflammatory/absorptive lesions, rather than the severity of them, is key for assessing leprosy in skeletal remains. Lesions were logged as 'present' if pathology was present in the area that could be adequately distinguished from post-mortem breakage or normal morphological variation that might be expected between individuals. If this was not possible the lesion was logged as 'absent'. Some subjectivity remains when determining whether lesions are present/absent in morphologically marginal cases, as the morphology and severity of leprosy lesions inherently varies between individuals in a given location. In these instances, it is a judgement call on the part of the researcher on a case-by-case basis, taking into account the overall distribution of lesions when applying Lepro-C and erring on the side of caution if pathology cannot be determined. To be recorded as 'active' or 'healed', the lesion had to be characterised by the presence of woven bone or lamellar bone, respectively (Weston, 2008; 2011). If 'active' and 'healed' lesions were both present in the same location, this was noted accordingly.

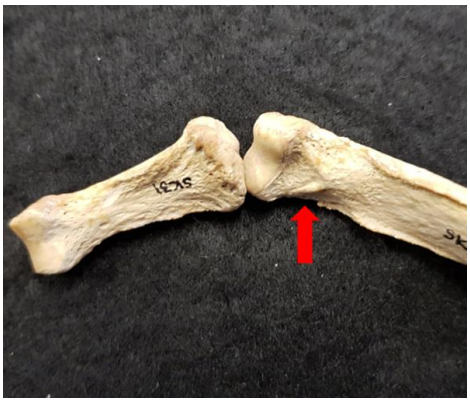
Table 4.4: RMS Lesions (images by author).

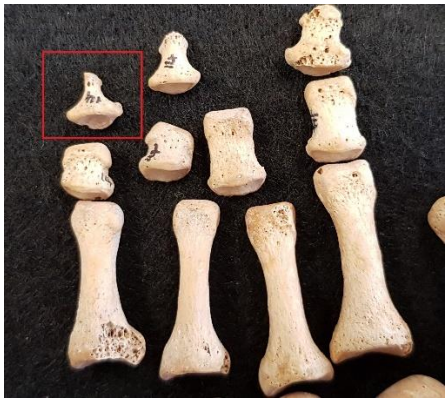
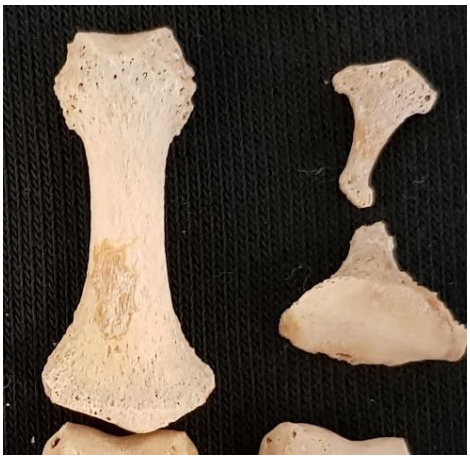
Lesion	Morphology	Image	References
Remodelling of nasal aperture	The morphology is variable. It could be; pitting extending medio-laterally from either side of the ANS, with pores ~1-2mm in diameter; remodelling exposing nutrient canals; pitting of larger diameter than along margins, perhaps where primary granulomata have developed; rounding of margins capped by new cortical bone, with sporadic pitting (this last morphology is what the image shows).		Møller-Christensen (1961; 1978) Andersen and Manchester (1992)
Absorption of Anterior maxillary alveolus	Absorption of the alveolar bone generally confined to the maxillary incisors, resulting in characteristic crescent moon shape, may extend past incisors in advanced cases. Image shows the lunate form of absorption seen in advanced cases.		Møller-Christensen (1961; 1978) Andersen and Manchester (1992)

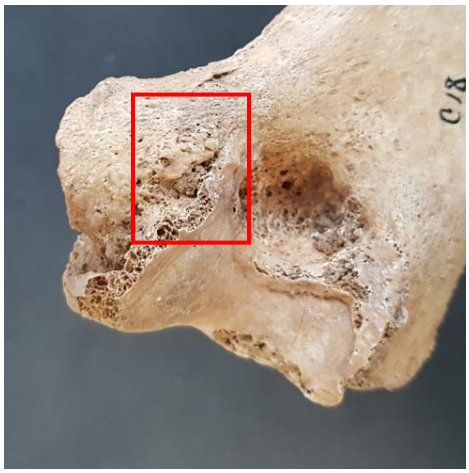
Absorption of anterior nasal spine	When not fully obliterated, the remaining spine will be a protuberance with erosive surface pitting, when obliterated, lesion will be indistinguishable from the overall remodelling of nasal aperture. Image shows where anterior nasal spine has been fully absorbed, with second image showing a lateral view.	 	Møller-Christensen (1961; 1978) Andersen and Manchester (1992)
Pathological pitting of nasal surface of maxilla	Diffuse pitting of nasal surface radiating from midline, pores with smooth margins may range from 1mm in size, to complete perforation/ obliteration of palate in extreme cases. Image shows extensive pitting overall nasal surface		Møller-Christensen (1961; 1978) Andersen and Manchester (1992) Access to collection to take this picture kindly granted by the BARC

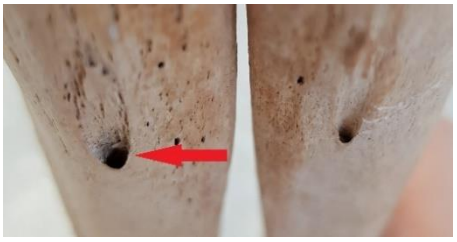
Pathological pitting of oral surface of maxilla	Diffuse pitting of nasal surface radiating from midline, pores may range from 1mm in size, to complete perforation/obliteration of palate in advanced cases. Image shows extensive pitting on nasal surface.		Møller-Christensen (1961; 1978) Andersen and Manchester (1992) Access to collection to take this picture kindly granted by the BARC

Table 4.5: Remaining leprosy lesions (images by author unless otherwise stated).

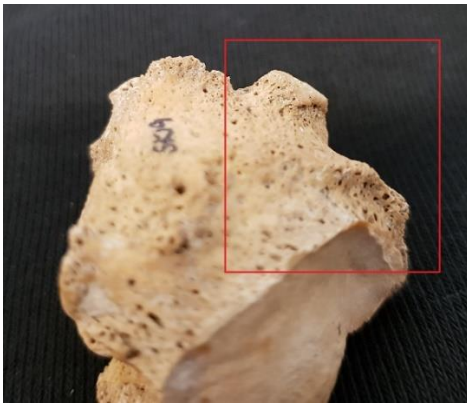
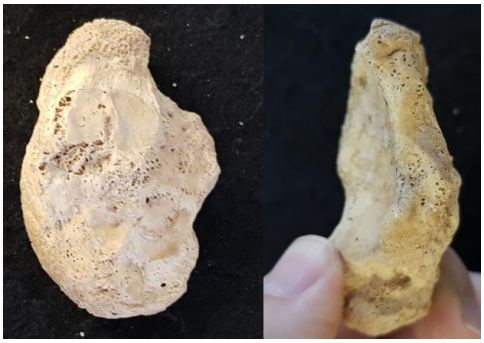
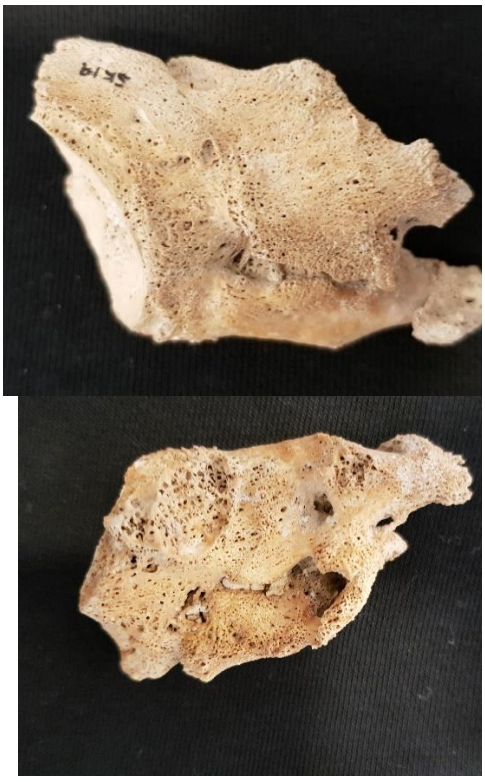
Lesion	Morphology	Image	References
Palmar grooving of distal proximal phalanx	Smooth v-shaped groove on palmar surface of proximal phalanx due to sustained contraction flexure due to leprous neuropathy		Andersen and Manchester (1987)
Arthropathy	Bony manifestations of arthropathy in leprosy are variable, from pitting of margins of articular surfaces akin to rheumatoid arthritis, particularly of PIP/DIP joints of hands/feet. Arthropathy may also be septic, leading to an amorphous mix of lytic foci, pitting, and reactive bone formation. Peri-articular lytic lesions may also be present, perhaps indicative of cyst or primary granuloma	 	Atkin et al. (1987); Mandal, et al. (2008); Graham et al. (2010); Chauhan et al. (2010); Bhat and Prakash (2012); Alam and Al Emadi (2014); Fernandes et al. (2014); El Gendy et al. (2016)

Acroosteolysis	Absorption of distal phalanx that starts at distal end and gradually proceeds proximally. Pitting may be present, with eventual complete obliteration. However, small size of bone may mean they are simply not recovered rather than fully absorbed. Image shows this on distal foot phalanx.		Andersen, Manchester and Ali (1992)
Absorption of phalanges/metacarpals /metatarsals	Progressive and gradual absorption of affected bone from distal end. Any remaining bone may show pitting and/or reactive bone growth. Image shows this on distal end of proximal foot phalanx.		Andersen, Manchester and Ali (1992) Access to collection to take this picture kindly granted by the BARC
Concentric remodelling	Gradual reduction in circumference of shafts of phalanges, metacarpals, and metatarsals. May not progress equally across bone surface, giving remaining bone a broadly conical appearance from distal end to midshaft – 'candy sucked', or two pieces of bone giving an 'hourglass' appearance. May be accompanied by		Andersen, Manchester and Ali (1992)

	septic arthritis. Image shows hourglass morphology on intermediate hand phalanx.		
Knife-edge remodelling	Similar to the above, but remodelling only occurs on the lateral-medial cortical/endosteal surfaces, leading to a knife-edge appearance of remaining bone		Andersen, Manchester and Ali (1992)
Leprogenic odontodysplasia	Root constriction, particularly of maxillary incisors.		Matos and Santos (2013)
Lesion on distal humerus	May be lytic or blastic, depending on the response of bone to hypertrophy of ulnar nerve. This has yet to be identified in the archaeological record. Image shows osteophyte formation on posterior medial epicondyle.		Donaghy (2003); Bataille et al.(2012); Lugao et al. (2015); Fonseca et al. (2018) Access to collection to take this picture kindly granted by the BARC

Lesion on proximal ulna	May be lytic or blastic, depending on the response of bone to hypertrophy of ulnar nerve. This is a novel lesion first observed in this research. Image shows inflammatory pitting on anterior proximal ulnar		Donaghy (2003); Bataille et al (2012); Lugao et al. (2015); Fonseca et al. (2018)
Periosteal new bone formation around nutrient foramina	Periosteal new bone formation at and around nutrient foramina due to periosteal disturbance as response to local nerve hypertrophy or localised infection. Image shows plaque of new bone formation on nutrient foramen of posterior proximal tibia		Thappa et al. (1992); Moonot et al. (2005)
Enlargement of nutrient foramina	Increase of diameter of nutrient foramina in response to nerve hypertrophy. Image shows enlargement of nutrient foramen on posterior proximal left tibia		Thappa et al. (1992); Moonot et al.(2005)

PNBF on distal tibia	Plaques of new bone on cortical surface bone. Either active or healed. Bone may be either longitudinally striated, nodular, or porous and disorganised. PNBF of affected surfaces can range from diffuse to small plaques of a few mm. Image shows longitudinally striated new bone formation, with some surface porosity also, demonstrating the mix of morphologies that can occur.		Andersen, Manchester and Ali (1992) Access to collection to take this picture kindly granted by the BARC.
PNBF on distal fibula	Plaques of new bone on cortical surface bone. Either active or healed. Bone may be either longitudinally striated, nodular, or porous and disorganised. PNBF of affected surfaces can range from diffuse to small plaques of a few mm. Image shows highly porous active new bone formation.		Andersen, Manchester and Ali (1992)

Dorsal tarsal exostoses	Nodular periosteal new bone formation at sites of ligament attachment in response to sustained pressure on bone surface, particularly as a sequelae to failure of plantar arch due to leprous neuropathy (medial cuneiform in image)		Andersen and Manchester (1988)
Navicular squeezing	Reduction in width of navicular bone due to pressure from surrounding bones resulting from foot-drop due to leprous neuropathy. Evidence of compression fracture may be evident		Kulkarni and Mehta (1983); Andersen and Manchester (1988)
Carpal and tarsal disintegration	Obliteration/ankylosis of carpal and tarsal bones characterised by extensive malformation of original bones, and possible deposition of new amorphous bone in response to either sustained novel kinetic pressures or to secondary septic infection due to leprous neuropathy		Harverson and Warren (1979); Kulkahni and Mehta (1983) Tarsal disintegration with, with new bone ankylosing surviving remnants of navicular, cuneiforms and phalanges. Top: dorsal surface; bottom: plantar

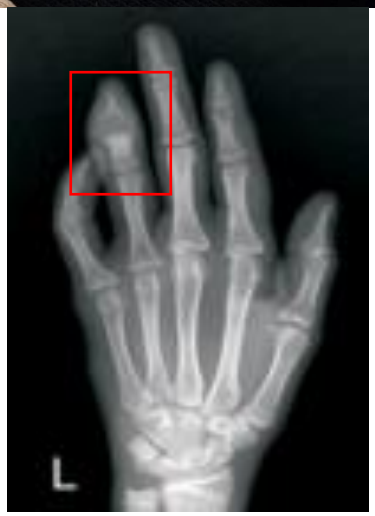
Ossification of intraosseous membrane	Sections of new bone that extend from lateral surface of tibia and/or medial surface of fibula stimulated by progress of infection up the soft tissues of lower extremities by leprosy bacilli. May extend to several mm in length.		Lewis et al. (1995) Access to collection to take this picture kindly granted by the BARC
Dactylitis	Remodelling of phalanges and/or metacarpals due to inflammation. Lesions can be due to primary infection of periosteum by leprosy bacilli, or secondary infection as result of leprous neuropathy. Cortical expansion may occur if cortical/endosteal bone becomes infected, resulting in destructive [peri]articular lesions in some cases (see 4th left DIP joint in bottom image).	 	Atkin et al. (1987); Moonot et al.(2005) Bottom image from (Devi and Kulkarni, 2019: 240)

Table 4.6: Non-specific lesions.

Lesion	Morphology	Image	References
Maxillary sinusitis	Either; fine cortical pitting, spicule formation. Extensive inflammatory pitting may be present, and spicules		Boocock, Roberts and Manchester (1995) Access to collection to take this picture kindly granted by the BARC
Osteomyelitis	Cortical expansion of affected bone, accompanied by cloacae, with possible extensive reactive bone formation and involucrum in response to infection, with sequestrum. Image shows left tibia with large cloaca on distal anterior surface		Aufderheide and Rodriguez-Martin (1998); Ortner (2003) Access to collection to take this picture kindly granted by the BARC

Osteitis	Cortical expansion of affected bone, with possible inflammatory changes/new bone formation to cortical surfaces of bone (fibula in image)		Aufderheide and Rodriguez-Martin (1998); Ortner (2003)

4.2.5 Lepro-C - The 'Leprosy Criteria'

Table 4.7 defines the categorical definitions used for Lepro-C, adapted from MIP (Appleby et al., 2015) for use in leprosy diagnosis. Chapter 2 showed that leprosy is clinically variable in how it manifests, so the definitions for each category are necessarily broad to account for the range of lesions that may occur and for the appropriate differential diagnosis to ensue depending on what lesions are observed, and in what locations, for a given individual. Lepro-C itself is outlined in Table 4.8 and allows the specific nature of individual lesions to be considered when diagnosing the disease.

Table 4.7: Lepro-C category definitions for leprosy

MIP Stage	Definition
Not consistent	The distribution and combination of lesions could not have been caused by leprosy, or too few lesions are present;
Consistent	The distribution and combination of lesions could have been caused by leprosy, but there are many other possible causes;
Highly consistent	The distribution and combination of lesions could have been caused by leprosy, but a few other possible causes need consideration;
Diagnostic of	The distribution and combination of lesions could only have been caused by leprosy.

In order for an individual to be given a higher Lepro-C rating, a mix of proliferative/inflammatory and absorptive lesions in key regions across the skeleton needed to be observed, with the lesions based on those observed clinically as noted above. Combinations of proliferative and absorptive lesions, especially when concurrently observed on the lower long bones, and hands, feet, and cranium respectively, are characteristic of leprosy, and so each Lepro-C category requires an increasingly extensive combination of proliferative/inflammatory and absorptive lesions. Given the variability of the clinical manifestations of leprosy, it was essential for these criteria to take account of this variability but not be too complex. The criteria in Table 4.8 capture this variability, but is also practical for use in the macroscopic assessment of leprosy.

Table 4.8: The Leprosy Criteria (Lepro-C).

Diagnostic	Full RMS (all 5 aspects affected). At least one bilateral absorptive *and* at least one bilateral proliferative/inflammatory postcranial lesion associated with leprosy must also be present.
Highly consistent	Presence of at least one absorptive *and* two inflammatory RMS lesions, or *vice versa*, up to the full five aspects of RMS, but postcranial criteria not satisfied to be diagnostic. OR At least one absorptive *and* at least one inflammatory RMS lesion (e.g. absorption of anterior nasal spine and inflammatory pitting of oral surface of palatine process) *in addition* to the presence of at least one bilateral absorptive *and* at least one bilateral proliferative/inflammatory postcranial lesion associated with leprosy. OR **If at least 2 RMS lesions present, but RMS prerequisites above not met,** presence of at least two bilateral absorptive postcranial lesions *and* at least one bilateral proliferative/inflammatory postcranial lesion associated with leprosy, or *vice versa* (e.g. evidence of absorption of hand *and* foot phalanges in conjunction with bilateral tibial PNBF) **A combination of unilateral and bilateral lesions (where applicable) are highly consistent with a borderline form of lepromatous leprosy**. **Unilateral lesions may indicate tuberculoid leprosy.**
Consistent	One absorptive *and* one inflammatory RMS lesion, with one bilateral absorptive or one bilateral proliferative/inflammatory postcranial lesion associated with leprosy, or two or more postcranial lesions indicative of the same underlying process (e.g. two absorptive lesions) OR At least two RMS lesions indicative of same underlying process (e.g. two absorptive lesions and no inflammatory lesions, and *vice versa*). May be present with up to one inflammatory and/or one absorptive postcranial leprosy lesion, or two or more postcranial lesions indicative of the same process. OR **If RMS prerequisites above not met, or no RMS lesions at all**, presence of at least one postcranial bilateral absorptive lesion associated with leprosy (e.g. concentric remodelling) *and* at least one bilateral postcranial proliferative/inflammatory lesion associated with leprosy, (e.g. bilateral new bone formation on the tibia and fibula) or *vice versa* OR presence of at least two postcranial lesions indicative of the same underlying process (e.g. two absorptive lesions and no inflammatory lesions, and *vice versa)*. **A combination of unilateral and bilateral lesions (where applicable) is consistent with a borderline form of lepromatous leprosy, unilateral lesions (where applicable) are consistent with tuberculoid leprosy**.
Not consistent	A single lesion in the maxilla, or single affected postcranial area (i.e., foot/hand) often linked to leprosy

4.2.5.1 Lepromatous vs Tuberculoid Diagnosis in Skeletal Remains

The consensus is that Tuberculoid leprosy does not result in rhinomaxillary lesions (Spekker et al., 2022), and is characterised by unilateral postcranial lesions in the regions you would expect to see leprosy lesions (see Table 4.5). Therefore, the Lepro-C criteria above account for this by allowing for an assessment of tuberculoid leprosy if only unilateral lesions are present. However, the fact that is does not cause rhinomaxillary lesions means it cannot at present be accounted for in the 'diagnostic' category.

4.2.6 Data Analysis

Firstly, data were tabulated and then described to illustrate the broad demographic characteristics of the assemblages. Overall Lepro-C categorisations across the assemblage were then considered (i.e. how many individuals were consistent, highly consistent etc.), giving a crude prevalence rate of leprosy in the overall assemblage, and in particular age groups. The occurrence of lesions was also considered against the actual number of relevant bones observed in regions of the skeleton, to determine the true prevalence rates (TPR) of lesions in the assemblage. True prevalence was first calculated across the whole assemblage for skeletal regions (head, left arm, right arm, etc.), with the TPR for specific lesions also considered to gain insight into the skeletal regions affected by lesions and the most and least common lesions across the assemblage, respectively.

Following this, each lesion under consideration was detailed by the number of individuals affected by age and sex, and the Lepro-C categories of individuals these lesions occurred in by age and sex. Statistical analyses were also carried out. Chi-squared tests were used to test broad demographic relationships in the dataset (Shennan, 1997), such as rates of males and females across the dataset, and their ages. A 95% confidence interval was adopted for chi-square tests. The occurrence of lesions in individuals and their relationship to age categories was tested using *phi* coefficient to assess whether there were any systematic relationships between lesions and the ages of individuals affected. The *phi* coefficient uses a 2x2 grid to analyse the co-occurrence of variables (Verma and Abdel-Salam, 2019: 184). It gives a value of 1 and -1 showing strong positive or weak relationships respectively and is equal to Pearson correlation but for binary variables (De Caceres et al., 2008). This analysis was conducted for each lesion against each age group, to give detailed statistical data on specific lesions and their relationship to specific age groups, to assess whether certain lesions tended to occur (nor not) in individuals of a certain age. Individuals where the skeletal element was not present to assess a lesion were excluded from the analysis to not skew the data. There were 4 coefficient tests carried out for each lesion, as there were 4 adult age groups, so to protect against Type I errors, Bonferroni correction was applied, which made the alpha value for these tests p = .01

(the original alpha value of .05 divided by 5 (the dependent variable (the lesion concerned) and the 4 age groups tested)(Emerson, 2020).

This analysis was also conducted for lesions and the Lepro-C categories of individuals. This was done to assess whether certain lesions systemically occur in individuals within certain Lepro-C categories. Assessing the relationship of lesions to Lepro-C categories was important to assess the nuance and variability of leprosy lesion occurrence, as aside from the rhinomaxillary syndrome lesions required for the *diagnostic* category, the precise lesions that might be displayed by an individual in a lower category can vary, as the criteria are necessarily broad to account for the variability of leprosy lesions between individuals. So it was important to assess the rates of each lesion in each Lepro-C category as they may be useful indicators of leprosy if they frequently occur in higher categories and not the lower ones, and *vice versa*. The alpha value for this was also .01 after Bonferroni correction, as there were also 5 variables in each comparison (the lesion concerned and the 4 Lepro-C categories)(Emerson, 2020). The relationship of lesions to each other was also tested using phi, to see what the relationships between them were. An alpha value of .01 was adopted for these tests also, to protect against type 1 errors also (Emerson, 2020).

Binomial logistic regression was also used for more complex testing of how age, sex and site may have affected the presence/absence of lesions in the dataset. Binomial logistic regression tests the effect that multiple independent variables had on the presence/absence of individual lesions. The regression analysis included adult individuals where a year age group could be determined. Individuals aged 46+ were automatically excluded from the analysis when running the regression model on SPSS due to redundancy (i.e. the presence/absence values could be predicted from the other three adult age categories). Therefore, the regression models test the effect that the individual's age (17-25, 26-35, and 36-45 year age groups) had on the presence and absence of lesions. These were also the adult age groups most affected by lesions overall, so it was important to see their effect on the regression models, given the objective assessing the nuance and variability of lesion occurrence in adults affected by leprosy lesions in this thesis. The effects of sex and site were also tested in the regression model. Only lesions where there were 10 or more individuals affected were tested, as commonly adopted for regression testing (van Smeden et al., 2016). As also recommended for regression analysis (Emerson, 2020), Bonferroni correction was applied to the p value to reduce the risk of Type 1 errors (false positives) as multiple variables were being tested all at once to see if they influenced the lesion being present or not. This meant dividing the alpha (.05) by the number of variables, which in this case was 6; 1 dependent variable (the lesion in question), and 3 independent variables (age (subdivided into 17-25, 26-35 and 36-45), site, sex)). This means

the alpha variable for significance in these binomial logistic regression models after Bonferrroni correction is p = .008.

These phi and binomial regressions were essential to assess the nuance and variability in the expression of leprosy in skeletal remains, which was one of the aims of this research.

Cohen's kappa was used to test the intraobserver error rates for the lesions under consideration in this study on a subset of 20 individuals from Winchester, who were recorded twice. The presence and absence of each lesion from the first and second recordings were tested against each other. This was done to test the replicability of the method by seeing if lesions were being identified consistently, which was essential as rigour and replicability was an objective of the thesis, and a key part of the Lepro-C method. Cohen's kappa gives a value of -1 to 1, with -1 being strong disagreement between observers, and 1 being strong agreement. These intraobserver error tests were essential to test the replicability of identifying the lesions in the Lepro-C method, as developing this method to increase diagnostic rigour in the assessment of leprosy was an aim of this research. The alpha value for significance adopted for these tests intraobserver error tests was .05, as there was only 1 comparison made in each test – the presence/absence rate of the lesion concerned between the two recordings, so Bonferroni correction was not required (Emerson, 2020).

The statistical analyses were completed using SPSS version 21.

Chapter 5: Results

The following chapter details the results. This chapter first covers the demographic data, including overall rates of age and sex at Chichester and Winchester, as well as the surface preservation. It then covers overall rates of individuals displaying no lesions, and the Lepro-C and True Prevalence rates of individuals displaying lesions.

The next section then considers the rates of each lesion by age and sex of individuals at Chichester and Winchester. This was done to assess whether there were any patterns of lesion occurrence by age and sex. The rates of each lesion by Lepro-C category are also detailed, this was important, particularly for postcranial lesions, to see if any consistently occur in the more stringent Lepro-C categories, as this suggests a consistent link to rhinomaxillary lesions. For statistical analysis, Phi coefficient was first used to test the rates of lesions against specific adult year age groups (17-25, 26-35, 36-45, 46+) to see whether there was any relationship. This was then built upon by adopting binomial logistic regression, which allows for a more complex consideration of several variables all at once. The independent variables used to test whether they had an effect on the presence of lesions were age, sex and site. Intraobserver error testing was also conducted for 20 individuals at Winchester who were recorded twice, to assess the replicability of the method used in this research. This test used Cohen's kappa.

The final section of this chapter considers the overall relationship of lesions to each other, using phi coefficient. Rates of cranial vs postcranial lesions are compared first. This is followed by an assessment of the relationship of rhinomaxillary lesions to each other, then the relationship of rhinomaxillary syndrome lesions to postcranial lesions. Testing postcranial lesions against rhinomaxillary syndrome lesions in this way was done to assess if any postcranial lesions are positively related to rhinomaxillary syndrome lesions, as a strong positive relationships would suggest that some postcranial lesions may be useful indicators of leprosy. The relationship of postcranial lesions to each other is also assessed. This section ends with an assessment of rates of unilateral and bilateral lesions.

5.1 Demography of the Sample

5.1.1 Sex Estimation

Biological sex could be determined for 192 (76.2%) of the 252 individuals in the study sample (Table 5.1; Fig. 5.1). The assemblage was comprised of mostly male individuals (58.3%), with just 17.6% of

the overall assemblage being female. In the specific sites, Chichester and Winchester males made up 65.6% and 50.4% of their respective assemblages, with only 13.0% and 23.1% of individuals in Chichester and Winchester being female, respectively. The higher rates of males compared to females at Chichester and Winchester were statistically significant when tested using a Chi-square test ($X^2 = 5.95$, 1 d.f.; $p = .015$).

Table 5.1: Distribution of individuals by estimated sex in the study sample.

	Site					
	Chichester		Winchester		Total	
Sex	N	%	N	%	N	%
Male	86	65.6	61	50.4	147	58.3
Female	17	13	28	23.1	45	17.6
Indeterminate	28	21.3	32	26.4	60	23.8
Total	**131**		**121**		**252**	

Fig. 5.1: Sex distribution in Chichester and Winchester.

5.1.2 Age-at-death

The age-at-death distributions were evenly spread for the adults in the assemblage, with the exception of the 17-25 year olds at Chichester who made up only 8.5% of that assemblage. The number of males were similar for each age group aged 26-35 years and older, as were the number of females. The exception was the 17-25 year age group at Winchester, where both were represented near-equally (Table 5.2; Fig. 5.2).

Table 5.2: Summary of adult age and sex group distribution at Chichester and Winchester.

Sex and Year Age Group	**Chichester**		**Winchester**		
Male	**N**	**%**	**N**	**%**	**Total**
17-25	5	5.9	7	14	12
26-35	26	30.5	15	30	41
36-45	22	25.9	12	24	34
46+	26	30.6	13	26	39
Adult	6	7.1	3	6	9
Total males	**85**		**50**		**135**
Females					
17-25	2	11.8	6	31.6	8
26-35	6	35.3	4	21.1	10
36-45	5	29.4	4	21.1	9
46+	-	-	5	26.3	5
Adult	4	23.5	-		4
Total Females	**17**		**19**		**36**
Indeterminate					
17-25	4	14.8	2	11.8	6
26-35	6	22.2	2	11.8	8
36-45	4	14.8	1	5.9	5
46+	2	7.4	2	11.8	4
Adult	11	40.7	10	58.8	21
Total Indeterminate	**27**		**17**		**44**
Total	**129**		**86**		**215**

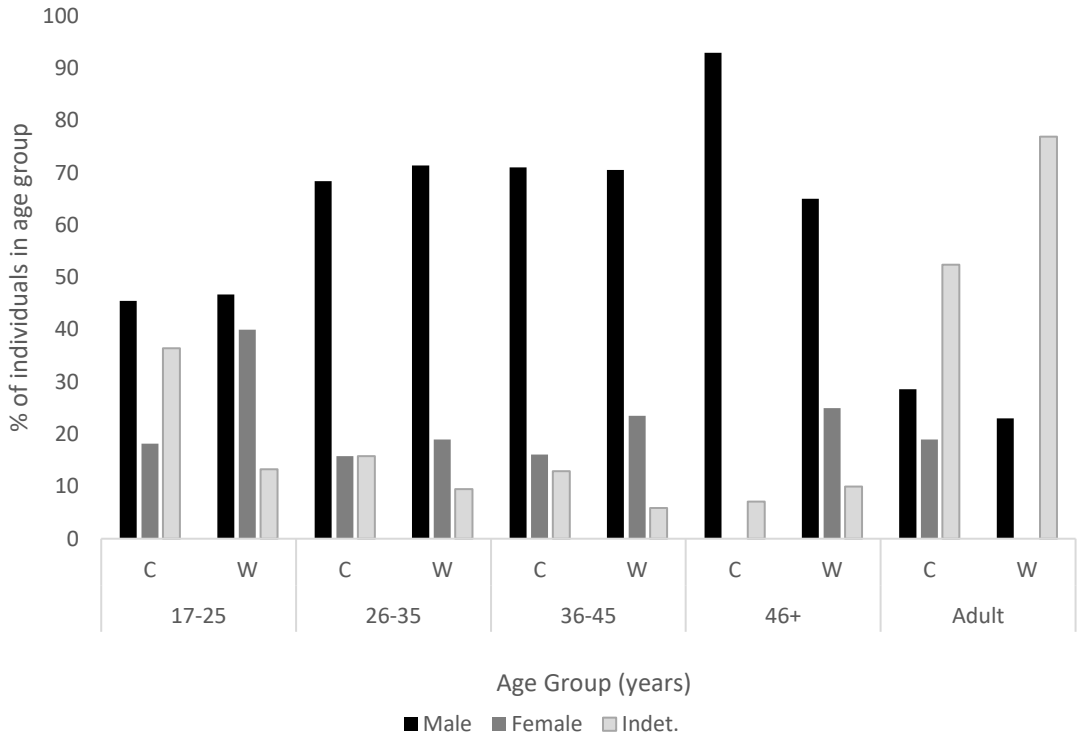


Fig. 5.2: Sex distribution (%) of adult age groups in Chichester and Winchester. C = Chichester, W = Winchester.

The majority (n=35) of non-adults came from Winchester, with only two non-adults recorded at Chichester dating to the time it functioned as a leprosarium (Area A). At Winchester, those aged 0-11 months and 12–14-year-olds represented the largest cohorts, each comprising 20% of non-adult individuals. This was followed by 5–7-year-olds and 13–15-year-olds. The representation of non-adults between Winchester and Chichester is the largest demographic disparity between the two assemblages (Fig. 5.3), with 94.6% of non-adult individuals observed in this research coming from Winchester. The age distribution of the non-adults is summarised in Table 5.3 and Fig. 5.3.

Table 5.3: Summary of non-adult age group distribution at Chichester and Winchester.

	Chichester		Winchester		
	N	%	N	%	Total
0-11 months	-	-	7	20.0	7
1-4	-	-	6	17.1	6
5-7	1	50.0	5	14.3	6
9-10	1	50.0	2	5.7	3
12-14	-	-	7	20.0	7
13-15	-	-	5	14.3	5
14-16	-	-	3	8.6.0	3
Total	**2**		**35**		**37**

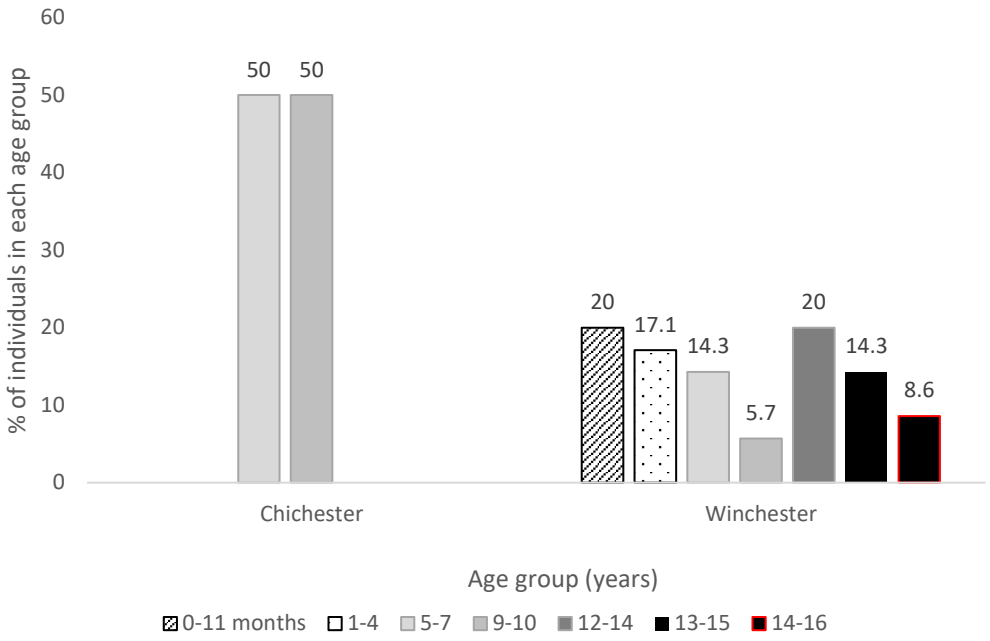


Fig. 5.3: Age distribution of non-adults in Chichester and Winchester by percentage of age groups.

5.1.3 Surface Preservation

The surface preservation was generally good across the dataset (Table 5.4), with 91.3% of individuals with a 'good' surface preservation as per the MOLA categories (Connell, 2012) allowing for the assessment of lesions for most individuals.

Table 5.4: Summary of surface preservation of all individuals in the study by age group.

	Preservation score						
	Poor		*Moderate*		*Good*		*Total*
Age (years)	N	%	N	%	N	%	N
0-11 months	1	5.6	-	-	6	2.6	7
1-4	3	16.7	-	-	2	0.9	5
5-7	2	11.1	-	-	4	1.7	6
9-10	-	-	-	-	3	1.3	3
12-14	-	-	-	-	7	3	7
13-15	-	-	-	-	4	1.7	4
14-16	-	-	-	-	5	2.2	5
17-25	-	-	1	25	25	10.9	26
26-35	4	22.2	-	-	55	23.9	59
36-45	1	5.6	-	-	47	20.4	48
46+	1	5.6	1	25	46	20	48
Adult	6	33.3	2	50	26	11.3	34
Total	***18***		***4***		***230***		***252***

5.1.4 Individuals Displaying No Lesions

Just as important in this analysis was the number of individuals buried at the leprosaria sites that did not display any skeletal manifestations of leprosy. The age and sex distribution of these individuals may reveal information about the age at which lesions manifest, cultural information about the understanding of the disease, and may help guide improvements to Lepro-C. Individuals displaying no lesions are summarised in Table 5.5.

5.1.4.1 Chichester

In Chichester, nine individuals displayed no lesions associated with leprosy. All were male, and were most commonly aged 26-35 years old, with four individuals (50%) falling into this group.

5.1.4.2 Winchester

At Winchester, 36 individuals displayed no lesions associated with leprosy. Of these, 11 were male, eight female and 17 of indeterminate sex. There was no age pattern for the males or females. Fourteen individuals of indeterminate sex were non-adults (82.4%), with ages ranging from newborn to 16 years.

Table 5.5: Summary of male and female individuals at the Chichester and Winchester leprosaria displaying no lesions, by age group.

	Chichester				Winchester			
	M		F		M		F	
Age group	N	%	N	%	N	%	N	%
0-4	-	-	-	-	2	18.2	2	25
5-10	-	-	-	-	4	36.4	1	12.5
11-16	-	-	-	-	3	27.3	2	25
17-25	1	12.5	-	-	-	-	-	-
26-35	4	50	-	-	-	-	-	-
36-45	2	25	-	-	-	-	-	-
46+	1	12.5	-	-	2	18.2	3	37.5
Adult	1	12.5	-	-	-	-	-	-
Total	**9**		**-**		**11**		**8**	

5.1.5 Individuals Displaying Lesions

The following considers overall rates of Lepro-C categories for individuals in the dataset. This is followed by the consideration of the most affected regions of the skeleton by considering true prevalence rates of leprosy lesions by age and sex, and then the most prevalent lesions overall.

5.1.5.1 Rates of Lepro C Categories at Chichester and Winchester

Table 5.6 and Fig. 5.4 shows the overall distribution of Lepro-C categories in the dataset. Table 5.7, 5.8 and 5.9, and Fig. 5.5 and 5.6 presents the number and percentage of Lepro-C categorisation for individuals of indeterminate sex, males and females in the study respectively.

Table 5.6: Overall number of individuals in each Lepro-C category.

Lepro-C Category	**Number of Individuals**
Not consistent	104
Consistent	97
Highly consistent	47
Diagnostic	4
Total	252

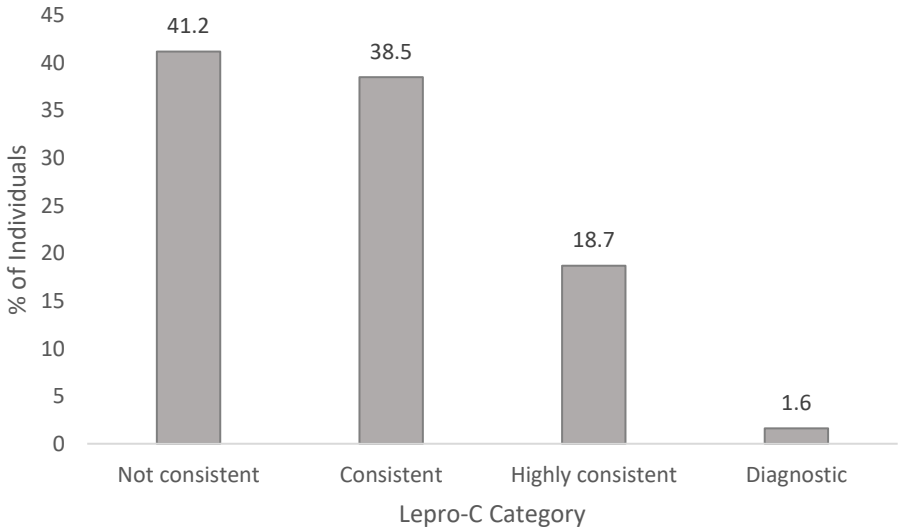


Fig. 5.4: Percentage of overall number of individuals in each Lepro-C category.

5.1.5.1.1 Not Consistent

Overall, there were 104 individuals with lesions *not consistent* with leprosy in the dataset. Of these, 44 were male (42.3%), 23 female (22.1%), and 37 of indeterminate sex (35.5%). For males, 46+ years was the dominant age group, with 18 *not consistent* individuals being of this age (40.1%). For females, 36-45 was the most dominant year age group overall, with 6 *not consistent* individuals being of this age (26.1%). While most dominant overall, it was not the most dominant age group for females when looking at Chichester and Winchester separately, as 36-45 years and 'adult' were

equally prevalent at Chichester, as was 46+ at Winchester, each with four *not consistent* individuals being of those ages. For indeterminate sex individuals, those aged 'adult' were most prevalent, with 13 *not consistent* individuals falling into this category (35.1%).

5.1.5.1.2 Consistent

Overall, there were 97 individuals with lesions *consistent* with leprosy in the dataset. Of these, 71 were male (73.2%), 7 female (7.2%), and 19 of indeterminate sex (19.6%). For males, 36-45 was the most dominant year age group, with 21 *consistent* individuals being of this age (29.5%). However, this was very closely followed by the 46+ year age group, with 19 *consistent* individuals being of this age (26.7%). For females, the 17-25 and 26-35 year age groups were equally prevalent, with three *consistent* individuals in each group (37.5% each). The 'adult' age group was dominant for indeterminate sex individuals, with 8 individuals being of this age (42.1%).

5.1.5.1.3 Highly Consistent

Overall, there were 47 individuals with lesions *highly consistent* with leprosy in the dataset. Of these, 28 were male (59.6%), 15 female (31.9%), and 4 of indeterminate sex (8.5%). For males, 26-35 was the most dominant age group overall, with 15 *highly consistent* individuals being of this age (53.6%). For females, most *highly consistent* individuals were aged 17-25 years overall, with five individuals being of this age (33.3%). This was closely followed by the 26-35 year age group, with four individuals affected (26.7%). The pattern was different however when looking at Chichester and Winchester separately, with 26-35 (50%) and 17-25 year age groups (36.4%) the most prevalent respectively. Female numbers in this category were low at Chichester. There was no pattern for the four indeterminate sex individuals falling into this category.

5.1.5.1.4 Diagnostic

Of the 252 individuals in the study sample, four individuals (1.6%) had lesions considered *diagnostic* of leprosy in the study sample. These were all males. The two males at Chichester were aged 26-35 and 36-45 years, while the males at Winchester were both aged 26-35 years (Table 5.8).

Table 5.7: Rates of Lepro-C categories in indeterminate sex adults and non-adults at Chichester and Winchester by age.

	Not Consistent				*Consistent*				*Highly Consistent*				*Total*
	C		W		C		W		C		W		
	N	%	N	%	N	%	N	%	N	%	N	%	Total
0-1	-	-	6	31.6	-	-	-	-	-	-	-	-	6
1-4	-	-	-	-	-	-	1	9.1	-	-	-	-	1
5-7	-	-	2	10.5	-	-	-	-	-	-	-	-	2
9-10	-	-	-	-	1	12.5	-	-	-	-	-	-	1
12-14	-	-	1	5.3	-	-	-	-	-	-	1	50	2
13-15	-	-	2	10.5	-	-	-	-	-	-	-	-	2
14-16	-	-	2	10.5	-	-	-	-	-	-	-	-	2
17-25	1	5.6	-	-	2	25	2	18.2	1	50	-	-	6
26-35	3	16.7	1	5.3	2	25	-	-	1	50	1	50	8
36-45	4	22.2	-	-	-	-	1	9.1	-	-	-	-	5
46+	2	11.1	-	-	-	-	2	18.2	-	-	-	-	4
Adult	8	44.4	5	26.3	3	37.5	5	45.5	-	-	-	-	21
Total	**18**		**19**		**8**		**11**		**2**		**2**		**60**

C = Chichester, W = Winchester

Table 5.8: Rates of Lepro-C categories for male individuals in Chichester and Winchester by age.

	Not Consistent				*Consistent*				*Highly Consistent*				*Diagnostic*				*Total*
	C		W		C		W		C		W		C		W		
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	
1-4	-	-	2	10.5	-	-	-	-	-	-	-	-	-	-	-	-	2
5-7	1	4	2	10.5	-	-	-	-	-	-	-	-	-	-	-	-	3
9-10	-	-	2	10.5	-	-	-	-	-	-	-	-	-	-	-	-	2
12-14	-	-	2	10.5	-	-	-	-	-	-	-	-	-	-	-	-	2
13-15	-	-	-	-	-	-	-	-	-	-	1	7.7	-	-	-	-	1
14-16	-	-	1	5.3	-	-	-	-	-	-	1	7.7	-	-	-	-	2
17-25	1	4	1	5.3	4	9.1	5	18.5	-	-	1	7.7	-	-	-	-	12
26-35	7	28	-	-	9	20.5	7	25.9	9	60	6	46.2	1	50	2	100	41
36-45	3	12	2	10.5	14	31.8	7	25.9	4	26.7	3	23.1	1	50	-	-	34
46+	11	44	7	36.8	14	31.8	5	18.5	1	6.7	1	7.7	-	-	-	-	39
Adult	2	8	-	-	3	6.8	3	11.1	1	6.7	-	-	-	-	-	-	9
Total	25		19		44		27		15		13		2		2		147

C = Chichester, W = Winchester

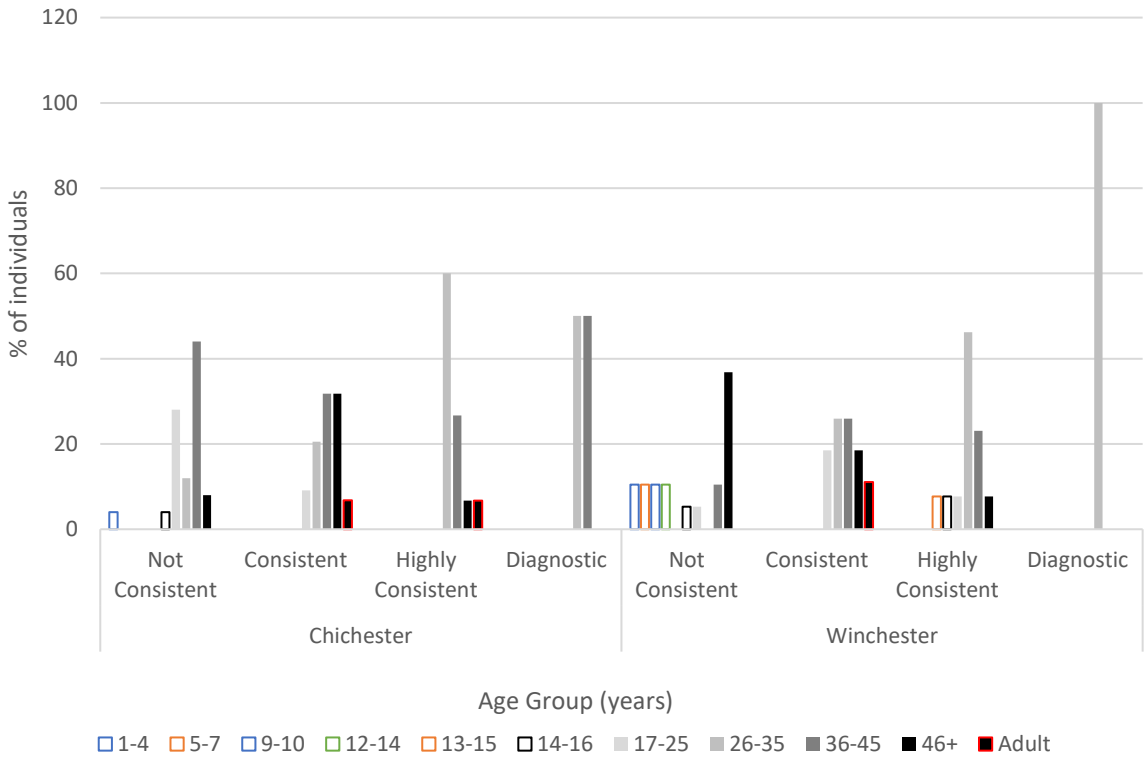


Fig. 5.5: Age distribution of male individuals in each Lepro-C category at Chichester and Winchester by percentage.

Table 5.9: Rates of Lepro-C categories for female individuals in Chichester and Winchester by age.

	Not Consistent				*Consistent*				*Highly Consistent*				*Total*
	C		W		C		W		C		W		
	N	%	N	%	N	%	N	%	N	%	N	%	
0-12 months	-	-	1	7.7	-	-	-	-	-	-	-	-	1
1-4	-	-	2	15.3	-	-	-	-	-	-	-	-	2
5-7	-	-	1	7.7	-	-	-	-	-	-	-	-	1
12-14	-	-	1	7.7	-	-	-	-	-	-	2	18.2	3
13-15	-	-	1	7.7	-	-	-	-	-	-	-	-	1
14-16	-	-	-	-	-	-	-	-	-	-	1	9.1	1
17-25	-	-	-	-	1	33.3	2	50	1	25	4	36.4	8
26-35	2	20	1	7.7	2	66.7	1	25	2	50	2	18.2	10
36-45	4	40	2	15.3	-	-	-	-	1	25	2	18.2	9
46+	-	-	4	30.8	-	-	1	25	-	-	-	-	5
Adult	4	40	-	-	-	-	-	-	-	-	-	-	4
Total	**10**		**13**		**3**		**4**		**4**		**11**		**45**

C = Chichester, W = Winchester

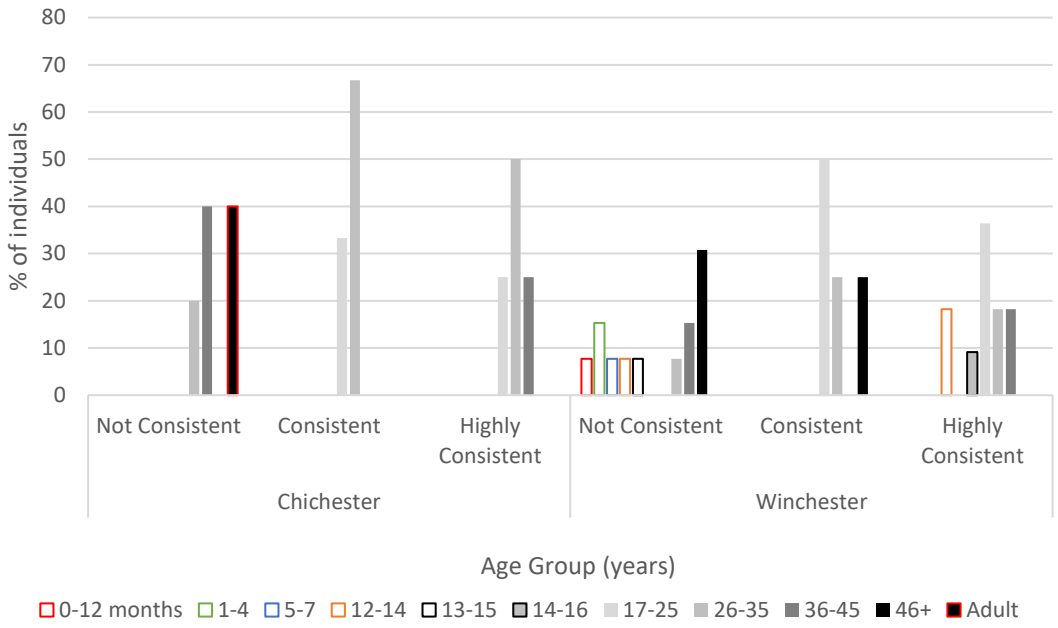


Fig. 5.6: Age distribution of female individuals in each Lepro-C category at Chichester and Winchester by percentage.

5.1.5.2 True Prevalence Rates for Skeletal Regions Affected by Leprosy

The overall true prevalence rates for lesion location are presented in Table 5.10.

5.1.5.2.1 Overall True Prevalence Rates

The most affected skeletal regions overall were skulls, left and right legs, and left and right feet, with TPR percentages ranging from 40.4% to 52.2%.

Table 5.10: True prevalence rates for skeletal regions from both sites.

	Observed	Affected	TPR %
Skulls	191	83	43.6
Left Arm	214	18	8.4
Right Arm	218	16	7.3
Left Hand	206	24	11.7
Right Hand	208	30	14.4
Left Leg	226	110	48.7
Right Leg	226	118	52.2
Left Foot	198	80	40.4
Right Foot	203	88	43.4

5.1.5.2.2 True Prevalence Rates for Males

The most affected skeletal regions for males overall were crania, left and right legs, and left and right feet, with TPR percentages ranging from 43.3% to 58.9%. The overall TPR rates for males are detailed in Table 5.11 and Fig. 5.7, and detailed by adult year age groups in Table 5.12. The TPR percentage rates for males Chichester and Winchester are detailed by year age group in Fig. 5.8.

Table 5.11: True prevalence rates for skeletal regions in male individuals from both sites.

	Observed	Affected	TPR %
Crania	120	52	43.3
Left Arm	134	14	10.5
Right Arm	137	14	10.2
Left Hand	134	19	14.2
Right Hand	135	25	18.5
Left Leg	140	76	54.3
Right Leg	141	83	58.9
Left Foot	124	59	47.6
Right Foot	128	66	51.6

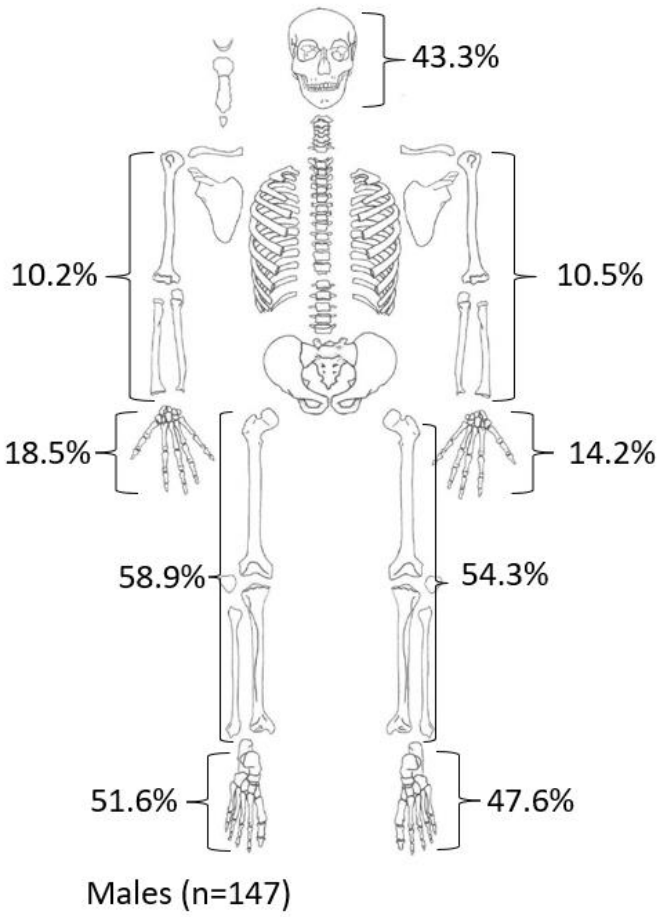


Fig. 5.7: TPR percentages for skeletal regions in male individuals overall.

For males and adult year age groups, left and right legs were the most affected skeletal regions overall, particularly in the 17-25 and 26-35 year age groups, with TPR percentages over 70% in these year age groups. There was an increase in TPR rates in left and right feet in the 26-35 and 36-45 year age groups, with TPR percentages ranging between 54.8% and 65.7% - much higher than the 33.3% TPR rates in the 17-25 age groups. Rates for skulls affected by lesions peaked in the 26-35 age group (66.6%). For individual sites, Winchester had the highest adult TPR percentages for the left and right legs in the 17-25 and 26-35 year age group, with 100% of left legs and 83.3% and 92.8% of right legs of individuals of this age affected respectively (Fig. 5.8).

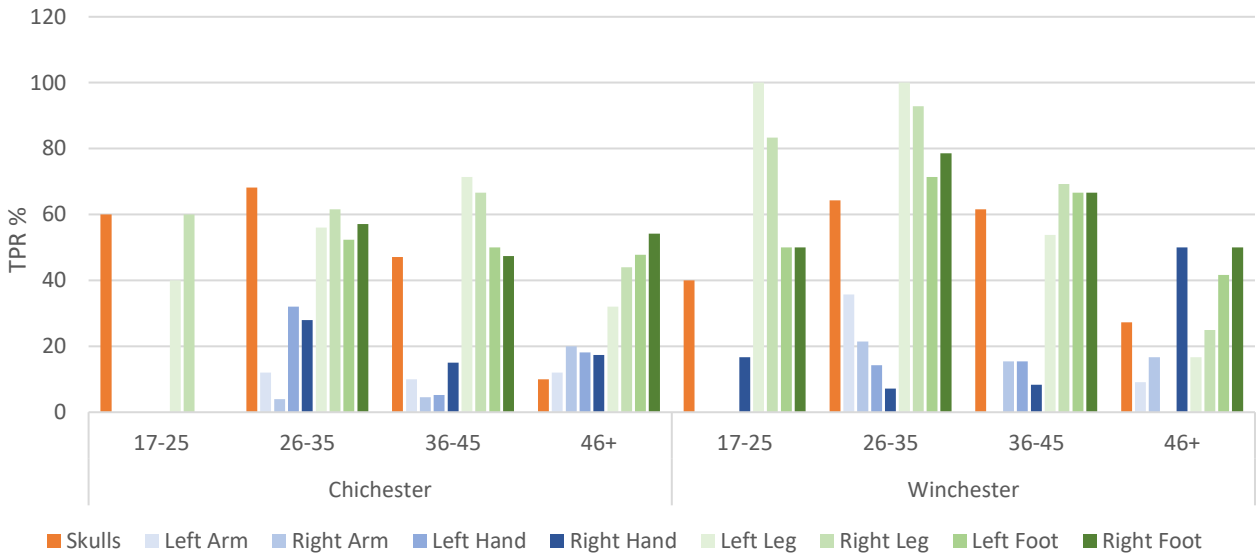


Fig. 5.8: Comparison of TPR percentages of adult males at Chichester and Winchester by year age group.

Table 5.12: Overall TPR rates of adult males by year age group.

	17-25			26-35			36-45			46+		
	O	A	%	O	A	%	O	A	%	O	A	%
Skulls	10	5	50	36	24	66.7	30	16	53.3	31	5	16.1
Left Arm	9	0	0	39	8	20.5	33	2	6.1	36	4	11.1
Right Arm	11	0	0	39	4	10.3	35	3	8.6	37	7	18.9
Left Hand	11	0	0	39	10	25.6	32	3	9.4	34	4	11.8
Right Hand	10	1	10	39	8	20.5	32	4	12.5	35	10	28.5
Left Leg	11	8	72.7	39	28	71.8	34	22	64.7	37	10	27.0
Right Leg	11	8	72.7	40	29	72.5	34	23	67.6	37	14	37.8
Left Foot	9	3	33.3	35	21	60	28	16	57.1	35	16	45.7
Right Foot	9	3	33.3	35	23	65.7	31	17	54.8	36	19	52.8

***O= Observed, A=Affected**

5.1.5.2.3 True Prevalence Rates for Females

The most affected skeletal regions for females overall were crania, and left and right legs, with TPR percentages ranging from 45.2-56.8%. The left arm was least affected, with no elements affected at all. The rates are detailed in Table 5.13 and 5.14, and Fig. 5.9 and 5.10.

Table 5.13: True prevalence rates for skeletal regions for female individuals at both sites.

	Observed	Affected	TPR %
Crania	37	21	56.8
Left Arm	41	0	0
Right Arm	43	1	2.3
Left Hand	40	5	12.5
Right Hand	42	4	9.5
Left Leg	42	19	45.2
Right Leg	40	21	52.5
Left Foot	38	14	36.8
Right Foot	38	14	36.8

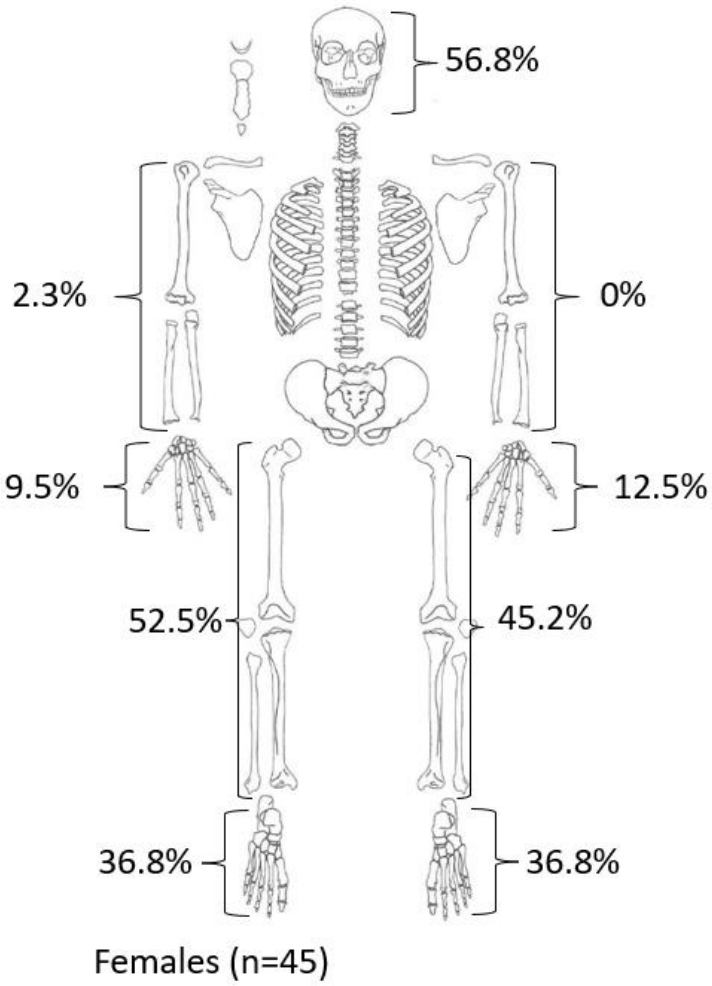


Fig. 5.9: TPR percentages for skeletal regions in females overall.

For females and adult year age groups overall, TPR percentages were highest in the 17-25 year age group, particularly for lesions to skulls, left leg and right leg, with percentages ranging from 62.5-85.7%. Rates generally declined in the 26-35 and older age groups (Table 5.14). When considering the sites separately, TPR percentages were highest in the 17-25 year olds at Winchester, with skulls, left and right legs, and left feet having percentages ranging from 83.3-100%. The caveat to these percentages is that rates of females were much lower in the dataset than males. For example, 100% of 17-25 female skulls were affected at Chichester, but there was only 1 female skull of this age at Chichester.

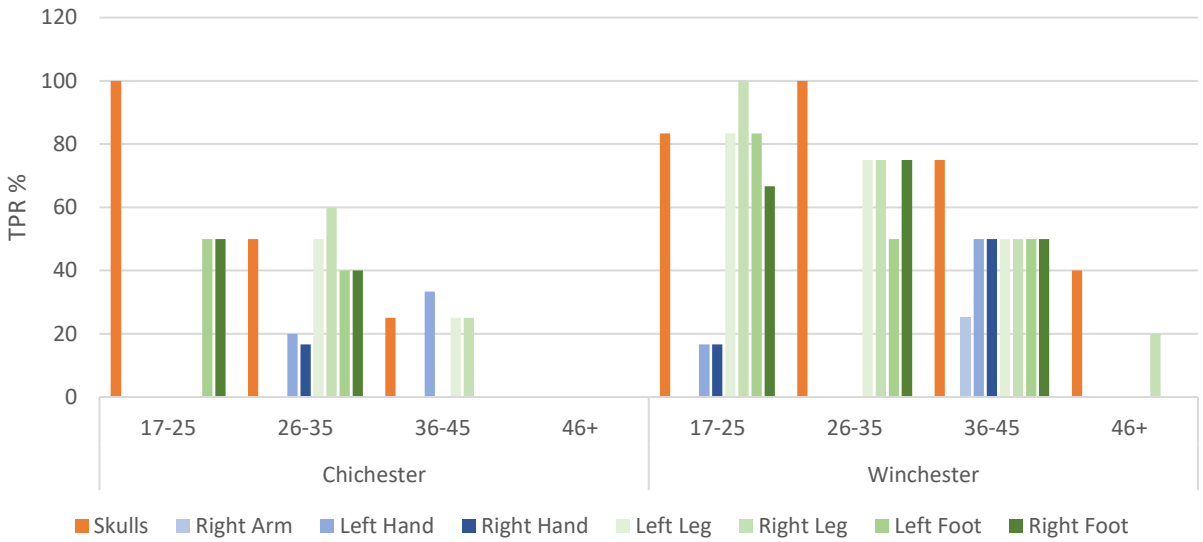


Fig. 5.10: Comparison of TPR percentages of skeletal regions by year age group for females at Chichester and Winchester.

Table 5.14: Overall TPR rates for skeletal regions for adult females by adult year age group.

	17-25			26-35			36-45			46+		
	O	A	%	O	A	%	O	A	%	O	A	%
Skulls	7	6	85.7	9	6	66.7	8	4	50	5	2	40
Left Arm	7	0	0	10	0	0	9	0	0	5	0	0
Right Arm	8	0	0	10	0	0	9	1	11.1	5	0	0
Left Hand	8	1	12.5	9	1	11.1	7	3	42.9	5	0	0
Right Hand	8	1	12.5	10	1	10	8	2	25	5	0	0
Left Leg	8	5	62.5	10	6	60	8	3	37.5	5	0	0
Right Leg	8	6	75	9	6	66.7	8	3	37.5	5	1	20
Left Foot	8	6	75	9	4	44.4	7	2	28.6	5	0	0
Right Foot	8	5	62.5	9	5	55.6	7	2	28.6	5	0	0

*** O = Observed, A = Affected**

5.1.5.2.4 True Prevalence Rates for Non-adults

For non-adults, the most commonly affected regions were the skull, left leg and right leg. TPR percentage rates were much lower than for adults, however. The rates are summarised in Table 5.15 and Fig. 5.11.

Table 5.15: TPR percentages for non-adults overall.

	Observed	Affected	TPR %
Skulls	32	5	15.7
Left Arm	33	1	3
Right Arm	34	0	0
Left Hand	30	0	0
Right Hand	30	0	0
Left Leg	32	8	25
Right Leg	35	9	25.7
Left Foot	31	3	9.7
Right Foot	30	3	10

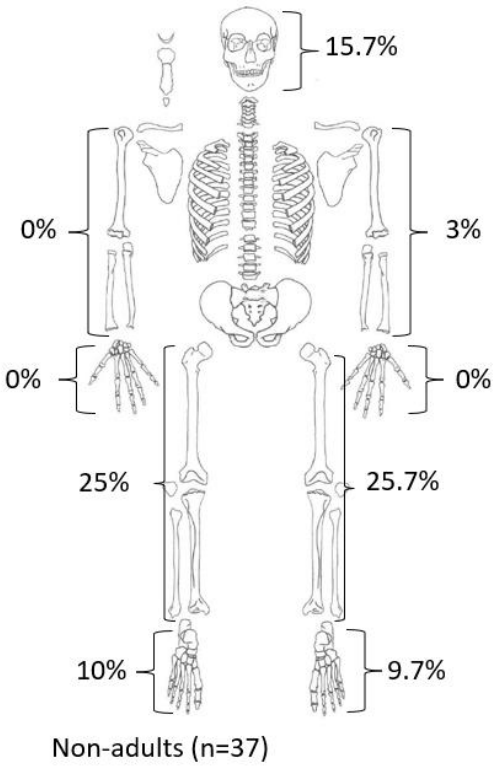


Fig. 5.11: TPR percentages for skeletal regions in non-adults overall.

5.1.5.2.5 True Prevalence Rates for Specific Lesions

Table 5.16 lists the lesions associated with leprosy that were most commonly observed in the study sample (over 20% true prevalence rate), while Table 5.17 list lesions that had a true prevalence rate

of less than 10%. These thresholds were chosen as they seemed reasonable to get a sense of the most and least prevalent lesions by TPR in the dataset.

Periosteal new bone formation to the distal tibia and fibula were the most prevalent lesions in the study sample, followed by acroosteolysis of the distal foot phalanges. The rates of periosteal new bone formation on the distal tibia and fibula were compared using a chi-square test, but this was not significant (X^2=0.0009, 1 d.f.; p= .98). At Chichester remodelling of the nasal aperture and nasal palatine process also had a prevalence rate of over 20%. The true prevalence rates of periosteal new formation of the distal tibia at Chichester and Winchester were tested using a chi-square, which indicated there was no significant difference in TPR rates between the sites (X^2=1.15, 1 d.f.; p= .28), with the same also for a similar test on rates of periosteal new bone formation to the distal fibula (X^2=0.18, 1 d.f.; p= .66). Encouragingly, four of the five rhinomaxillary syndrome lesions were among the most common lesions in the dataset.

Table 5.16: Leprosy lesions with a TPR over 20% in the overall sample, by most prevalent.

Lesion	Affected	Observed	TPR %
PNBF distal tibia	245	423	65.0
PNBF distal fibula	235	405	58.0
Acroosteolysis (distal foot phalanges)	233	541	43.0
Anterior nasal spine	63	172	36.6
Pitting of oral palatine process	53	173	30.6
Remodelling of nasal aperture	24	79 (C)	30.3
Pitting of nasal palatine process	16	79 (C)	29.4

(C) = Chichester only

Lesions that had a prevalence lower than 10% all occurred in the upper limb, with the exception of the concentric remodelling of the foot phalanges. The least commonly observed lesion that has been associated with leprosy in the literature was osteoarthritis of the carpals as the result of carpal disintegration.

Table 5.17: Leprosy lesions with a TPR under 10% in the overall sample, by least prevalent.

Lesions	Affected	Observed	TPR %
Osteoarthritis (carpals)	18	2091	0.9
Remodelling of metacarpals	59	1787	3.3
Lateral epicondyle of humerus	16	410	3.9
Acroosteolysis (distal hand phalanges)	13	200 (C)	6.5
Foot phalanges	46	576 (W)	8.0
Proximal ulna	34	402	8.4

(C) = Chichester only; (W) Winchester only

Table 5.18 and 5.19 compares the prevalence of leprosy lesions by site (see also Fig. 5.12 and 5.13). Periosteal new bone formation to the distal tibia and fibula were the most prevalent lesion at both Chichester and Winchester. At Chichester, 62.9% and 56.4% of tibiae and fibulae were affected

respectively, with 67% of tibiae and 59.4% fibulae affected at Winchester. This was followed by the absorption of the nasal spine at Chichester, and acroosteolysis of the feet at Winchester.

Table 5.18: Lesions with a true prevalence rate above 20% at Chichester and Winchester, in order of prevalence.

Chichester	A	O	%	Winchester	A	O	%
PNBF distal tibia	129	205	62.9	PNBF distal tibia	146	218	67.0
PNBF distal fibula	109	193	56.4	PNBF distal fibula	126	212	59.4
Absorption of anterior nasal spine	28	78	35.9	Acroosteolysis (distal foot phalanges)	204	459	44.4
Acroosteolysis (distal foot phalanges)	29	82	35.4				
Remodelling of nasal aperture	24	79	30.3	Absorption of anterior nasal spine	35	94	37.2
Pitting of oral palatine process	20	79	25.3	Pitting of oral palatine process	33	94	35.1
Pitting of nasal palatine process	16	79	20.2				

A = Affected; O = Observed

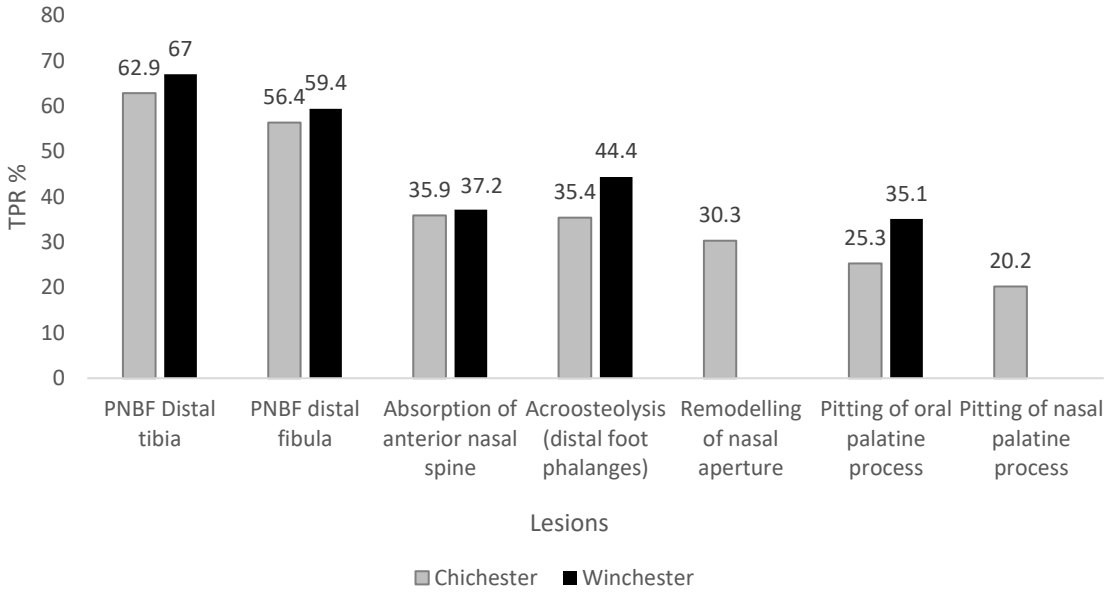


Fig. 5.12: Lesions with TPR rates above 20% at Chichester and Winchester. TPR of remodelling of nasal aperture <20% at Winchester.

Table 5.19: Lesions with a true prevalence rate of less than 10% in Chichester and Winchester.

Chichester	No/% TPR	Winchester	No/% TPR
Osteoarthritis (carpals)	5/745; 0.7%	Osteoarthritis (carpals)	13/1346; 0.9%
Palmar grooving	8/616; 1.2%	Remodelling of metacarpals	14/940; 1.4%
Distal humerus	7/204; 3.43%	Palmar grooving	9/600; 1.5%
Remodelling of metacarpals	45/847; 5.3%	Distal humerus	9/206; 4.36%
Acroosteolysis (Distal hand phalanges)	13/200; 6.5%	Absorption of proximal foot phalanges	46/576; 8%
Proximal ulna	16/199; 8%	Proximal ulna	18/203; 8.9%

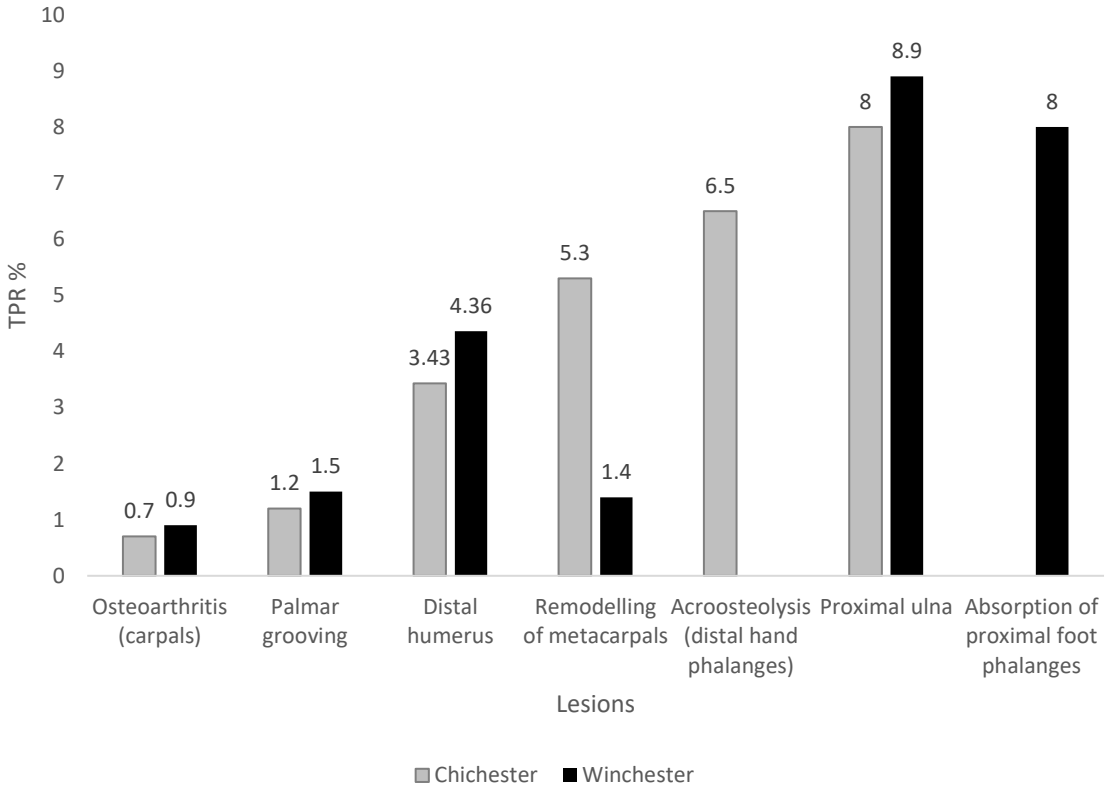


Fig. 5.13: Lesions with lowest TPR rates at Chichester and Winchester.

5.1.6 Summary

The above shows that males were more common than females in the dataset, significantly so. It also shows that the adult age groups were similarly represented. The surface preservation was also good for both sites. Fewer individuals were in each Lepro-C category as the criteria got more stringent. The above also shows that rhinomaxillary syndrome lesions had a relatively high TPR in the dataset. It also shows that males had a higher TPR than females, but this could also be due to the relatively low numbers of females in the dataset.

5.2 Consideration of Each Lesion

The following considers each lesion associated with leprosy in turn. This was done to determine whether there were any patterns across the dataset, particularly whether any age or sex group were more affected by any single lesion. The age group most affected by each lesion in both males and females at Chichester and Winchester is summarised in Table 5.89.

5.2.1 Rhinomaxillary Syndrome Lesions

5.2.1.1 Remodelling of the Margins of the Nasal Aperture

5.2.1.1.1 Chichester

At Chichester, 79 individuals had the nasal aperture preserved to be assessed, of which 24 individuals (30.4%) displayed evidence of remodelling of the nasal aperture (Table 5.20; Fig. 5.14). Of the 55 males, 19 individuals were affected (34.5%), for females, 3 of the 10 were affected (30%), and for indeterminate individuals, 2 of 14 were affected (14.3%).

For males, remodelling of the nasal aperture was most prevalent in the 26-35 year age group, with 12 (57.1%) of males of that age displaying this lesion. There is a reduction in rates in the 36-45 and 46+ year age groups, with only 4 (33.3%) and 1 (6.7%) individuals of those ages affected respectively. There were two individuals in the 17-25 year age group affected by this lesion also (40% of males in that age group), so there is an increase in the prevalence of this lesion in the male 26-35 year age group. For females, the most affected age group was 17-25, with 100% of individuals affected, although this was the only female of that age at Chichester with the nasal aperture preserved to assess this lesion. The remaining two females were aged 26-35 years (33.3% of females in that age group). There was no pattern for the two indeterminate sex individuals; they were aged 17-25 and 26-35 respectively.

5.2.1.1.2 Winchester

At Winchester, 100 individuals had the nasal aperture preserved to be assessed, of which 17 individuals (17%) displayed remodelling of the nasal aperture. Of the 52 males, 11 were affected (21.2%), for females 5 of the 27 were affected (18.52%), and for indeterminate sex individuals, 1 of 21 were affected (4.8%). For males, remodelling of the nasal aperture was most prevalent in the 26-35 year age group, with seven individuals of that age (46.7%) displaying this lesion. The rates decline in the 36-45 and 46+ year age groups, with 2 and one individuals affected (16.7% and 11.1% of those age groups respectively). Of the 5 individuals aged 17-25 years with the nasal aperture preserved at Winchester, none displayed the lesion. For females, remodelling of the nasal aperture was equally

prevalent in the 12-14, 17-25, and 36-45 year olds, with 33.3% of each age group affected. Remodelling of the nasal aperture was already present in males and females by the age of 12-14 years.

Table 5.20: Summary of male and female individuals affected by remodelling of the nasal aperture in Chichester and Winchester, by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	Male		Female		Male		Female	
Age group	N	%	N	%	N	%	N	%
12-14	-	-	-	-	-	-	1	33.3
13-15	-	-	-	-	1	25	-	-
17-25	2	40	1	100	-	-	2	33.3
26-35	12	57.1	2	33.3	7	46.7	1	33.3
36-45	4	33.3	-	-	2	16.7	1	25
46+	1	6.7	-	-	1	11.1	-	-
Total	**19**		**3**		**11**		**5**	

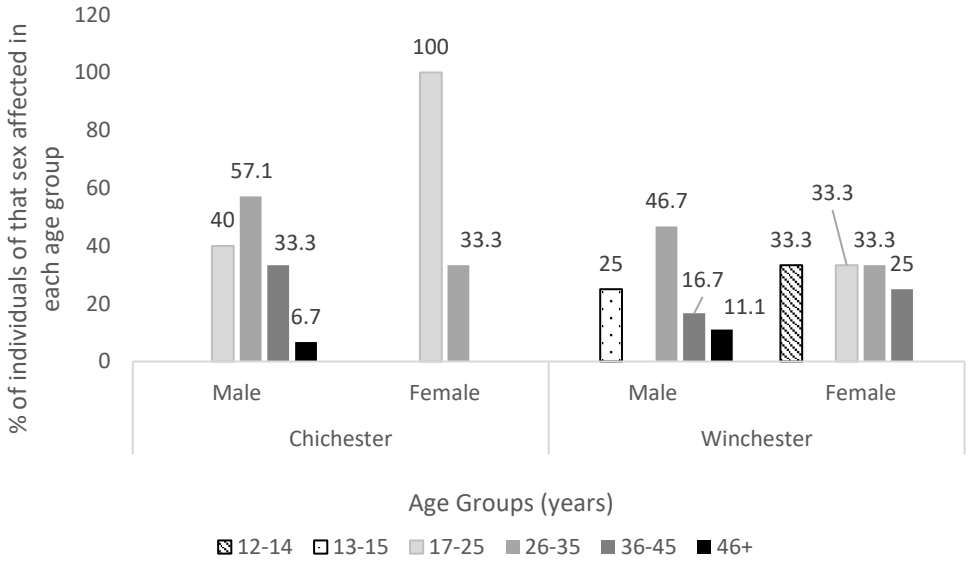


Fig. 5.14: Proportion (%) of male and female individuals within age groups affected by remodelling of nasal aperture at Chichester and Winchester.

5.2.1.1.3 Lepro-C and Remodelling of Nasal Aperture

Of the 41 individuals across the two assemblages displaying this lesion, 6 had lesions *consistent* (14.6%) with leprosy overall, 31 *highly consistent* (75.6%), and 4 *diagnostic* (9.8%). The most

frequently affected age group with nasal aperture remodelling in the upper Lepro-C groups was the 26-35 year age group, with 18 (34.6% of individuals of that age) and 3 (5.8%) individuals affected for *highly consistent*, and *diagnostic* respectively. Lepro-C and remodelling of the nasal aperture rates in relation to age are summarised in Table 5.21 and Fig. 5.15.

Table 5.21: Overall summary of Lepro-C categories of individuals affected by remodelling of the nasal aperture by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories					
	Consistent		*Highly Consistent*		*Diagnostic*	
Age (years)	N	%	N	%	N	%
12-14	-	-	1	14.3	-	-
13-15	-	-	1	25	-	-
17-25	2	9.5	4	19.0	-	-
26-35	3	5.8	18	34.6	3	5.8
36-45	1	2.9	5	14.3	1	2.9
46+	-	-	2	6.3	-	-
Total	**6**		**31**		**4**	

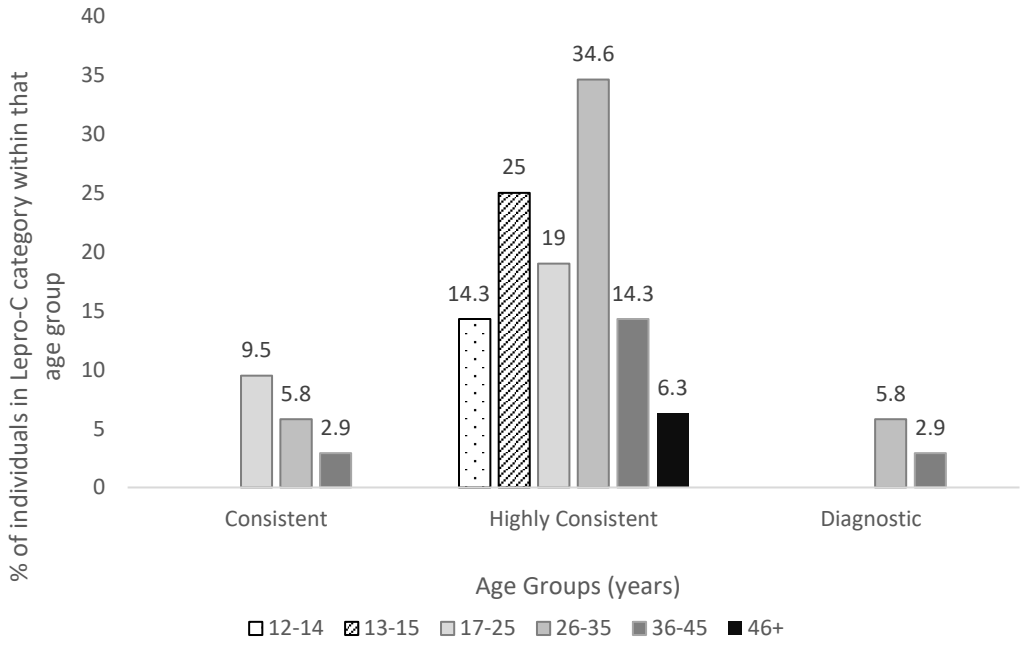


Fig. 5.15: Proportion (%) of individuals within age groups affected by remodelling of the nasal aperture in each Lepro-C category.

5.2.1.2 Absorption of Anterior Nasal Spine

5.2.1.2.1 Chichester

At Chichester, 76 individuals had this element preserved to be assessed, of which 28 individuals (36.8%) displayed absorption of the anterior nasal spine (Table 5.22; Fig. 5.16). Of the 52 males, 21 were affected (40.4%), for females, 4 of 10 affected (40%), and for indeterminate sex individuals, 3 of 34 were affected (8.8%).

For males, absorption of the anterior nasal spine was most prevalent in the 26-35 year age group, with 13 individuals affected (61.9% of male individuals of that age). There was a decline in rates of the lesion in the 36-45 years and 46+ year age categories, with 3 (27.3%) and 1 (4.5%) individuals affected. For adult males, where an age could not be determined, 1 individual was affected (50% of 'adult' male individuals). For females, the most affected age group was 17-25, with 100% of females of that age affected, although this was the only female of that age at Chichester with the nasal aperture preserved to assess this lesion. The remaining three females were aged 26-35 and 36-45 years (33.3% of females of those ages affected respectively). For those of indeterminate sex, 40% of individuals aged 26-35 years, and 33.3% of individuals aged 17-25 were affected respectively (no other indeterminate sex individuals were affected).

5.2.1.2.2 Winchester

At Winchester, 95 individuals had this element preserved to be assessed, of which 35 individuals (36.8%) displayed absorption of the anterior nasal spine. Of the 48 males, 21 were affected (43.8%), for females, 10 of 27 were affected (37%) and for indeterminate sex individuals, 4 of 20 were affected (20%).

For adult males, absorption of the anterior nasal spine was most prevalent in the 26-35 year age group, with nine individuals affected (64.3% of males in that age group). There was a decline in rates in the 36-45 and 46+ year age groups, with 6 (60%) and 3 (38%) male individuals affected in these age groups respectively. Two non-adult male individuals aged 13-15 and 14-16 also displayed this lesion, each representing 100% and 50% of individuals in those age groups, reflecting the low numbers of non-adult individuals of those ages. For females, prevalence was similar for the adult age groups affected; 4 individuals aged 17-25 years (66.6% of females in that age group), 6 aged 36-45 (66.6%) and 3 aged 46+ (75%) individuals affected. There was also a 12-14 year old female affected (33.3%). There was no pattern for indeterminate sex individuals.

Table 5.22: Summary of male and female individuals affected by absorption of the anterior nasal spine in Chichester and Winchester, by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	Male		Female		Male		Female	
Age (years)	N	%	N	%	N	%	N	%
12-14	-	-	-	-	-	-	1	33.3
13-15	-	-	-	-	1	100	-	-
14-16	-	-	-	-	1	50.0	-	-
17-25	3	33.3	1	100	1	20.0	4	66.6
26-35	13	61.9	2	33.3	9	64.3	2	66.6
36-45	3	27.3	1	33.3	6	60.0	3	75
46+	1	4.5	-	-	3	38.0	-	-
Adult	1	50	-	-	-	-	-	-
Total	**21**		**4**		**21**		**10**	

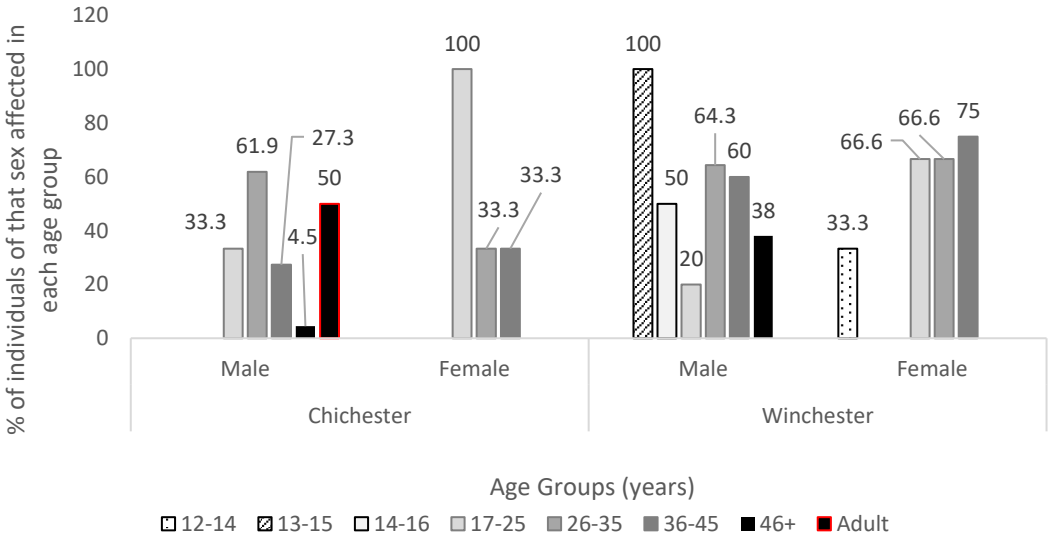


Fig. 5.16: Proportion (%) of male and female individuals within age groups affected by absorption the anterior nasal spine at Chichester and Winchester.

5.2.1.2.3 Lepro-C and Absorption of Anterior Nasal Spine

Of the 63 individuals across the two assemblages displaying this lesion, 1 was *not consistent* (1.6%), 17 were *consistent* (27%), 41 *highly consistent* (66.7%), and 3 diagnostic (4.8%). The most prevalent year age group for the *consistent*, *highly consistent*, and *diagnostic* categories was 26-35, with 6 (11.8% of individuals of that age), 20 (39.2%) and 3 (5.9%) individuals of that age in each category

respectively. Lepro-C and absorption of anterior nasal spine rates in relation to age are summarised in Table 5.23 and Fig. 5.17.

Table 5.23: Overall summary of Lepro-C categories of individuals affected by absorption of anterior nasal spine by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories							
	Not Consistent		*Consistent*		*Highly Consistent*		*Diagnostic*	
Age (years)	N	%	N	%	N	%	N	%
12-14	-	-	-	-	2	28.6	-	-
13-15	-	-	-	-	1	25.0	-	-
14-16	-	-	-	-	1	25.0	-	-
17-25	-	-	5	25	6	30.0	-	-
26-35	-	-	6	11.8	20	39.2	3	5.9
36-45	1	3.2	3	9.8	8	28.5	1	3.2
46+	-	-	3	10.0	2	6.7	-	-
Adult	-	-	-	-	1	33.3	-	-
Total	**1**		**17**		**41**		**4**	

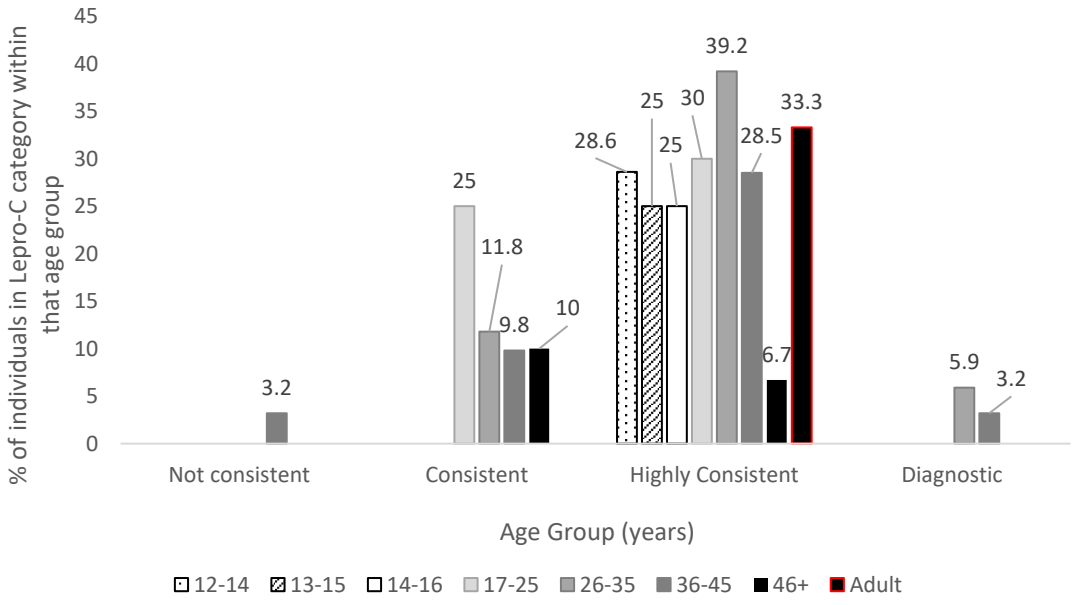


Fig. 5.17: Proportion (%) of individuals within age groups affected by absorption of anterior nasal spine in each Lepro-C category.

5.2.1.3 Absorption of Anterior Maxillary Alveolus

5.2.1.3.1 Chichester

At Chichester, 79 individuals had this element preserved to be assessed, of which 14 individuals (17.7%) displayed absorption of the anterior maxillary alveolus (Table 5.24; Fig. 5.18). Of the 55

males, 10 were affected (18.2%), for females 3 of 10 were affected (30%) and for indeterminate sex individuals, 1 of 14 were affected (7.1%). For males, this lesion was most common in individuals aged 36-45 years, with 4 individuals affected (30.8% of males of that age), the next most common age was 17-25 (25% of males of that age affected). The 3 females were aged 17-25, 26-35 and 36-45 years, with 100% of females aged 17-25 years affected (although this was the only female of that age). The indeterminate sex individual was aged 17-25 years.

5.2.1.3.2 Winchester

At Winchester, 101 individuals had this element preserved to be assessed, of which 15 individuals (14.8%) displayed absorption of the anterior maxillary alveolus. Of the 53 males, 9 were male (17.0%) and for females, 6 of 27 were affected (22.2%) None of the 21 indeterminate individuals with this element preserved were affected. For males, alveolar absorption was most prevalent in the 26-35 year age group, with 4 individuals affected (28.6% of male individuals of that age). Rates then declined in the 36-45 and 46+ year age groups, with 2 (16.7%) and 1 (9.1%) male individuals o those ages affected respectively. There was also a non-adult male individual aged 13-15 displaying this lesion also, 100% of males of this age, reflecting the low numbers of males of this age. For adult females, this lesion was most prevalent in the 17–25-year age groups with 2 individuals affected (33.3% of females of that age). A female was also aged 12-14 years (100% of females of that age at Winchester).

Table 5.24: Summary of male and female individuals affected by absorption of the maxillary alveolus in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	Male		Female		Male		Female	
Age (years)	N	%	N	%	N	%	N	%
12-14	-	-	-	-	-	-	1	33.3
13-15	-	-	-	-	1	100	-	-
14-16	-	-	-	-	-	-	1	100
17-25	1	25.0	1	100	1	25.0	2	33.3
26-35	4	19.0	1	16.7	4	28.6	1	33.3
36-45	4	30.8	1	33.3	2	16.7	1	25.0
46+	1	6.7	-	-	1	9.1	-	-
Total	**10**		**3**		**9**		**6**	

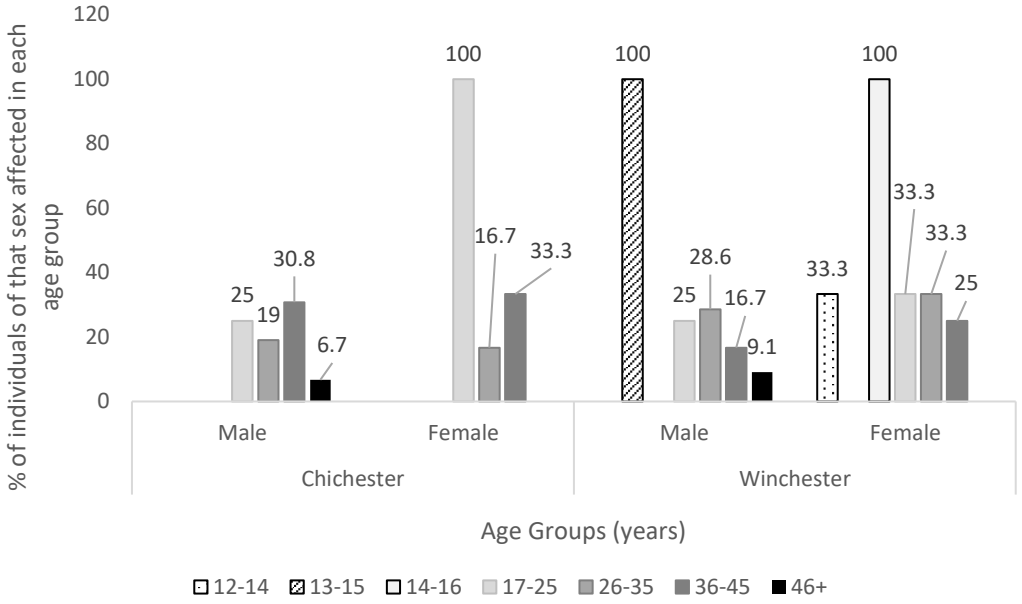


Fig. 5.18: Proportion (%) of male and female individuals within age groups affected by absorption of the maxillary alveolus at Chichester and Winchester.

5.2.1.3.3 Lepro-C and Absorption of Anterior Maxillary Alveolus

Of the 29 individuals across the two assemblages displaying this lesion, 1 was *not consistent* (3.4%), 4 were *consistent* (13.7%), 20 *highly consistent* (69%), and 4 *diagnostic* (13.8%). The most commonly affected adult age group for *highly consistent* was 17-25, (25% of individuals of that age being *highly consistent* and displaying the lesion), and *diagnostic* was 26-35 years, with 5.7% individuals of that age being *diagnostic* and displaying the lesion. The most common age group to be classed *consistent* displaying this lesion was the 36-45 years cohort, with 5.6% of individuals affected). Lepro-C and pitting of nasal palatine process rates in relation to age are summarised in Table 5.25 and Fig. 5.19.

Table 5.25: Overall summary of Lepro-C categories of individuals affected by absorption of the maxillary alveolus by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories							
	Not Consistent		*Consistent*		*Highly Consistent*		*Diagnostic*	
Age (years)	N	%	N	%	N	%	N	%
12-14	-	-	-	-	1	14.3	-	-
13-15	-	-	-	-	1	25	-	-
14-16	-	-	-	-	1	33.3	-	-
17-25	-	-	1	4.0	5	25	-	-
26-35	-	-	1	2.0	6	11.8	3	5.9
36-45	-	-	2	5.6	5	13.9	1	2.8
46+	1	2.9	-	-	1	2.9	-	-
Total	1		4		20		4	

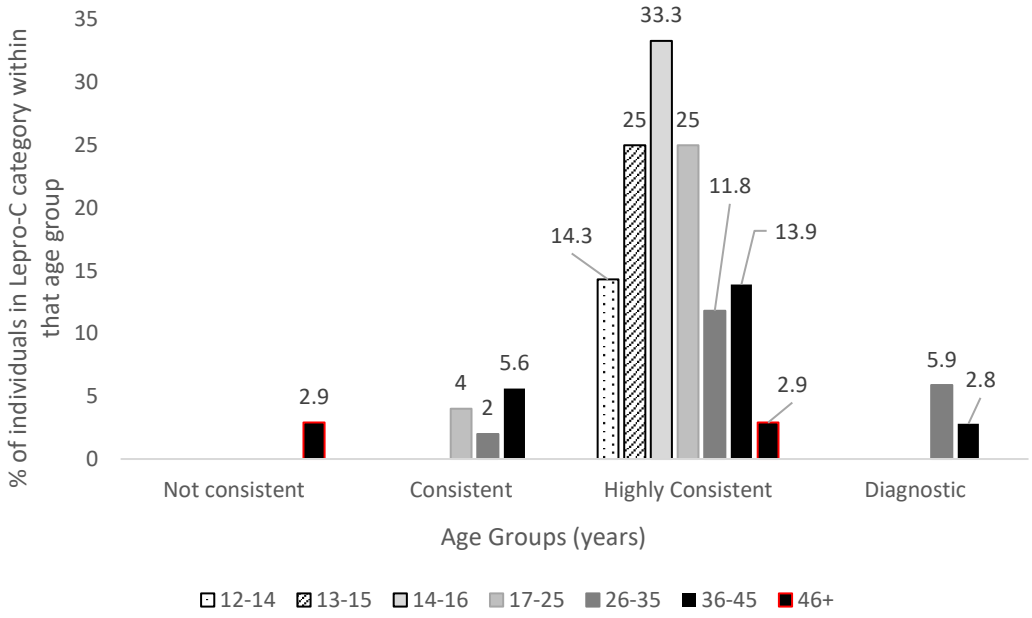


Fig. 5.19: Proportion (%) of individuals within age groups affected by absorption of the maxillary alveolus in each Lepro-C category.

5.2.1.4 Pitting of Oral Palatine Process

5.2.1.4.1 Chichester

At Chichester, 78 individuals had this element preserved to be assessed, of which 21 individuals (26.9%) displayed pitting on the oral surface of the palatine process (Table 5.26; Fig. 5.20). Of the 55 males, 15 were affected (27.3%), for females, 4 of 10 were affected (40%) and 2 of 13 indeterminate sex individuals affected (15.4%). For males, oral pitting was most prevalent in the 26-35 and 36-45 year age groups with 38.1% and 38.4% of males of those ages affected respectively,

there was an outlying 'adult' individual, who was only individual in this category with the element preserved, and happened to display the lesion. For females, this lesion was equally prevalent in the 26-35 and 36-45 year age group with 33.3% of females of those ages affected respectively. There was an outlying individual aged 17-25, the only female individual of this age with the element preserved to be assessed, so 100% were affected. The two individuals of indeterminate sex were aged 17-25 and 26-35 years.

5.2.1.4.2 Winchester

At Winchester, 100 individuals had this element preserved to be assessed, of which 33 individuals (33%) displayed pitting on the oral surface of the palatine process. Of the 51 males, 15 were affected (29.4%), 14 of 27 females were affected (51.9%), and 4 of 22 indeterminate sex individuals affected (18.2%). For adult males, oral pitting was most prevalent in the 26-35 year age group, with 7 individuals affected (50% of males of that age). Rates then declined slightly in 36-45 year age group, with 4 individuals affected (36.4% of individuals of that age). Two non-adult males aged 13-15 (100%) and 14-16 (50%) respectively also displayed this lesion, but low numbers skew the percentages. For adult females, oral pitting was most prevalent in the 26-35 year age group, with 3 individuals affected (100% of females of that age), with rates declining in the 36-45 and 46+ year age groups, with 3 (25%) and 1 (40%) individuals affected respectively. Rates were also high for females aged 17-25 with the skeletal element preserved, with 5 individuals (83.3% of females in that age group). Two female non-adults aged 12-14 (66.7%) and one aged 14-16 (100) also displayed this lesion. The low numbers of females skew the percentages. There was no pattern in the indeterminate sex individuals.

Table 5.26: Summary of male and female individuals affected by pitting on the oral surface of the palatine process in Chichester and Winchester by age groups. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	Male		Female		Male		Female	
Age (years)	N	%	N	%	N	%	N	%
12-14	-	-	-	-	-	-	2	66.7
13-15	-	-	-	-	1	100	-	-
14-16	-	-	-	-	1	50.0	1	100
17-25	-	-	1	100	2	40.0	5	83.3
26-35	8	38.1	2	33.3	7	50.0	3	100
36-45	5	38.4	1	33.3	4	36.4	1	25.0
46+	1	6.7	-	-	-	-	2	40.0
Adult	1	100	-	-	-	-	-	-
Total	**15**		**4**		**15**		**14**	

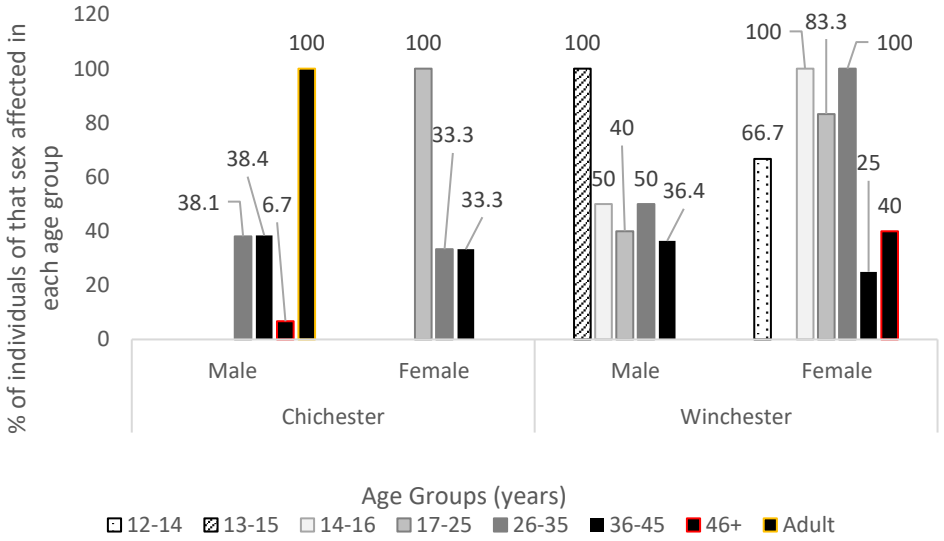


Fig. 5.20: Proportion (%) of male and female individuals within age groups affected by oral pitting of palatine process at Chichester and Winchester.

5.2.1.4.3 Lepro-C and Pitting of Oral Palatine Process

Of the 54 individuals across the two assemblages displaying this lesion, 2 were *not consistent* (3.7%), 13 *consistent* (24.1%), 35 *highly consistent* (64.8%), and 4 diagnostic (7.4%). The most prevalent age group for *consistent* and *highly consistent* individuals displaying this lesion was 17-25 years, with 19% and 33.3% of individuals of that age being *consistent* and *highly consistent* and also displaying the lesion respectively. The most prevalent age group for *diagnostic* was 26-35 years with 5.9% of individuals that age being *diagnostic* and also displaying the lesion. Lepro-C and pitting of oral palatine process rates in relation to age are summarised in Table 5.27 and Fig. 5.21.

Table 5.27: Overall summary of Lepro-C categories of individuals affected by pitting of oral palatine process by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories							
	Not Consistent		*Consistent*		*Highly Consistent*		*Diagnostic*	
Age (years)	N	%	N	%	N	%	N	%
12-14	-	-	-	-	3	42.8	-	-
13-15	-	-	-	-	1	25	-	-
14-16	-	-	-	-	2	50	-	-
17-25	-	-	4	19	7	33.3	-	-
26-35	1	2.0	3	5.9	14	27.4	3	5.9
36-45	-	-	5	14.7	6	17.7	1	2.9
46+	1	3.0	1	3.0	1	3.0	-	-
Adult	-	-	-	-	1	50.0	-	-
Total	**2**		**13**		**35**		**4**	

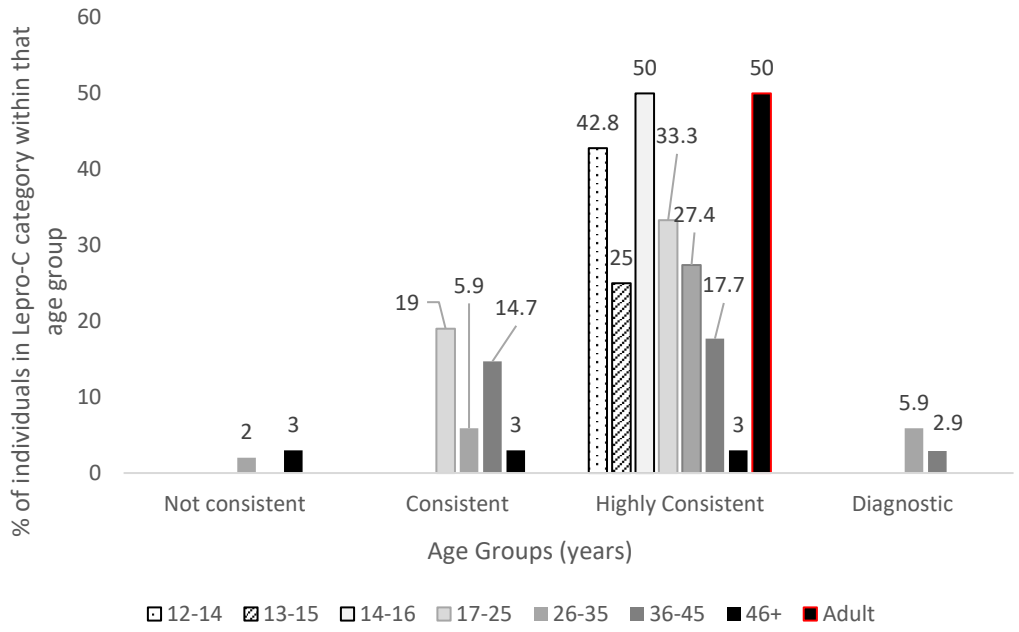


Fig. 5.21: Proportion (%) of individuals within age groups affected by pitting of oral palatine process in each Lepro-C category.

5.2.1.5 Pitting of Nasal Palatine Surface

5.2.1.5.1 Chichester

At Chichester, 78 individuals had this element preserved to be assessed, of which 16 displayed (20.5%) pitting on the nasal surface of the palatine process (Table 5.28; Fig. 5.22). Of the 55 males, 10 were affected (18.2%), 4 of 10 female were affected (40%), and 2 of 13 indeterminate sex individuals were affected (15.4%). For males, nasal pitting was most prevalent in the 36-45 year age group, with 4 individuals affected in each group (30.8% of males that age). Of the 4 females displaying nasal pitting, 3 were aged 26-35 years (50% of females that age), and the other aged 17-25 years, the only female of that age with the skeletal element preserved to be assessed.

5.2.1.5.2 Winchester

At Winchester, 100 individuals had this element preserved to be assessed, of which 15 displayed pitting on the nasal surface of the palatine process. Of these, 6 of 51 males were affected (11.8%), 6 of 27 females (22.2%) and 3 of 22 indeterminate sex individuals (13.6%). For males, nasal pitting was most prevalent in the 26-35 year age group, with 3 individuals affected (21.4% of indiivduals of that age). This was an increase on the rates for the 36-45 year age group, where two individuals were affected (18.2% of males with age with the nasal surface of the maxilla preserved). The other

male individual was a non-adult aged 14-16 (50% of males that age). For adult females, this lesion was equally prevalent in 17-25 and 36-45 year olds, with 33.3% of those age groups affected respectively. For non-adult females, this lesion was most prevalent in the 14-16 year age group (100%) although there was only a single individual of that age, reflecting the small numbers (33.3%).

Table 5.28: Summary of male and female individuals affected by pitting on the nasal surface of the palatine process in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	Male		Female		Male		Female	
Age (years)	N	%	N	%	N	%	N	%
12-14	-	-	-	-	-	-	2	66.7
14-16	-	-	-	-	1	50	1	100
17-25	-	-	1	100	-	-	2	33.3
26-35	4	19	3	50	3	21.4	1	33.3
36-45	4	30.8	-	-	2	18.2	-	
46+	1	6.7	-	-	-	-	-	-
Adult	1	100	-	-	-	-	-	-
Total	**10**		**4**		**6**		**6**	

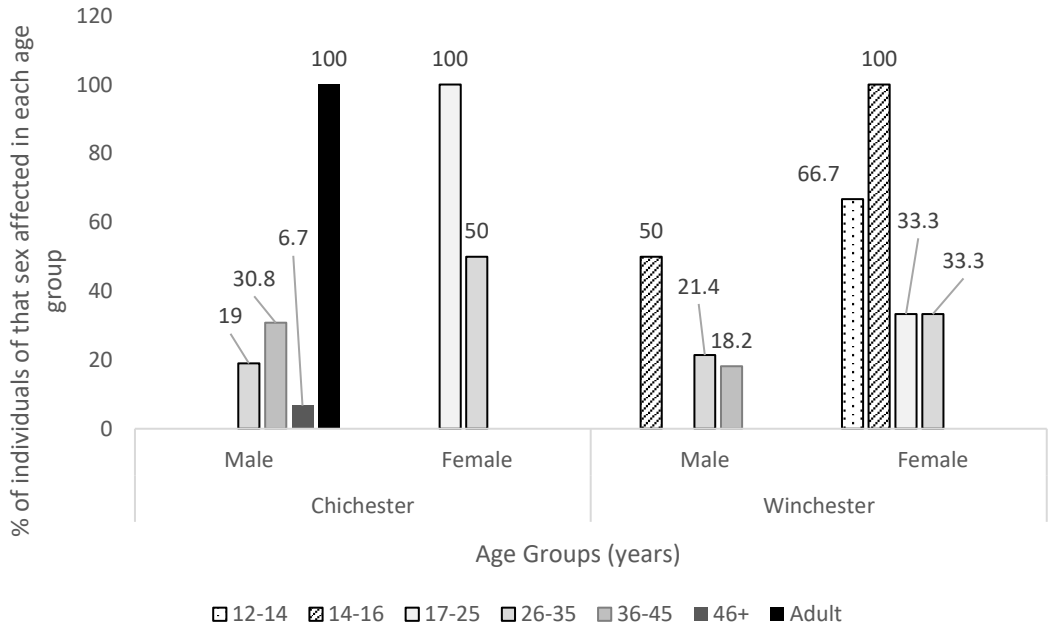


Fig. 5.22: Proportion (%) of male and female individuals within age groups affected by nasal pitting of palatine process at Chichester and Winchester.

5.2.1.5.3 Lepro-C and Pitting of Nasal Palatine Process

Of the 31 individuals across the two assemblages displaying this lesion, 4 were *consistent* (12.9%), 23 *highly consistent* (74.2%), and 4 *diagnostic* (12.9%). The most prevalent adult age group for *highly consistent*, where an age could be determines, was 17-25, with 19% of individuals of that age being *consistent* and displaying the lesion, with 12-14 being the most prevalent non-adult group, with 50% of individuals of that age being classed as *highly consistent* and displaying the lesion. The most prevalent age group for *diagnostic* was 26-35 years, with 34.9% of individuals of that age displaying the lesion being classed as *diagnostic*. Lepro-C and pitting of nasal palatine process rates in relation to age are summarised in Table 5.29 and Fig. 5.23.

Table 5.29: Overall summary of Lepro-C categories of individuals affected by pitting of nasal palatine process by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories					
	Consistent		*Highly Consistent*		*Diagnostic*	
Age (years)	N	%	N	%	N	%
12-14	-	-	2	28.5	-	-
14-16	-	-	2	50	-	-
17-25	1	4.8	4	19.0	-	-
26-35	2	3.9	8	15.7	3	5.9
36-45	1	2.9	5	14.7	1	2.9
46+	-	-	1	3.0	-	-
Adult	-	-	1	33.3	-	-
Total	**4**		**23**		**4**	

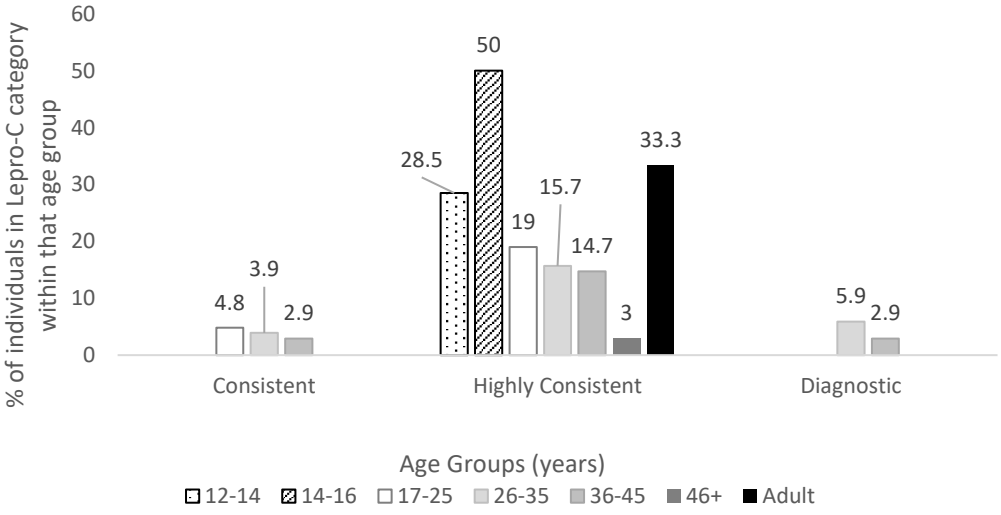


Fig. 5.23: Proportion (%) of individuals within age groups affected by pitting of nasal palatine process in each Lepro-C category.

5.2.2 Rhinomaxillary Syndrome Statistics

5.2.2.1 Phi Coefficient

The five rhinomaxillary syndrome (RMS) lesions were tested against specific age groups using Phi coefficient. All adult individuals with a preserved maxilla, and where an age could be determined, were included in each test to assess whether there is a link between the occurrence (or non-occurrence) of lesions and individuals in certain age groups (Table 5.30).

Table 5.30: Detail of Phi coefficient values for adults where an age could be determined, testing the relationship of the presence and absence of RMS lesions and age groups.

	RMS Lesion									
Age (years)	Nasal aperture	Sig.	Nasal spine	Sig.	Anterior alveolus	Sig.	Oral palatine surface	Sig.	Nasal palatine surface	Sig.
17-25	.007	.937	.094	.283	.121	.152	.166	.051	.055	.518
26-35	.316*	<.001	.211	.015	.025	.767	.122	.151	.135	.113
36-45	-.101	.234	-.022	.799	.057	.501	.018	.835	.027	.748
46+	-.262*	.002	-.298*	<.001	-.183	.030	-.292*	<.001	-.224*	.008

* = significant at 0.01

Significant relationships at the 0.01 level were found between the 26-35 year age group for remodelling of the nasal aperture and absorption of the anterior nasal spine, with coefficient values of 0.316 (p = <.001) and 0.211 (p = .015) respectively. Inflammatory pitting of the nasal (phi = 0.135, p = .113) and oral (phi = 0.122, p = .151) palatine processes, was also positively related with the 26-35 year age group, but not as strongly. This age group contains the strongest positive relationships for RMS lesions. By contrast, the 36-45 year age groups showed a very weak relationship with RMS lesions, and the 46+ year age group was strongly negatively related with all five RMS lesions, with values ranging from -0.298 to -0.183, all significant at the 0.01 alpha value.

5.2.2.2 Binomial Logistic Regression

Binomial logistic regression was used as it allows to test the affect that multiple independent variables had on the presence/absence of lesions. The analysis included adult individuals where a year age group could be determined. Individuals aged 46+ were automatically excluded from the analysis when running the regression model on SPSS due to redundancy (i.e. the presence/absence values could be predicted from the other three adult age categories). Therefore, the regression models test the effect that individuals age (17-25, 26-35, and 36-45 year age groups) had on the presence and absence of lesions. These were also the adult age groups most affected by lesions overall, so it is interesting to see their effect on the regression models. The effects of sex and site were also tested. As recommended for regression analysis (Emerson, 2020), Bonferroni correction

was applied to the p value to reduce the risk of Type 1 errors (false positives) as multiple variables are being tested all at once to see if they had an effect on the lesion being present or not. This means dividing the alpha (p = .05) by the number of variables. So for these tests there were 6 variables; 1 dependent - the lesion in question; and three independent variables - age (subdivided 17-25, 26-35 and 36-45 years), site and sex. This means the alpha variable for significance for the independent variables in these binomial logistic regression models for these tests is p = .008. This was also the alpha value adopted for the overall model.

For independent variables, individuals aged 26-35 were found to have a significant effect on the model for the absorption of the nasal aperture (Wald = 10.417, *p* = .001), absorption of the anterior nasal spine (Wald = 12.184, *p* = <.001), and oral pitting of the maxilla (Wald = 9.476, *p* = .002), i.e. this age group had a strong influence on the presence of the lesions. The chi square for the overall model for absorption of the nasal aperture (X^2 = 19.060, d.f. 5, *p* = .002), absorption of the anterior nasal spine (X^2 = 17.546, d.f. 5, *p* = .004), and oral pitting of the maxilla (X^2 = 20.017, d.f. 5, *p* = .001) was significant also. The models for absorption of the anterior maxillary alveolus and nasal pitting of the maxilla suggest that the age of individuals had no influence on the presence of the lesions. The regressions indicate that site and biological sex did not have a strong influence on the presence of lesions, i.e. individuals at Chichester and Winchester, or males and females were no more likely than the other to display rhinomaxillary lesions.

Table 5.31: Results of binomial logistic regression for rhinomaxillary syndrome lesions.

	Independent variables					
Lesion		**Age**				
Nasal Aperture	**17-25**	**26-35**	**36-45**	**Site**	**Sex**	**P value of overall model**
Wald/Chi	4.226	10.417	2.773	1.157	.379	19.060
Sig (p)	.040	.001*	.096	.282	.538	.002*
Odds ratio	6.705	13.035	4.150	.624	1.387	
Anterior Nasal Spine	**17-25**	**26-35**	**36-45**	**Site**	**Sex**	
Wald/Chi	6.662	12.184	5.958	1.921	.081	17.546
Sig (p)	.010	<.001*	.015	.166	.776	.004*
Odds ratio	6.982	9.105	5.086	1.789	1.145	
Anterior Maxillary Alveolus	**17-25**	**26-35**	**36-45**	**Site**	**Sex**	
Wald/Chi	3.990	3.049	3.482	.039	.157	6.519
Sig (p)	.046	.081	.062	.843	.692	.259
Odds ratio	6.319	4.173	4.768	.911	.809	
Oral Pitting	**17-25**	**26-35**	**36-45**	**Site**	**Sex**	
Wald/Chi	5.838	9.476	5.062	2.005	3.722	20.017
Sig (p)	.016	.002*	.024	.157	.054	.001*
Odds ratio	7.121	8.801	5.224	1.834	.398	
Nasal Pitting	**17-25**	**26-35**	**36-45**	**Site**	**Sex**	
Wald/Chi	2.201	4.087	2.842	.926	1.430	9.660
Sig (p)	.138	.043	.092	.336	.232	.085
Odds ratio	6.114	8.874	6.584	.604	.513	

*significant at .008

5.2.3 Other Cranial Lesions

5.2.3.1 Severe Maxillary Sinusitis

5.2.3.1.1 Chichester

At Chichester 86 individuals had this skeletal element preserved to be assessed, of these 3 individuals (3.5%) presented with severe maxillary sinusitis (Table 5.32; Fig. 5.24). Of these, 1 of 62 males was affected (1.6%), and 2 of 12 indeterminate sex individuals were affected (16.7%). None of the 12 females were affected. The male individual was aged 26-35 years old (4.5% of males of that age). The indeterminate sex individuals were aged 9-10 years (the only indeterminate sex individual of that age) and 26-35 years old (40% of indeterminate sex individuals of that age). Two individuals displayed no rhinomaxillary syndrome lesions in addition, but individual C88 was *diagnostic* of leprosy.

5.2.3.1.2 Winchester

At Winchester, 108 individuals had this skeletal element preserved to be assessed, of which 3 individuals (2.8%) also presented with severe maxillary sinusitis. All three affected individuals were male, of 55 total males (5.5%), with two aged 26-35 years (14.3% of males that age) and one aged 14-16 (50 of males that age%). All three individuals displayed at least two rhinomaxillary syndrome lesions in addition.

Table 5.32: Summary of male and female individuals affected by severe maxillary sinusitis in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	Male		Female		Male		Female	
Age (years)	N	%	N	%	N	%	N	%
14-16	-	-	-	-	1	50	-	-
26-35	1	4.5	-	-	2	14.3	-	-
Total	**1**		**0**		**3**		**0**	

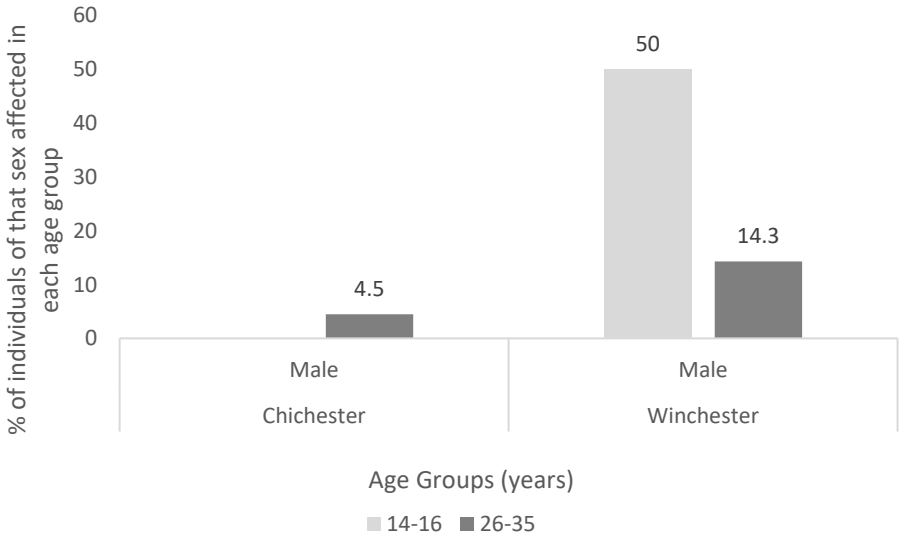


Fig. 5.24 Proportion (%) of male individuals within age groups affected by severe maxillary sinusitis at Chichester and Winchester.

5.2.3.1.3 Lepro-C and Severe Maxillary Sinusitis

Of the 6 individuals across the two assemblages displaying this lesion, 1 was *not consistent* (16.7%), 1 *consistent* (16.7%), and 3 *highly consistent* (66.7%) and 1 diagnostic (16.7%). The most prevalent

adult age group for *highly consistent* and diagnostic was 26-35 years, with 2 (3.1%), and 1 (1.9%) of individuals of this age affected in each category respectively. The most prevalent age group for *consistent* individuals was 9-10, with 1 individual in this age group affected (33.3%). Lepro-C and severe maxillary sinusitis in relation to age are summarised in Table 5.33 and Fig. 5.25.

Table 5.33: Overall summary of Lepro-C categories of individuals affected by severe maxillary sinusitis by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories							
	Not Consistent		*Consistent*		*Highly Consistent*		*Diagnostic*	
Age (years)	N	%	N	%	N	%	N	%
9-10	-	-	1	33.3	-	-	-	-
14-16	-	-	-	-	1	20	-	-
26-35	1	1.9	-	-	2	3.8	1	1.9
Total	**1**		**1**		**3**		**1**	

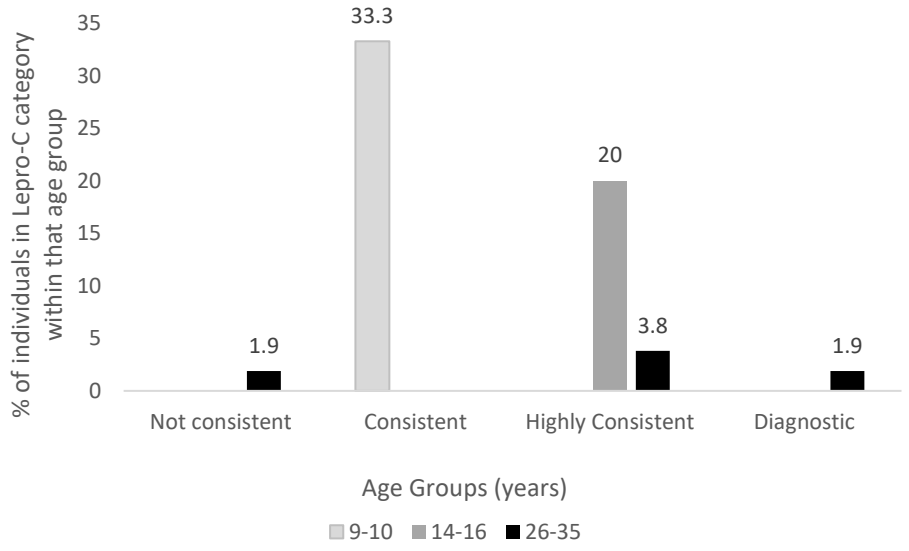


Fig. 5.25: Proportion (%) of individuals within age groups affected by severe maxillary sinusitis in each Lepro-C category.

5.2.3.2 Leprogenic Odontodysplasia

5.2.3.2.1 Chichester

At Chichester, 3 individuals (3.4%) presented with dental root malformation, of 87 with the maxillary incisors and canines preserved to be assessed (Table 5.34; Fig. 5.26). All 3 were male, of 59 males in

total (5.1%) with 2 aged 26-35 years old (8.3% of males of that age). The other was aged 36-45 years. The teeth affected were the right maxillary canine for skeleton C32 and C31, and maxillary central incisors for skeleton C367, respectively (Fig. 5.27).

5.2.3.2.2 Winchester

At Winchester, 105 individuals had the maxillary incisors and canines preserved to be assessed, of these, one male individual (0.9%) (SK8, 12-14 years), of 55 males in total (1.8% of males overall, 50% of males of that age) presented with root malformation that was consistent with leprogenic odontodysplasia, with both central incisors and the left maxillary incisor displaying constricted roots. One female individual aged 12-14 years (SK28) also displayed a shortened root of the right maxillary central incisor (33.3% of females of that age).

Table 5.34: Summary of individuals affected by possible leprogenic odontodysplasia in Chichester and Winchester by age and sex. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester		Winchester			
Age	Male		Male		Female	
(years)	N	%	N	%	N	%
12-14	-	-	1	50	1	33.3
26-35	2	8.3	-	-	-	-
36-45	1	6.7	-	-	-	-
Total	**3**		**1**		**1**	

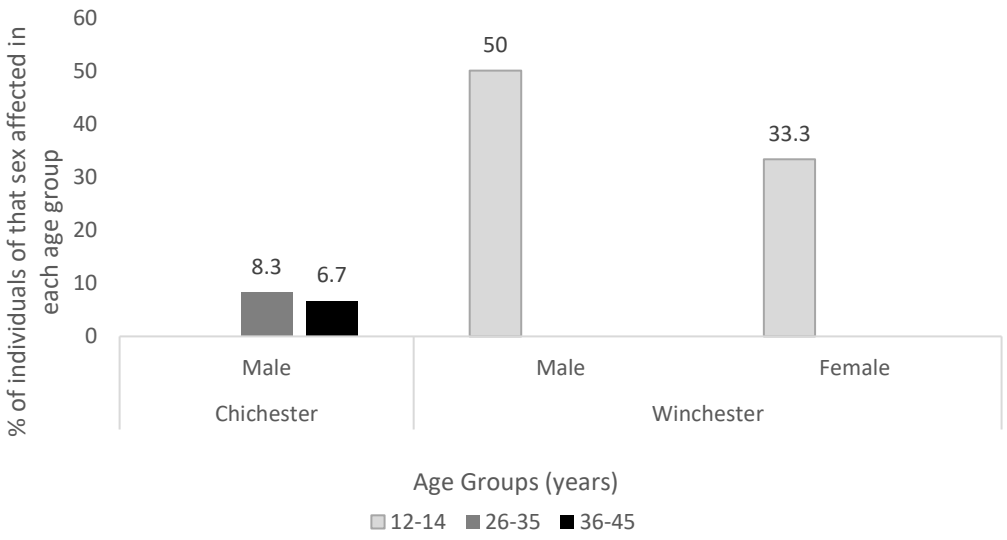


Fig. 5.26: Proportion (%) of male individuals within age groups affected by leprogenic odontodysplasia at Chichester and Winchester.

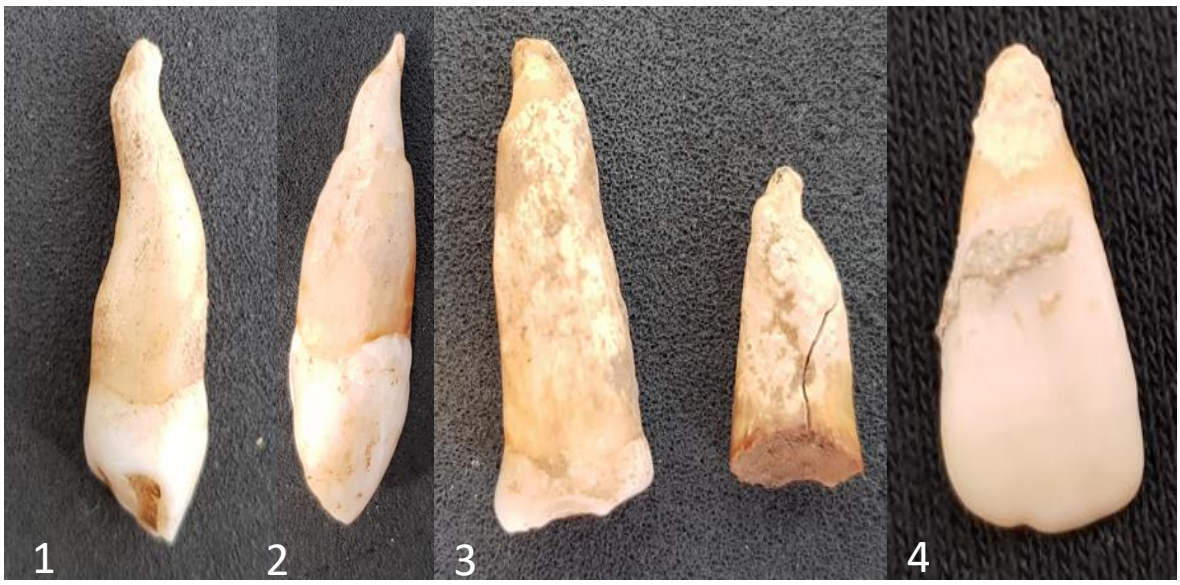


Fig. 5.27: Root malformation of maxillary incisors (1. C32, 2. C341, 3. C367, 4. SK28). Access to collection to take these images kindly granted by the BARC.

5.2.3.2.3 Lepro-C and Leprogenic Odontodysplasia

Of the 5 individuals across the two assemblages displaying this lesion, 2 were *not consistent* (40%), 2 *consistent* (40%), and 1 *highly consistent* (20%). The most prevalent age group for *consistent* was 26-35 years, with both *consistent* individuals affected being of this age (3.8% of that age group overall). The most prevalent age for *not consistent* and *highly consistent* categories was 12-14, with an individual of that age in each category (14.3% of individuals of that age in each case). Lepro-C and leprogenic odontodysplasia in relation to age are summarised in Table 5.35 and Fig. 5.28.

Table 5.35: Overall summary of Lepro-C categories of individuals affected by leprogenic odontodysplasia by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories					
	Not Consistent		*Consistent*		*Highly Consistent*	
Age (years)	N	%	N	%	N	%
12-14	1	14.3	-	-	1	14.3
26-35	-	-	2	3.8	-	-
36-45	1	2.5	-	-	-	-
Total	**2**		**2**		**1**	

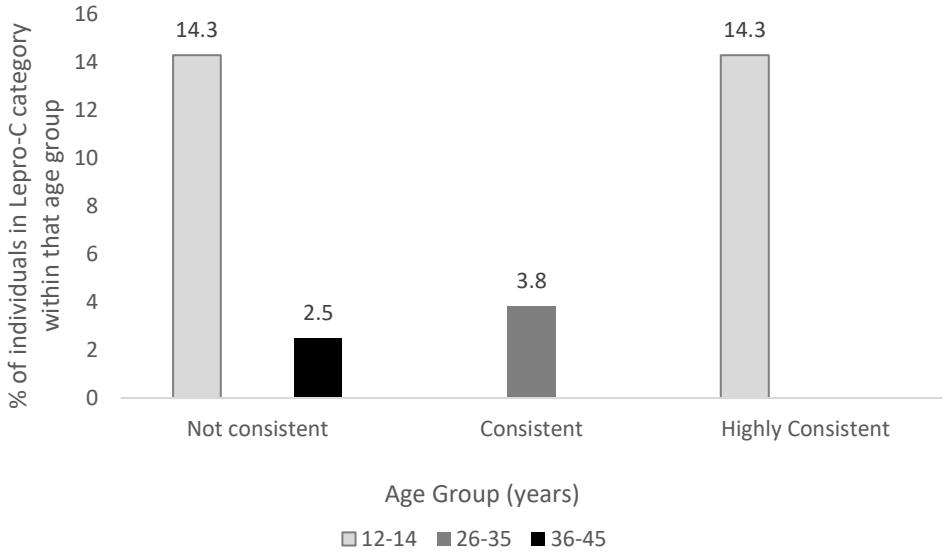


Fig. 5.28: Proportion (%) of individuals within age groups affected by leprogenic odontodysplasia in each Lepro-C category.

5.2.4 Upper Extremity Lesions

5.2.4.1 Palmar Grooving

5.2.4.1.1 Chichester

At Chichester, 107 individuals had the proximal hand phalanges preserved, of which 4 individuals (3.7%) displayed palmar grooving. Of these, 3 of 78 males were affected (3.8%) and 1 of 14 females (7.1%)(Table 5.36; Fig. 5.29). For males, palmar grooving was most prevalent in the 26-35 year age group, with two individuals affected (8% of males that age). The other individual was aged 46+ years (4.2% of males that age). The female displaying this lesion was also aged 26-35 years (16.7% of females that age).

5.2.4.1.2 Winchester

At Winchester, 111 individuals had the proximal hand phalanges preserved, of which 5 male individuals (4.5% overall, 8.4% of males) displayed palmar grooving. It was most prevalent in the 36-45 year and 'adult' age groups, with 2 individuals affected in each group (18.2% and 66.6% of males in those age categories respectively), with the other individual aged 17-25 years (16.7%). The high percentage of 'adults' affected reflects the small numbers of individuals in that category.

Table 5.36: Summary of male and female individuals affected by palmar grooving in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester	
	Male		Female		Male	
Age (years)	N	%	N	%	N	%
17-25	-	-	-	-	1	16.7
26-35	2	8.0	1	16.7	-	-
36-45	-	-	-	-	2	18.2
46+	1	4.2	-	-	-	-
Adult	-	-	-	-	2	66.6
Total	**3**		**1**		**5**	

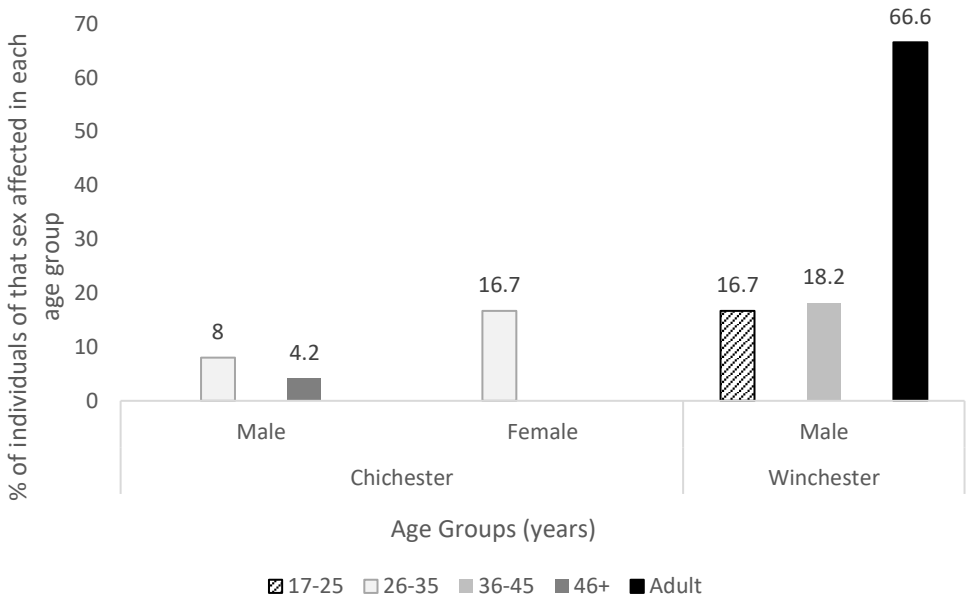


Fig. 5.29: Proportion (%) of male individuals within age groups affected by palmar grooving at Chichester and Winchester.

5.2.4.1.3 Lepro-C and Palmar Grooving

Of the 9 individuals across the two assemblages displaying this lesion, 5 were *consistent* (55.5%), 3 *highly consistent* (33.3%) and 1 *diagnostic* (11.1%). The most common age group for *consistent* was 'adult' with 2 individuals affected (12.5% of individuals in that category). Those aged 36-45 years were most represented in the *highly consistent* category (4.8%). The diagnostic individual was aged 26-35 (1.8% of individuals of that age). Lepro-C and palmar grooving in relation to age are summarised in Table 5.37 and Fig. 5.30.

Table 5.37: Overall summary of Lepro-C categories of individuals affected by palmar grooving by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories					
	Consistent		*Highly Consistent*		*Diagnostic*	
Age (years)	N	%	N	%	N	%
17-25	1	4.3	-	-	-	-
26-35	1	1.8	1	1.8	1	1.8
36-45	-	-	2	4.8	-	-
46+	1	2.2	-	-	-	-
Adult	2	12.5	-	-	-	-
Total	**5**		**3**		**1**	

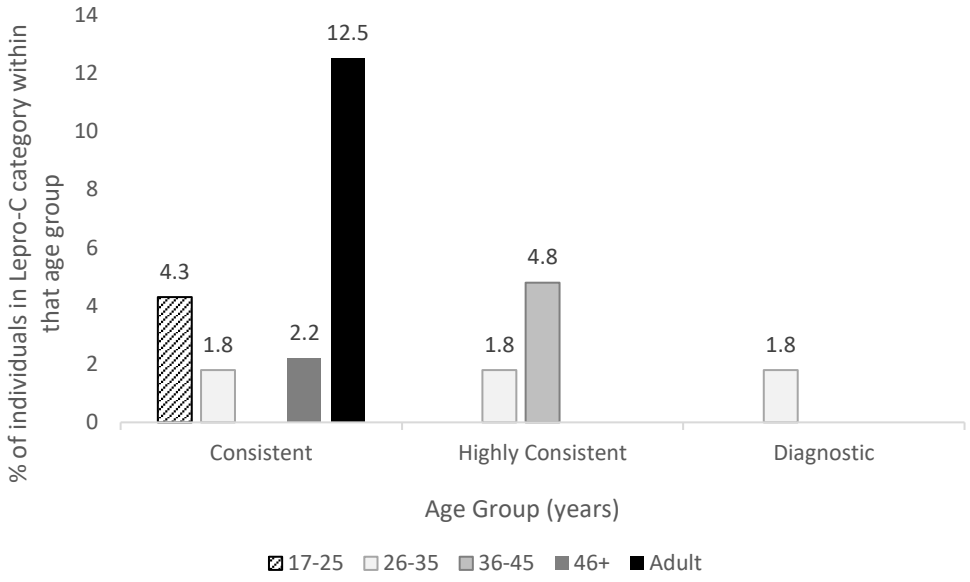


Fig. 5.30: Proportion (%) of individuals within age groups affected by palmar grooving in each Lepro-C category.

5.2.4.2 Absorption of Hand Phalanges and Metacarpals

5.2.4.2.1 Chichester

At Chichester, 109 individuals had the hand phalanges and metacarpals preserved to be assessed, of which 7 (6.4%) displayed absorption of hand phalanges (Table 5.38; Fig. 5.31). Of these 6 of 79 males were affected (7.6%), and 1 of 15 females (6.7%). For males, this lesion was most prevalent in 26-35 year age group (12% of males that age). Rates then declined in the 36-45 (9.1%) and 46+ year age groups (4.5%). Only 2 males presented with bilateral lesions (both aged 26-35 years), with all other individuals presenting with unilateral lesions. The female individual was aged 26-35 years and affected bilaterally (16.7% of females that age).

5.2.4.2.2 Winchester

At Winchester, 113 individuals had the hand phalanges and metacarpals preserved to be assessed, of which 4 individuals (3.5%) displayed absorption of hand phalanges. Of these, 3 of 59 males were affected (5.1%), and 1 of 26 females (3.9%). The most affected age group for male individuals, was 17-25 (16.7% of males that age) and was affected unilaterally. The female individual was aged 36-45 years and affected bilaterally. There was only a single individual in each of these age categories affected for males and females, however. The numbers are too low to draw a solid conclusion at Winchester and Chichester.

Table 5.38: Summary of male and female individuals affected by absorption of hand phalanges/metacarpals in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	Male		Female		Male		Female	
Age (years)	N	%	N	%	N	%	N	%
17-25	-	-	-	-	1	16.7	-	-
26-35	3	12.0	1	16.7	1	6.7	-	-
36-45	2	9.1	-	-	1	9.1	1	25
46+	1	4.5	-	-	-	-	-	-
Total	**6**		**1**		**3**		**1**	

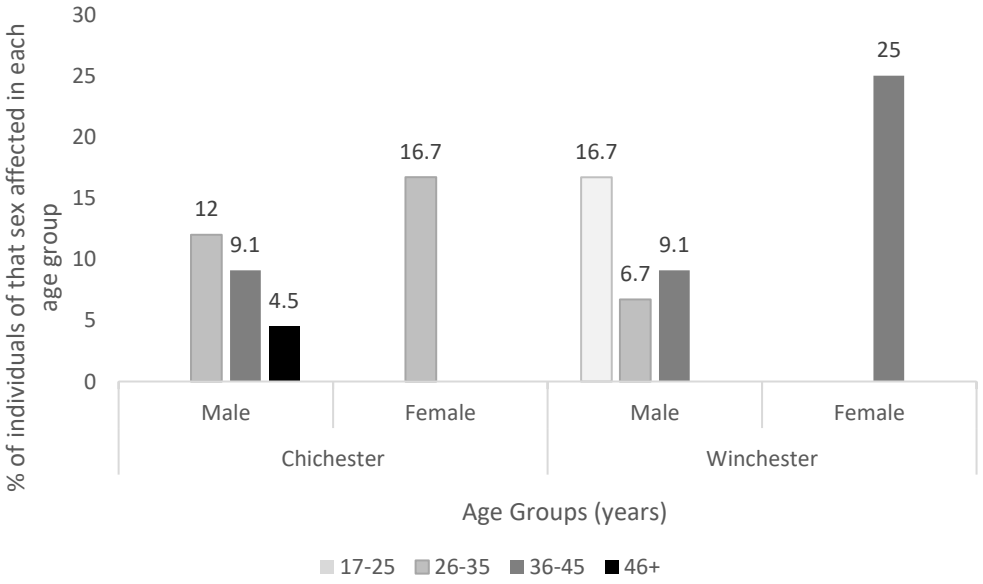


Fig. 5.31: Proportion (%) of male individuals within age groups affected by absorption of hand phalanges/metacarpals at Chichester and Winchester.

5.2.4.2.3 Lepro-C and Absorption of Hand Phalanges and Metacarpals

Of the 11 individuals across the two assemblages displaying this lesion, 5 were *consistent* (45.5%), 5 *highly consistent* (45.5%) and 1 *diagnostic* (9.1%). The most prevalent age group became younger as evidence for leprosy increased, with 36-45 years the most prevalent age group for *consistent* (4.5% of individuals that age), and 26-35 years the most prevalent group for *highly consistent* (5.6% of individuals that age) and *diagnostic* (1.6% of 26-35 year olds, and the only *diagnostic* individual in the dataset displaying this lesion). Lepro-C and absorption of hand phalanges and metacarpals in relation to age is summarised in Table 5.39 and Fig. 5.32, but the numbers are too low to draw a solid conclusion.

Table 5.39: Overall summary of Lepro-C categories of individuals affected by absorption of hand phalanges and metacarpals by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories					
	Consistent		*Highly Consistent*		*Diagnostic*	
Age (years)	N	%	N	%	N	%
17-25	1	4.2	-	-	-	-
26-35	1	1.6	3	5.6	1	1.6
36-45	2	4.5	2	4.5	-	-
46+	1	2.3	-	-	-	-
Total	**5**		**5**		**1**	

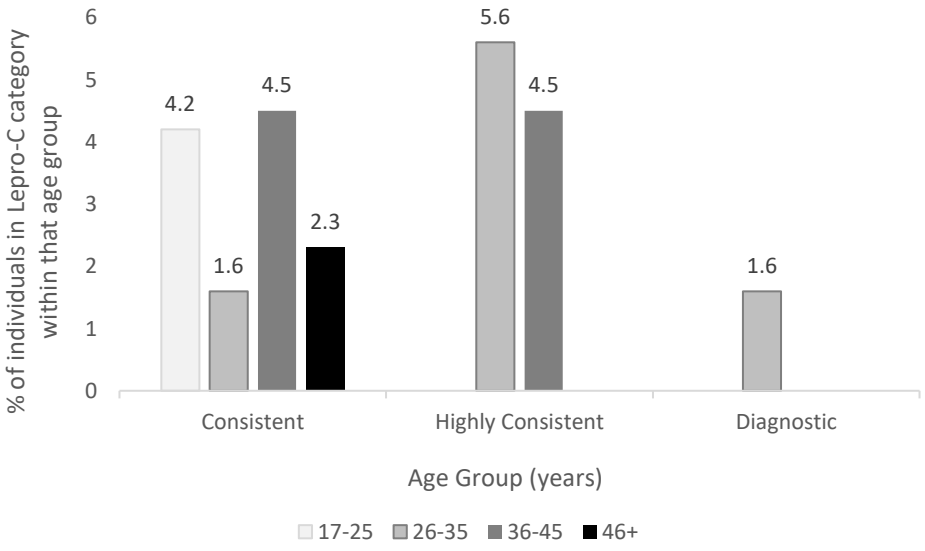


Fig. 5.32: Proportion (%) of individuals within age groups affected by absorption of hand phalanges and metacarpals in each Lepro-C category.

5.2.4.3 Concentric Remodelling of Metacarpals and Hand Phalanges

5.2.4.3.1 Chichester

No individuals in Chichester displayed concentric remodelling of metacarpals or phalanges.

5.2.4.3.2 Winchester

Four individuals at Winchester displayed concentric remodelling in the long bones of the hands, of 114 with the metacarpals preserved (3.5%). Of these, 2 of 59 males (3.4%), and 1 of 27 females (3.7%) and 1 of 23 indeterminate sex individuals (4.3%). The 2 male individuals were aged 36-45 and 46+ years (8.3% and 7.7% of male individuals of those ages respectively). The 46+ year old individual was affected unilaterally. There was no pattern in the female or indeterminate sex individuals as there was only a single individual in each category.

5.2.4.3.3 Lepro-C and Concentric Remodelling of Metacarpals

Of the 4 individuals across the two assemblages displaying this lesion, 2 were *consistent* (50%) and 2 *highly consistent* (50%). Only older age groups were affected, with 36-45 and 46+ years being the only age groups affected where an age could be determined. Lepro-C and absorption of hand phalanges and metacarpals in relation to age is summarised in Table 5.40 and Fig. 5.33 below.

Table 5.40: Overall summary of Lepro-C categories of individuals affected by concentric remodelling of metacarpals by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories			
	Consistent		*Highly Consistent*	
Age (years)	N	%	N	%
36-45	1	2.2	1	2.2
46+	-	-	1	2.2
Adult	1	5	-	-
Total	**2**		**2**	

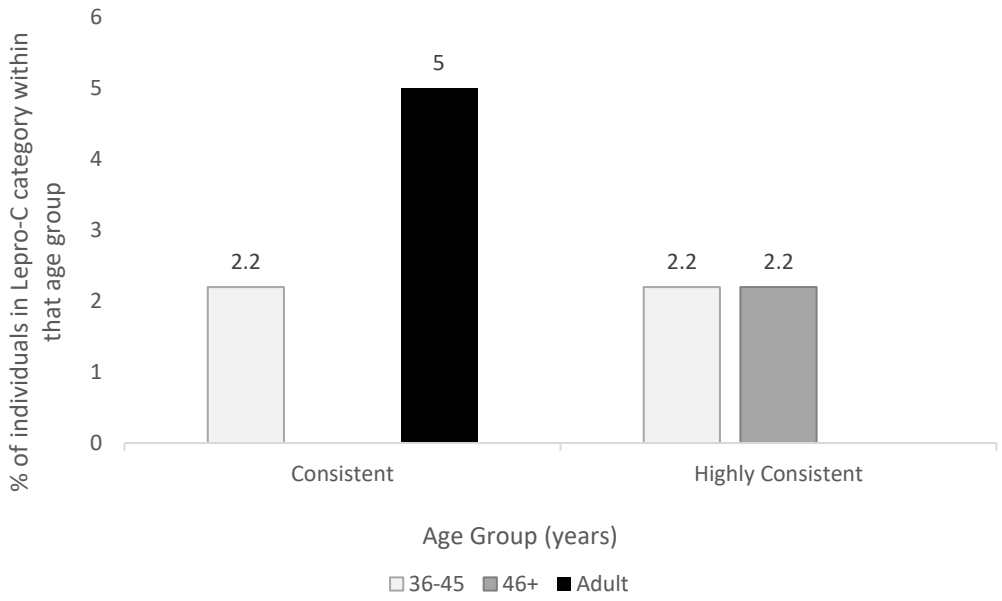


Fig. 5.33: Proportion (%) of individuals within age groups affected by concentric remodelling of in each Lepro-C category.

5.2.4.4 Knife-Edge Remodelling of Metacarpals

No individuals at Chichester or Winchester displayed knife-edge remodelling of metacarpals.

5.2.4.5 Distal Humerus

5.2.4.5.1 Chichester

At Chichester, 109 individuals had the medial epicondyles of the humerii preserved to be assessed, of which lesions to the medial epicondyle of the humerus were present in two individuals (1.8%); one male, aged 46+ (4% of males that age, and 1.3% of males overall) and one of indeterminate sex, also aged 46+ (the only indeterminate sex individual of that age, and 5.6% of indeterminate sex individuals overall)(Table 5.41; Fig. 5.34). Both individuals were affected bilaterally.

5.2.4.5.2 Winchester

At Winchester, lesions to the medial epicondyle of the humerus were also present in 2 individuals, of 110 with the medial epicondyle of the humerii preserved (1.8%); 1 male, of 58 total (1.7%) and 1 of indeterminate sex, of 26 total (3.8%). The male was aged 46+ years (7.8% of males that age) and the indeterminate sex individual was 'adult' (20% of indeterminate sex individuals in that category). The lesion presented unilaterally in both cases, on the right side for the 46+ years individual, and left side for the 'adult' individual.

Table 5.41: Summary of male and indeterminate sex individuals affected by lesions to the distal humerus in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	Male		Indeterminate		Male		Indeterminate	
Age (years)	N	%	N	%	N	%	N	%
46+	1	4.0	1	100	1	7.8	-	-
Adult	-	-	-	-	-	-	1	20
Total	**1**		**1**		**1**		**1**	

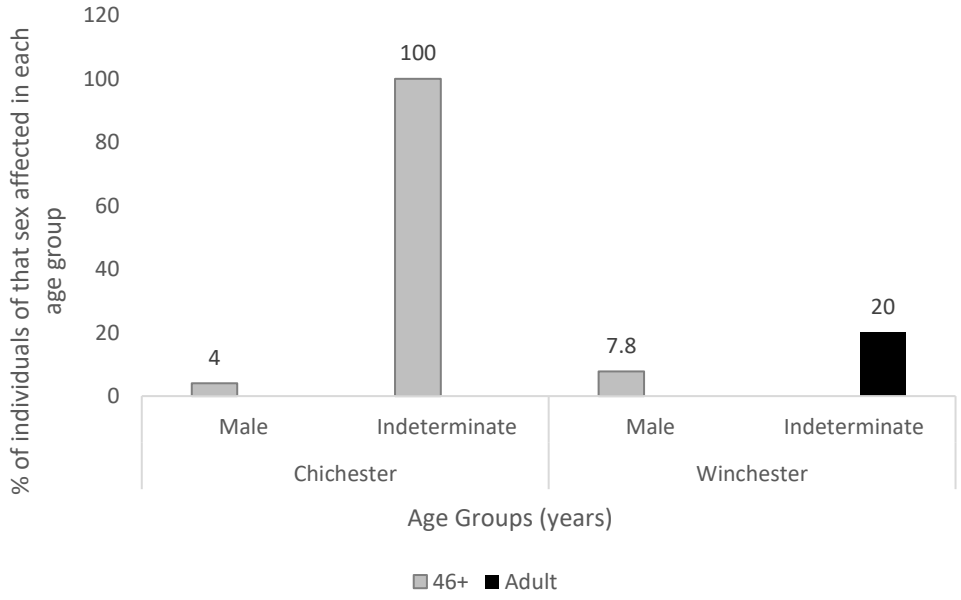


Fig. 5.34: Proportion (%) of individuals within age groups affected by lesions to the distal humerus at Chichester and Winchester.

5.2.4.5.3 Lepro-C and Distal Humerus

Of the 4 individuals across the two assemblages displaying this lesion, 1 was *not consistent* (25%) and 3 were *consistent* (75%). Only older age groups were affected (where an age could be determined), with the 1 *not consistent* individual aged 46+ years (2.2% of individuals in that age group and Lepro-C category affected by the lesion) and 2 *consistent* individuals aged 46+ years also (4.4% of individuals in that age group and Lepro-C category affected by the lesion). Lepro-C and lesions to the posteromedial epicondyle of humerus in relation to age is summarised in Table 5.42 and Fig. 5.35.

Table 5.42: Overall summary of Lepro-C categories of individuals affected by lesions to the distal humerus by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories			
	Not Consistent		*Consistent*	
Age (years)	N	%	N	%
46+	1	2.2	2	4.4
Adult	-	-	1	5.6
Total	**1**		**3**	

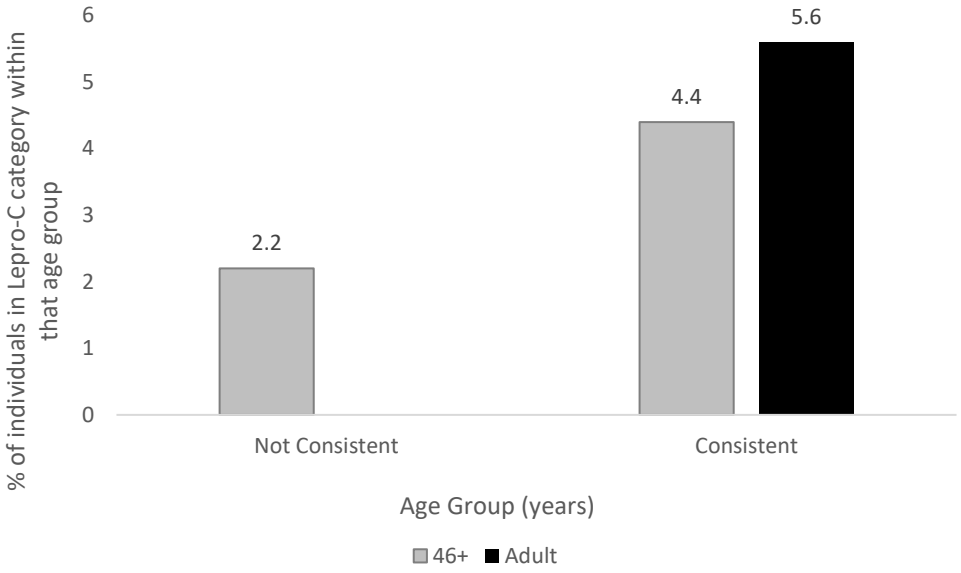


Fig. 5.35: Proportion (%) of individuals within age groups affected by lesions to the distal humerus in each Lepro-C category.

5.2.4.6 Proximal Ulna

5.2.4.6.1 Chichester

At Chichester, lesions to the proximal ulna were present in 6 individuals, of 107 where the lesion could be assessed (5.6%); 5 of 79 males were affected (6.3%) and 1 of 16 indeterminate sex individuals (6.3%)(Table 5.43; Fig. 5.36). For males, the most prevalent age group was 26-35 years (12% of males this age affected). There was a reduction in rates in the 36-45 and 46+ year age groups, with 1 individual affected in each (4.8% and 4.2% of males that age, respectively). The indeterminate sex individual was aged 46+ years (the only indeterminate sex individual of that age). This lesion presented unilaterally in 4 individuals (66.7%).

5.2.4.6.2 Winchester

At Winchester, 9 individuals presented with lesions to the proximal ulna, of 111 where the lesion could be assessed (8.1%). Of these, 7 of 58 males (12.1%), 1 of 26 females female (3.8%), and 1 of 27 indeterminate sex individuals (3.7%) were affected. For males, the most affected age group were the 26-35 year olds, with 5 individuals affected (33.3% of males that age), with the other two males aged 36-35 years (18.2% of males that age). Of the 26-35 year old individuals, 3 were affected bilaterally (75%). Both of the 36-45 year olds were affected unilaterally. The female was aged 36-45 years (25% of females that age), and affected unilaterally. The indeterminate sex individual was 'adult' and was affected unilaterally.

Table 5.43: Summary of male and female individuals affected by lesions to the proximal ulna in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	Male		Female		Male		Female	
Age (years)	N	%	N	%	N	%	N	%
26-35	3	12.0	-	-	5	33.3	-	-
36-45	1	4.8	-	-	2	18.2	1	25
46+	1	4.2	-	-	-	-	-	-
Total	**5**		**0**		**7**		**1**	

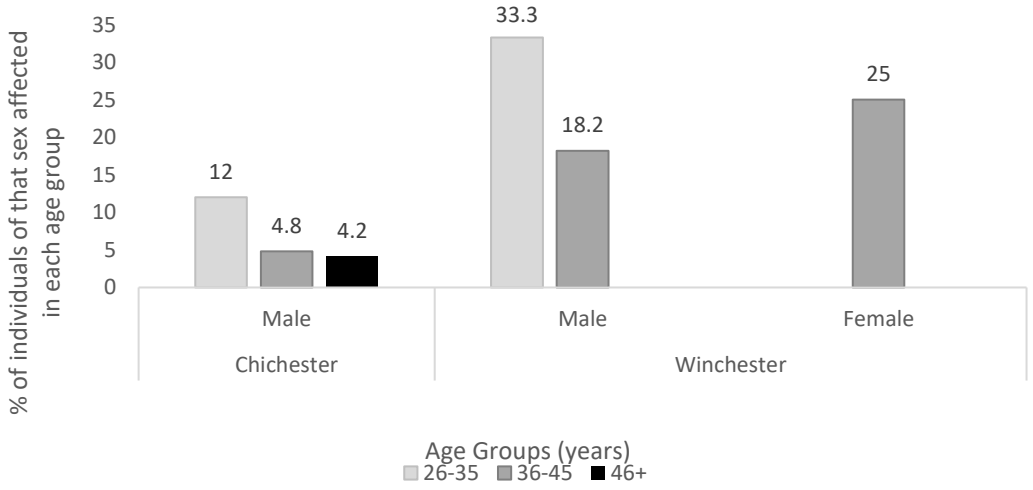


Fig. 5.36: Proportion (%) of individuals within age groups affected by lesions to the proximal ulna at Chichester and Winchester.

5.2.4.6.3 Lepro-C and Proximal Ulna

Of the 15 individuals across the two assemblages displaying this lesion, 1 was *not consistent* (6.7%), 5 *consistent* (33.3%), 5 *highly consistent* (33.3%) and 4 *diagnostic* (26.7%). For age, the 26-35 year age groups became more dominant as evidence for leprosy increased, with 3 *highly consistent* (5.4% of individuals of that age with the lesion in that Lepro-C category) and 3 *diagnostic* individuals (5.4% of individuals of that age with the lesion in that Lepro-C category) displaying this lesion respectively. Lepro-C and lesions to the proximal ulna in relation to age is summarised in Table 5.44 and Fig. 5.37.

Table 5.44: Overall summary of Lepro-C categories of individuals affected by lesions to the proximal ulna by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories							
	Not Consistent		*Consistent*		*Highly Consistent*		*Diagnostic*	
Age (years)	N	%	N	%	N	%	N	%
26-35	-	-	2	3.6	3	5.4	3	5.4
36-45	-	-	1	2.3	2	4.7	1	2.3
46+	1	2.3	1	2.3	-	-	-	-
Adult	-	-	1	6.3	-	-	-	-
Total	**1**		**5**		**5**		**4**	

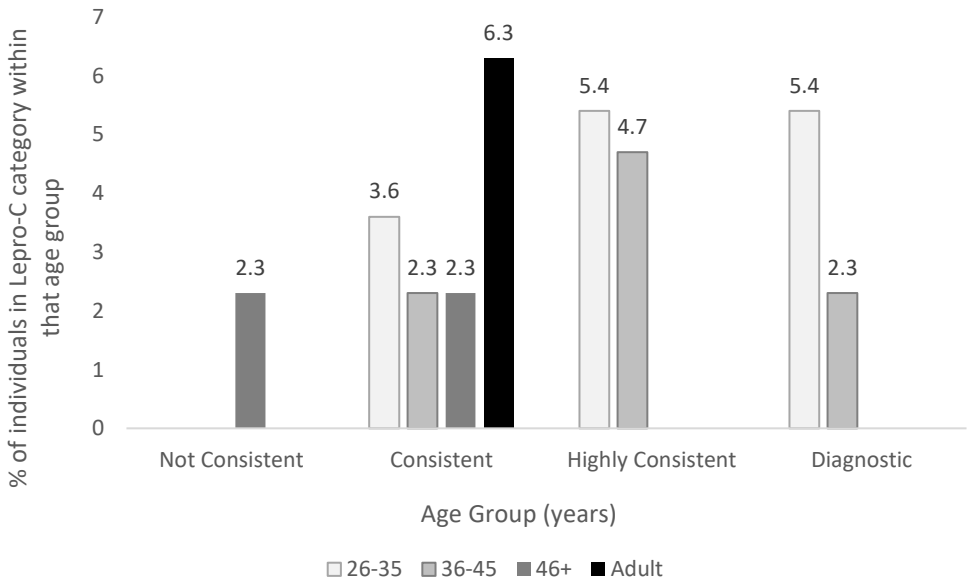


Fig. 5.37: Proportion (%) of individuals within age groups affected by lesions to the proximal ulna in each Lepro-C category.

5.2.5 Upper Extremity Lesion Statistics

5.2.5.1 Upper Extremity Lesions and Age

5.2.5.1.1 Phi Coefficient

The upper extremity lesions above were tested against adult age groups using Phi coefficient, with the test showing a positive relationship of lesions to the proximal ulna with the 26-35 year age group, with a phi value of 0.128 (p = .100). The strongest relationship however was lesions to the medial epicondyle and the 46+ year age group, with a phi value of .216 (p = .005), which was significant at the 0.01 level. The phi relationships are summarised in Table 5.45 below.

Table 5.45: Summary of Phi coefficient between upper postcranial lesions and adult age groups.

		Lesion					
Age (years)		Palmar grooves	Acroosteolysis	Phalanges	Remodelling of MCs	Humerus	Ulna
17-25	Phi	-.002	.041	-.041	-.054	-.053	-.118
	Sig	.979	.634	.603	.488	.496	.132
26-35	Phi	.043	.082	.074	-.093	-.098	.128
	Sig	.579	.336	.339	.232	.209	.100
36-45	Phi	-.021	-.075	.012	.127	-.076	.040
	Sig	.786	.379	.877	.103	.334	.609
46+	Phi	-.066	-.034	-.057	-.016	.216*	-.081
	Sig	.398	.690	.468	.841	.005	.298

* - significant to 0.01 level

5.2.5.1.2 Binomial Logistic Regression

Binomial logistic regression was used as it allows to test the affect that multiple independent variables had on the presence/absence of lesions (see Section 4.2.6). The regression models for upper postcranial lesions showed that age, site and sex did not have a strong influence on the occurrence of lesions (Table 5.46).

Table 5.46: Binomial logistic regressions for upper postcranial lesions

	Independent variables					
Lesion	**Age**					
Absorption Hand Phalanges	**17-25**	**26-36**	**36-45**	**Site**	**Sex**	**P value of overall model**
Wald/Chi	.321	1.749	1.627	.067	.011	2.943
Sig (p)	.571	.186	.202	.795	.917	.709
Odds ratio	2.294	4.399	4.301	.841	1.091	
Proximal Ulna	**17-25**	**26-36**	**36-45**	**Site**	**Sex**	
Wald/Chi	.000	3.423	2.043	4.381	1.170	13.563
Sig (p)	.998	.064	.153	.036	.279	.019
Odds ratio	.000	7.724	5.213	3.985	3.282	

5.2.5.2 Upper Postcranial Lesions and Lepro-C

The upper extremity lesions above were tested against Lepro-C categories using Phi coefficient, with all coefficients summarised in Table 5.47. Significant negative relationships were found between acroosteolysis and absorption of hand phalanges/metacarpals to the *not consistent* category, with values of -0.430 and -0.178 respectively. Acroosteolysis was also significantly positively related to the *highly consistent* Lepro-C category, with a phi value of 0.207, significant at the .01 level. The strongest positive relationship is between lesions to the proximal ulna and the *diagnostic* Lepro-C category, with a value of 0.522 which was significant at the 0.01 level. Palmar grooves, acroosteolysis and absorption of hand phalanges/metacarpals were also positively related to the *diagnostic* category, with values of 0.143, 0.221 and 0.153 respectively, with acroosteolysis significant at the .01 level.

Table 5.47: Summary of Phi coefficient values between the presence and absence of upper postcranial lesions and how they relate to Lepro-C categories of individuals.

		Lesion					
Lepro-C category		palmar grooves	acroosteolysis	phalanges	metacarpals	humerus	Ulna
Not consistent	Phi	-0.160	-0.430*	-0.178*	-0.105	-0.041	-0.168
	Sig	.018	.000	.008	.118	.546	.013
Consistent	Phi	0.147	0.199*	0.014	0.02	0.095	-0.028
	Sig	.030	.006	.831	.764	.159	.679
Highly consistent	Phi	0.041	0.207*	0.155	0.105	-0.65	0.061
	Sig	.548	.004	.021	.117	.335	.369
Diagnostic	Phi	0.143	0.221*	0.153	-0.13	-0.16	0.522*
	Sig	.034	.002	.023	.849	.813	<.001

* = significant at 0.01

5.2.6 Lower Extremity Lesions

5.2.6.1 Periosteal New Bone Formation on Distal Tibia

5.2.6.1.1 Chichester

At Chichester, periosteal new bone formation (PNBF) on the distal tibia was present in 54 individuals, of 107 where it could be assessed (50.4%) (Table 5.48; Fig. 5.38). Of these, 42 of 75 males (56%), 5 of 13 females (38.4%), and 7 of 19 indeterminate sex individuals (36.8%) were affected. For males where an age could be determined, PNBF on the distal tibia was most prevalent in the 36-45 year age group, with 14 individuals affected (66.7% of males that age), although rates in the 26-35 year age group were similar, with 13 individuals affected (61.9%). Rates were reduced in the 46+ years age group, with 9 individuals affected (39.1%). The lesion presented bilaterally in 28 male individuals, most of which were aged 26-35 years (35.7%). For females where an age could be determined, the most commonly affected age group was 26-35 years, with three individuals falling into this age category (60% of females that age). All females were affected bilaterally.

5.2.6.1.2 Winchester

At Winchester, PNBF on the distal tibia was present in 52 individuals, of 113 where this could be assessed (46%). Of these, 33 of 61 males (54.1%), 14 of 26 females (53.8%), and 5 of 26 indeterminate sex individuals (19.2%) were affected. For males where an age could be determined, PNBF on the distal tibia was most prevalent in the 26-35 year age group, with 14 individuals affected (93.3% of males that age). There was a reduction in rates in the 36-45 and 46+ year age groups, with 6 (50%) and 2 (15.4%) individuals affected respectively. However, 6 individuals were also aged 17-25 years (85.7% of males that age). Two non-adult male individuals displayed this lesion, aged 13-15, and 14-16 respectively (100% and 33.3% of males that age, reflecting the small numbers of non-adults in these age categories). Twenty-eight male individuals were affected bilaterally (84.8%). For adult females, PNBF on the distal tibia was most prevalent in the 17-25 year age group, with 6 individuals affected (100% of females that age). There was a reduction in rates in the 36-35 and 36-45 year age groups, with 3 (75%) and 2 (66.7%) individuals affected respectively. Three non-adult females aged 0-12 months, 12-14 and 14-16 also displayed this, although the percentages of the age group affected for non-adults reflects the low numbers. Eleven females were affected bilaterally (78.5%). There was no pattern for the indeterminate sex individuals.

Table 5.48: Summary of male and female individuals affected by periosteal new bone formation of the distal tibia in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	M		F		M		F	
Age group	N	%	N	%	N	%	N	%
0-12 months	-	-	-	-	-	-	1	100
6-10	1	100	-	-	-	-	-	-
12-14	-	-	-	-	-	-	1	33.3
13-15	-	-	-	-	1	100	-	-
14-16	-	-	-	-	1	50	1	100
17-25	3	60	-	-	6	85.7	6	100
26-35	13	61.9	3	60	14	93.3	3	75.0
36-45	14	66.7	1	25	6	50.0	2	66.7
46+	9	39.1	-	-	2	15.4	-	-
Adult	2	50.0	1	50	3	100	-	-
Total	**42**		**5**		**33**		**14**	

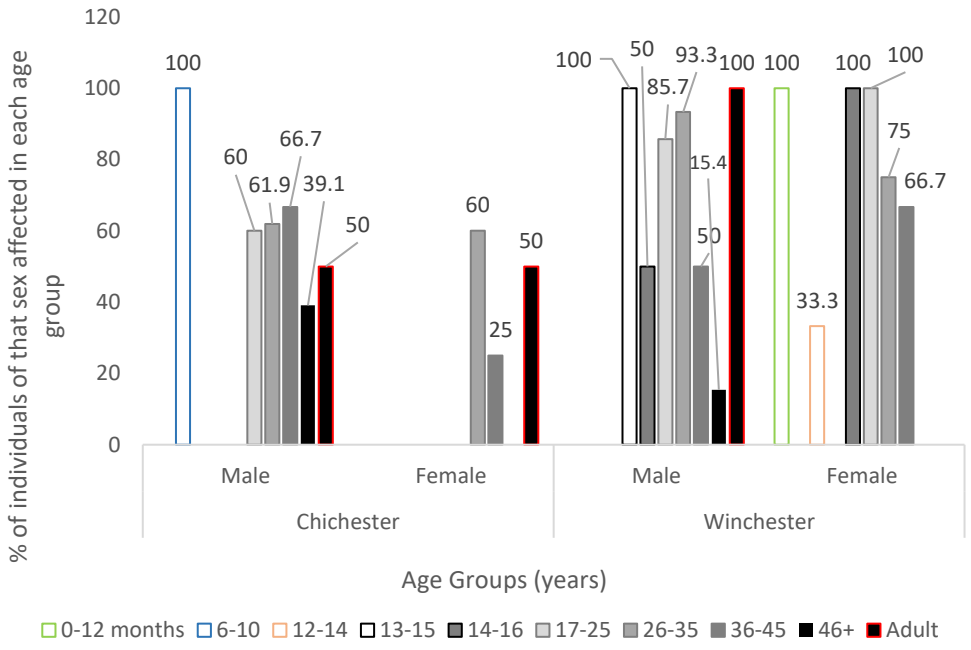


Fig. 5.38: Proportion (%) of individuals within age groups affected by periosteal new bone formation of the distal fibula at Chichester and Winchester.

5.2.6.1.3 Lepro-C and Periosteal New Bone Formation on Distal Tibia

Of the 106 individuals across the two assemblages displaying this lesion, 6 were *not consistent* (5.7%), 57 *consistent* (53.8%), 39 *highly consistent* (36.8%), and 4 *diagnostic* (3.8%). The 26-35 year age groups became more prevalent as evidence for leprosy increased, with 25.5% of individuals of this age displaying this lesion falling into the *consistent* category, and was the most affected age in the *highly consistent* and *diagnostic* categories, with 37.3% and 5.9% of 26-35 year olds displaying the lesion and falling into the *highly consistent* and *diagnostic* categories. This is in parallel to a marked decrease in individuals aged 46+ years, with 10% of individuals being of this age in the *consistent* category, decreasing to just 2.2% and no individuals of that age at all for the *highly consistent* and *diagnostic* categories respectively. Lepro-C and periosteal new bone of the distal tibia in relation to age is summarised in Table 5.49 and Fig. 5.39.

Table 5.49: Overall summary of Lepro-C categories for all individuals in the study sample affected by periosteal new bone formation on the distal tibia, by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories							
	Not Consistent		*Consistent*		*Highly Consistent*		*Diagnostic*	
Age group	N	%	N	%	N	%	N	%
0-12 months	1	14.3	-	-	-	-	-	-
6-10	1	11.1	-	-	-	-	-	-
12-14	-	-	-	-	2	28.6	-	-
13-15	-	-	-	-	1	33.3	-	-
14-16	-	-	-	-	2	40	-	-
17-25	1	4.0	11	44.0	5	20	-	-
26-35	-	-	13	25.5	19	37.3	3	5.9
36-45	-	-	14	32.6	9	20.9	1	2.3
46+	1	2.2	9	20	1	2.2	-	-
Adult	2	10.0	10	50	-	-	-	-
Total	**6**		**57**		**39**		**4**	

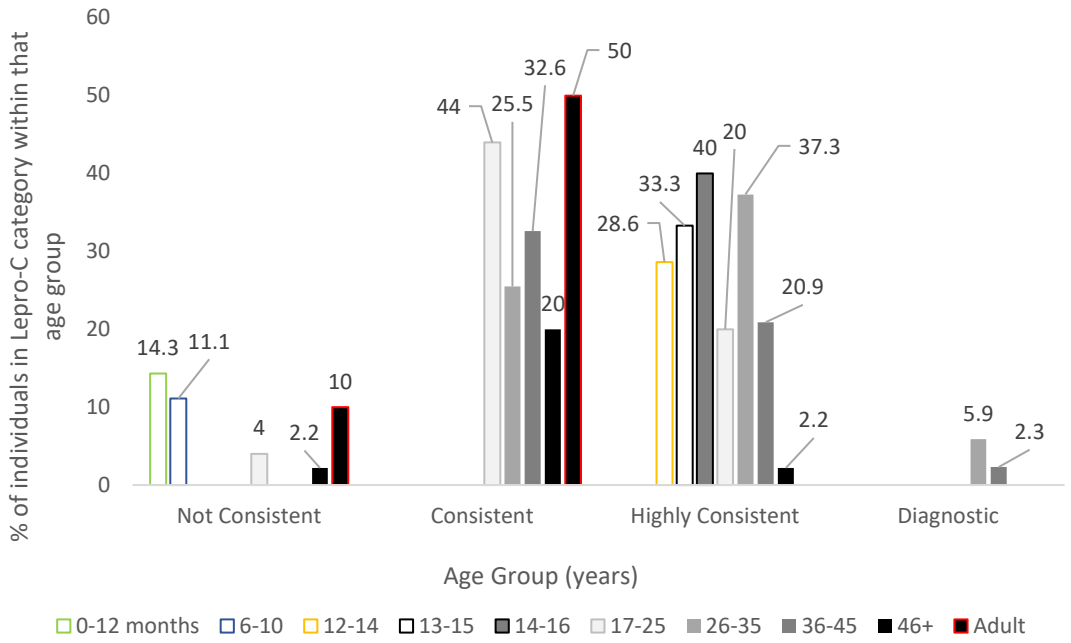


Fig. 5.39: Proportion (%) of individuals within age groups affected by periosteal new bone of the distal tibia in each Lepro-C category.

5.2.6.1.4 Three Types of Periosteal New Bone Formation Statistics

There were three main types of periosteal new bone formation on the distal tibia, categorised as longitudinally striated; porous and disorganised; and nodular (Fig. 5.40). These were tested against each other using Phi coefficient to see if there was a pattern of the occurrence of each of these morphologies of bone formation, first against each other, and then with rhinomaxillary syndrome lesions. Longitudinally striated new bone formation showed significant positive relationships with nodular and porous and disorganised new bone formation, with Phi values of 0.20 ($p = .003$ and 0.27 ($p = .000$) respectively, significant at 0.01 level. Nodular, and porous and disorganised showed no relationship, with a Phi value of 0.02 only ($p = .740$).

Longitudinally striated and porous and disorganised new bone formation were both showed a strong relationship with rhinomaxillary lesions, with a Phi values of 0.44 and 0.40 respectively (Table 5.50), both significant at the 0.01 confidence interval (p = .000 in both cases. Nodular new bone formation on the distal tibia did not have a strong relationship to rhinomaxillary lesions.

Fig. 5.40: Examples of new bone formation on distal tibia. Left – mix of longitudinal striations and porous and disorganised healed bone formation. Right – nodular bone formation. These morphologies can also be present on fibulae. Access to collection to take these images kindly granted by the BARC.

Table 5.50: Summary of Phi coefficient values that tested the relationship of the presence and absence of three morphologies of tibial periosteal new bone formation against the presence and absence of cranial lesions.

Type of bone formation	Phi	Significance
Longitudinally striated	0.44	.000
Porous and disorganised	0.40	.000
Nodular	0.04	.564

5.2.6.1.5 Horizontal Tibial Striations

The individuals displaying PNBF for the distal tibia were also checked for horizontal tibial striations, as this was a lesion noted by Møller-Christensen (1968). Sixteen individuals displayed some form of horizontal tibial striations, in all cases on the lateral aspect of the midshaft of the tibia. The morphology was variable, with 10 individuals displaying horizontal depressions on the cortical bone, with the other 6 displaying horizontal PNBF that protruded from the cortical surface. All individuals were male apart from one of indeterminate sex, and aged 17-25 to 46+ (and two 'adult' individuals). These striations occurred mainly in individuals aged 26-35 or 36-45, with 6 and 5 individuals being of this age respectively. However, those aged 26-35 displayed mainly horizontal depressions (n=5),

and those aged 36-45 displayed mainly horizontal PNBF (n=3). These lesions showed no strong relationships to age via phi analysis (Table 5.51), with values ranging from -0.137 to 0.094. For Lepro-C categories, horizontal tibial striations showed a strong relationship to the diagnostic category with a phi value of 0.223 (p = .001). These lesions occurred in two of the four diagnostic individuals. The strong relationship to the *diagnostic* category but not to age is because the two *diagnostic* individuals that displayed these horizontal striations were of different ages.

Table 5.51: Phi coefficient values for horizontal tibial striations in relation to age and Lepro-C categories.

Age (years)	Phi value	Significance	Lepro-C Category	Phi value	Significance
17-25	-0.068	.369	Not consistent	-0.214	.002
26-35	0.094	.170	Consistent	0.036	.597
36-45	-0.069	.361	Highly consistent	0.137	.046
46+	-0.137	.070	Diagnostic	0.223	.001

5.2.6.2. Periosteal New Bone Formation on Distal Fibula

5.2.6.2.1 Chichester

At Chichester, 49 individuals presented with PNBF on the distal fibula, of 107 where this could be assessed (45.8%). Of these, 40 of 74 males (54.1%), 2 of 13 females (15.4%), and 7 of 20 indeterminate sex individuals (35%) were affected (Table 5.52; Fig. 5.41). For males where an age could be determined, this lesion was most prevalent in the 26-35 year age group, with 16 individuals affected (72.7% of males that age). There was a reduction in rates for the 36-45 and 46+ year age groups, with 13 (61.9%) and 6 (27.3%) individuals affected. Fibular PNBF presented bilaterally in 25 male individuals (62.5%), most commonly in 26-35 age group (40%). There was no pattern in the female or indeterminate sex individuals.

5.2.6.2.2 Winchester

At Winchester, 45 individuals presented with PNBF on the distal fibula, of 114 where this could be assessed (39.5%). Of these, 30 of 61 males (49.2%), 10 of 26 females (38.5%), and 5 of 27 indeterminate sex individuals (18.5%). For adult males where an age could be determined, this lesion was most prevalent in the 26-35 year age group, with 14 individuals affected (93.3% of males

that age). There was a reduction in rates in the 36-45 and 46+ year age groups, with 5 (41.7%) and 2 (15.4%) individuals affected respectively. Two non-adults also presented with this lesion, aged 13-15 (100% of males that age) and 14-16 respectively (50%). The percentages of non-adults affected reflect the low numbers. PNBF on the distal fibula presented bilaterally in 25 males (66.7%), most commonly in the 26-35 year age group, with 12 individuals affected (48%). For adult females, the most commonly affected age group displaying this lesion was 17-25 years, with 5 individuals affected (83.3% of females that age). There was a reduction in rates into the 26-35 year age group, with 2 individuals affected (50%). Two non-adult females aged 12-14 and 14-16 displayed this lesion also, with the percentages of those age groups affected reflecting the low numbers of female non-adults. This lesion presented bilaterally in 8 females (80%), most commonly in the 17-25 year age group (62.5%). There was no pattern for the indeterminate sex individuals.

Table 5.52: Male and female individuals affected by periosteal new bone formation on the distal fibula in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	M		F		M		F	
Age group	N	%	N	%	N	%	N	%
12-14	-	-	-	-	-	-	1	33.3
13-15	-	-	-	-	1	100	-	-
14-16	-	-	-	-	1	50	1	100
17-25	3	60.0	-	-	4	57.1	5	83.3
26-35	16	72.7	1	20.0	14	93.3	2	50
36-45	13	61.9	1	25.0	5	41.7	1	33.3
46+	6	27.3	-	-	2	15.4	-	-
Adult	2	66.7	-	-	3	100	-	-
Total	40		2		30		10	

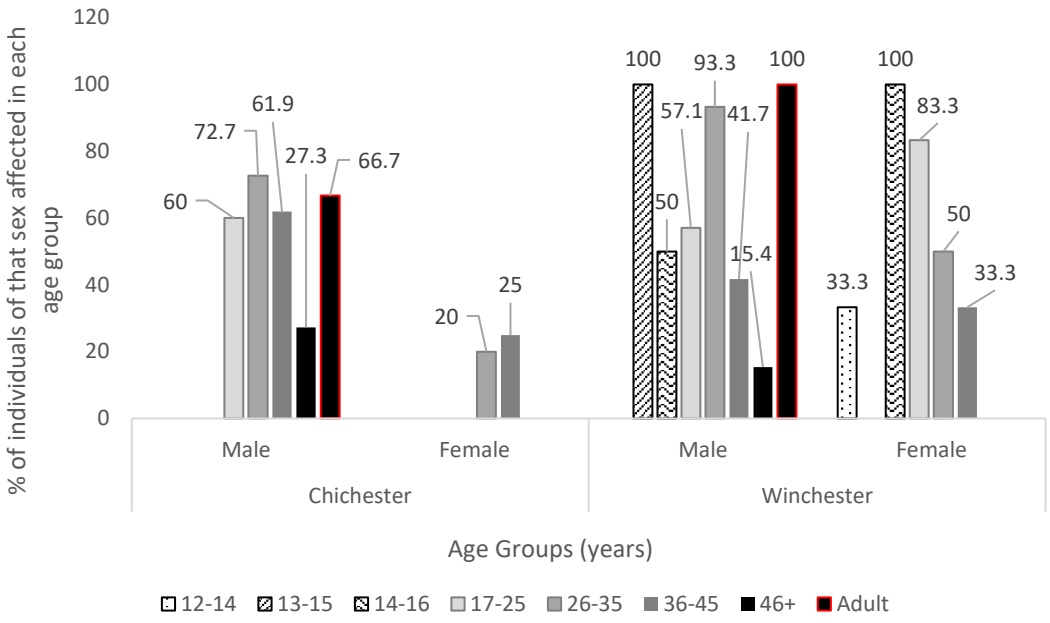


Fig. 5.41: Proportion (%) of individuals within age groups affected by periosteal new bone formation of the distal fibula at Chichester and Winchester.

5.2.6.2.3 Lepro-C and Periosteal New Bone Formation on Distal Fibula

Of the 94 individuals across the two assemblages displaying this lesion, 4 had lesions considered *not consistent* (4.3%), 53 *consistent* (56.3%), 33 *highly consistent* (35.1%), and 4 *diagnostic* (4.3%). For adult individuals, the 26-35 year age group became more prevalent relative to other age groups as evidence for leprosy increased, with 23.1% of affected individuals this age falling into the *consistent* category, and then 34.6% and 5.9% in the *highly consistent* and *diagnostic* categories. This is in parallel to a marked decrease in individuals aged 46+ years, with 18.2% of individuals that age displaying the lesion and falling into the *consistent* category but no individuals of that age at all for the *highly consistent* and *diagnostic* categories respectively. Lepro-C and periosteal new bone formation on the distal fibula in relation to age is summarised in Table 5.53 and Fig. 5.42.

Table 5.53: Overall summary of Lepro-C categories of individuals affected by periosteal new bone formation on the distal fibula by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories							
	Not Consistent		*Consistent*		*Highly Consistent*		*Diagnostic*	
Age group	N	%	N	%	N	%	N	%
12-14	-	-	-	-	2	28.6	-	-
13-15	-	-	-	-	1	33.3	-	-
14-16	-	-	-	-	2	40.0	-	-
17-25	-	-	11	44.0	3	12.0	-	-
26-35	2	3.8	12	23.1	18	34.6	3	5.8
36-45	1	2.3	12	27.3	7	15.9	1	2.3
46+	-	-	8	18.2	-	-	-	-
Adult	1	5.0	10	50	-	-	-	-
Total	**4**		**53**		**33**		**4**	

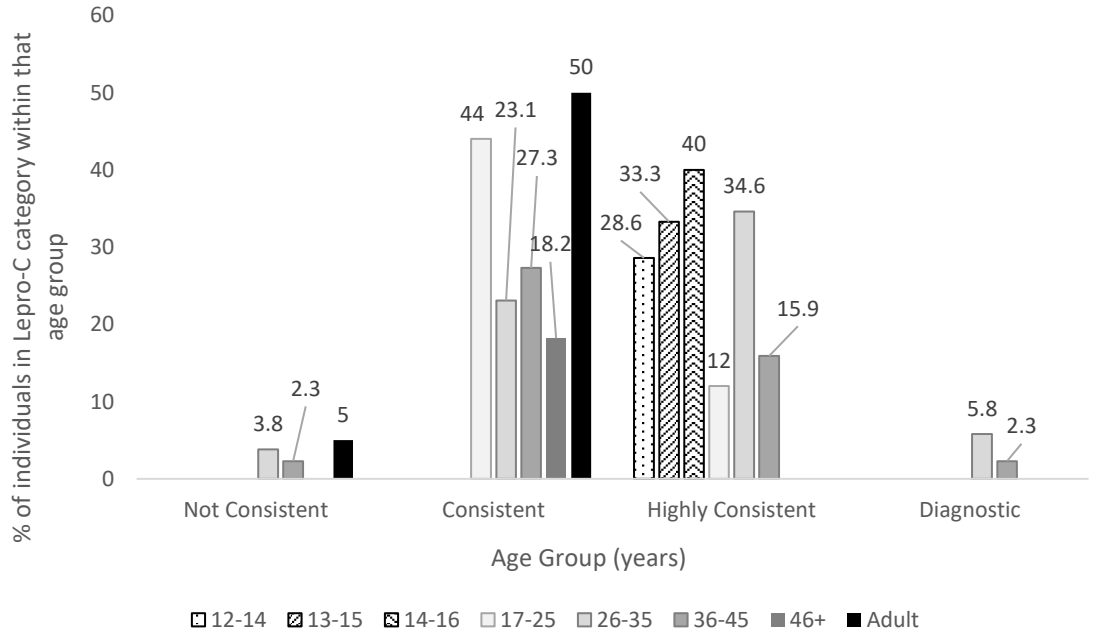


Fig. 5.42: Proportion (%) of individuals within age groups affected by periosteal new bone formation on the distal fibula in each Lepro-C category.

5.2.6.2.4 Distal Fibula Statistics

Similarly to the tibial lesions above, three categories of periosteal new bone formation (longitudinally striated, porous and disorganised, and nodular) were tested using Phi coefficient, first against each other and then to cranial lesions. Significant positive relationships were found between nodular and porous and disorganised new bone formation (Phi = 0.280, p = .007). Longitudinally striated new bone formation did not show a strong relationship with nodular or

porous and disorganised new bone formation (Phi = 0.49. *p* = .481 and Phi = .160, *p* = .022 respectively, however a strong positive relationship was found with rhinomaxillary lesions (Phi = 0.328, *p* = .000)(Table 5.54).

Table 5.54: Summary of Phi coefficient values that tested the presence and absence of tibial periosteal new bone formation of various morphologies against the presence and absence of cranial lesions.

Type of bone formation	Phi	Significance
Longitudinally striated	0.328	.000
Porous and disorganised	0.390	.000
Nodular	0.317	.000

5.2.6.3 Dorsal Tarsal Exostoses

5.2.6.3.1 Chichester

At Chichester, 22 individuals displayed dorsal tarsal exostoses, of 100 individuals where this could be assessed (22%) (Table 5.55; Fig. 5.43). Of these, 18 of 70 males (25.7%), 1 of 13 females (7.7%) and 3 of 17 indeterminate sex individuals (17.7%) were affected. For males, dorsal tarsal exostoses were most prevalent in the 46+ year age group, with 10 individuals affected (43.4% of males that age). The next most commonly affected age group was 26-35 years, with 6 individuals affected (27.3% of males that age). There was then a reduction in rates in the 36-45 year age group (10.5%). Twelve males were affected bilaterally (66.7%), most aged 46+ years (58.3%). There was no pattern in the female and indeterminate sex individuals.

5.2.6.3.2 Winchester

At Winchester, 26 individuals displayed dorsal tarsal exostoses, of 111 where they could be assessed (23.4%). Of these, 19 of 60 males (31.7%), 5 of 25 females (20%) and 2 of 26 indeterminate sex individuals (7.7%) were affected. For males where an age could be determined, the 36-45 and 46+ year age groups were affected equally, each with 5 individuals affected (41.7% of males those ages). Sixteen males were affected bilaterally (84.2%). For females, 17-25 and 26-35 years were the most commonly affected age groups, each with 2 individuals affected (40% and 50% of females those ages respectively). Three females were affected bilaterally (60%). There was no pattern for the indeterminate sex individuals.

Table 5.55: Summary of male and female individuals affected by dorsal tarsal exostoses in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	M		F		M		F	
Age group	N	%	N	%	N	%	N	%
17-25	-	-	-	-	2	28.6	2	40
26-35	6	27.3	-	-	5	33.3	2	50
36-45	2	10.5	1	25	5	41.7	1	25
46+	10	43.4	-	-	5	41.7	-	-
Adult	-	-	-	-	2	66.7	-	-
Total	**18**		**1**		**19**		**5**	

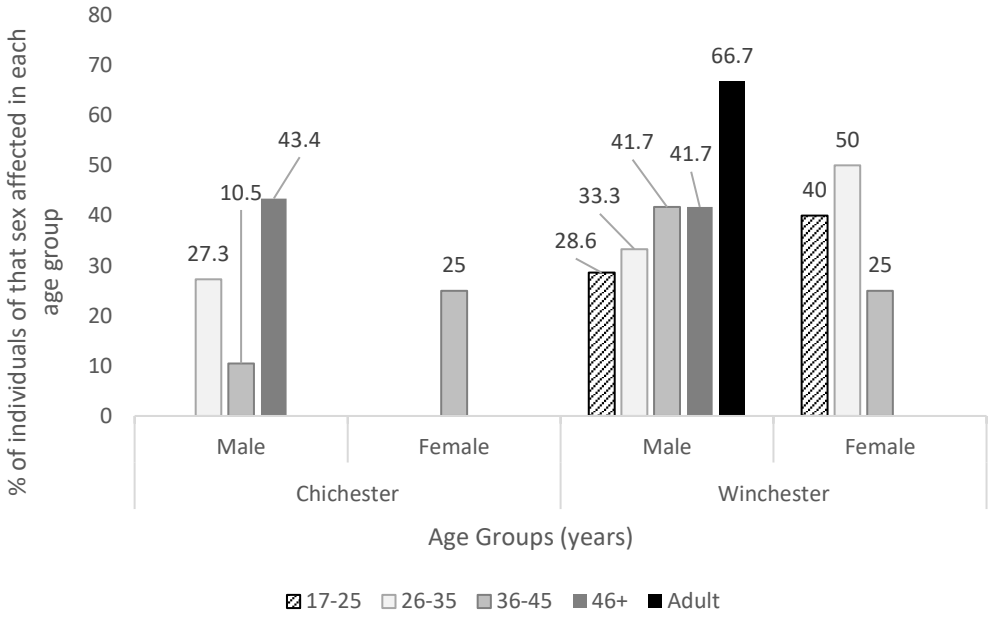


Fig. 5.43: Proportion (%) of individuals within age groups affected by dorsal tarsal exostoses at Chichester and Winchester.

5.2.6.3.3 Lepro-C and Dorsal Tarsal Exostoses

Of the 48 individuals across the two assemblages displaying this lesion, 7 were *not consistent* (14.6%), 28 *consistent* (58.3%), 11 *highly consistent* (22.9%), and 2 *diagnostic* (4.2%). The 26-35 year age group became more prevalent relative to other age groups as evidence for leprosy increased,

with 11.5% of 26-35 year olds displaying this lesions falling into the *consistent* category, becoming the most prevalent in the *highly consistent* (13.5% of 26-35 year olds displaying this lesion falling into this Lepro-C category), and the only age group displaying this lesion in the *diagnostic* category. This is in parallel to a marked decrease in individuals aged 46+ years, with 25% of individuals being of this age falling into the *consistent* category, 2.3% in the *highly consistent* categories respectively, and no individuals of that age at all displaying this lesion and being *diagnostic*. Lepro-C and dorsal tarsal exostoses in relation to age is summarised in Table 5.56 and Fig. 5.44.

Table 5.56: Overall summary of Lepro-C categories of individuals affected by dorsal tarsal exostoses on the distal fibula by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories							
	Not Consistent		*Consistent*		*Highly Consistent*		*Diagnostic*	
Age group	N	%	N	%	N	%	N	%
17-25	-	-	2	9.1	2	9.1	-	-
26-35	-	-	6	11.5	7	13.5	2	3.8
36-45	3	6.9	5	11.6	1	2.3	-	-
46+	4	9.1	11	25	1	2.3	-	-
Adult	-	-	4	14.3	-	-	-	-
Total	**7**		**28**		**11**		**2**	

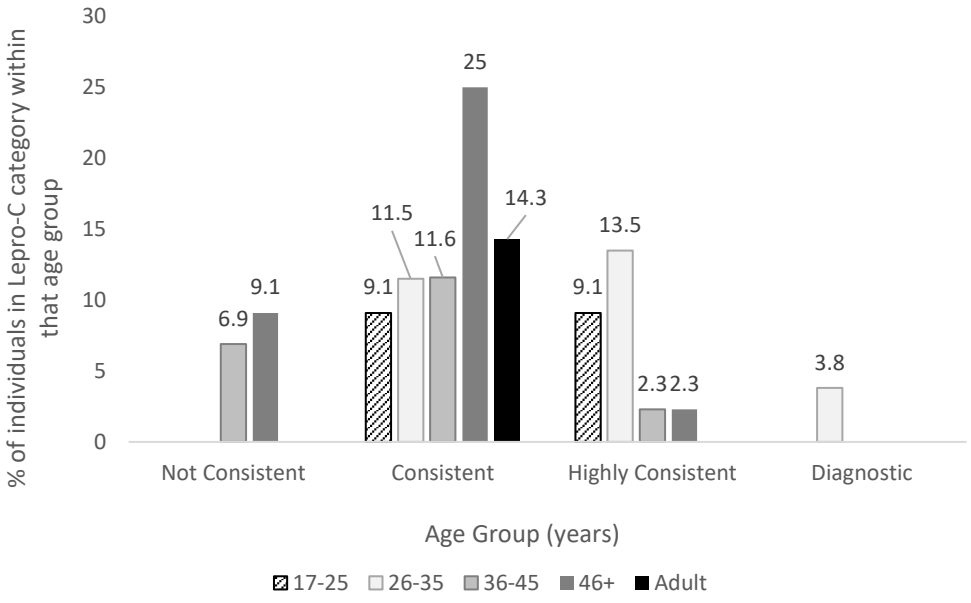


Fig. 5.44: Proportion (%) of individuals within age groups affected by dorsal tarsal exostoses in each Lepro-C category.

5.2.6.4 Navicular Squeezing

5.2.6.4.1 Chichester

At Chichester, two individuals displayed navicular squeezing, of 93 where this could be assessed (2.2%) (Table 5.57; Fig. 5.45). Of these one was male, of 67 males overall (1.5%), the other of indeterminate sex, of 16 overall (6.3%). The male individual was aged 46+ years (4.3% of males that age), and the indeterminate sex individual 26-35 years (25% of indeterminate sex individuals that age). Navicular squeezing presented unilaterally on the left navicular bone in both cases.

5.2.6.4.2 Winchester

At Winchester, two individuals displayed navicular squeezing, of 110 where this could be assessed (1.8%). Of these, one was male, of 60 overall (1.7%), and one female, of 24 overall (4.2%). The male was aged 26-35 years (6.7% of males that age), presenting bilaterally. The female individual was also aged 26-35 years (25% of females that age), presenting unilaterally on the right side.

Table 5.57: Individuals affected by navicular squeezing in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	M		Indeterminate		M		Female	
Age group	N	%	N	%	N	%	N	%
26-35	-	-	1	25	1	6.7	1	25
46+	1	4.3	-	-	-	-	-	-
Total	**1**		**1**		**1**		**1**	

Fig. 5.45: Proportion (%) of individuals within age groups affected by navicular squeezing at Chichester and Winchester.

5.2.6.4.3 Lepro-C and Navicular Squeezing

Of the 4 individuals across the two assemblages displaying this lesion, 3 had lesions throughout the skeleton that were considered *consistent* (75%) with leprosy and 1 was *diagnostic* (25%). The 26-35 year age group was most prevalent overall, with 2 *consistent* individuals (3.9% of individuals that age displaying the lesion and falling into the *consistent* category) and the *diagnostic* individual being of that age. The remaining individual was aged 46+ years and showed lesions *consistent* with leprosy overall (2.3%). Lepro-C and navicular squeezing in relation to age is summarised in Table 5.58 and Fig. 5.46.

Table 5.58: Overall summary of Lepro-C categories of individuals affected by navicular squeezing by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories			
	Consistent		*Diagnostic*	
Age group	N	%	N	%
26-35	2	3.9	1	1.9
46+	1	2.3	-	-
Total	**3**		**1**	

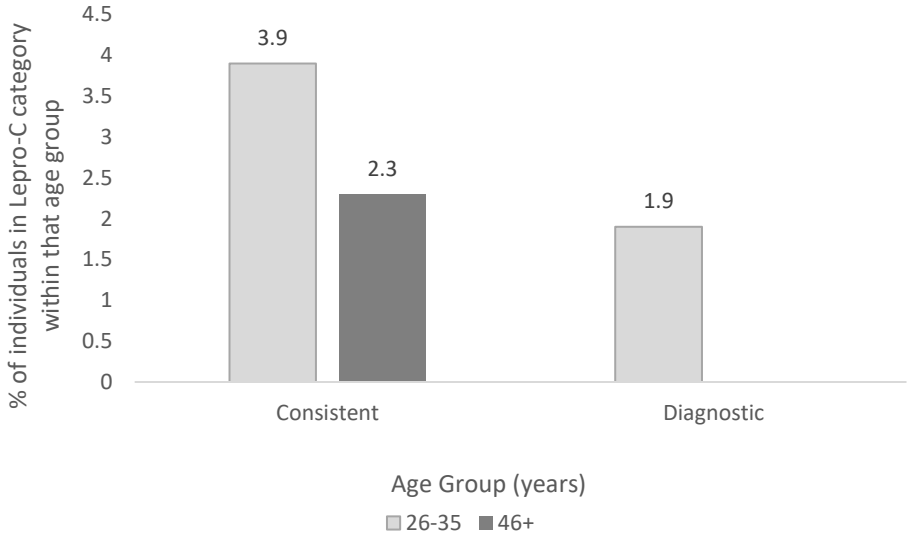


Fig. 5.46: Proportion (%) of individuals within age groups affected by navicular squeezing in each Lepro-C category.

5.2.6.5 Tarsal Disintegration

5.2.6.5.1 Chichester

At Chichester, 10 individuals displayed tarsal disintegration, of 101 where this could be assessed (9.9%)(Table 5.59; Fig. 5.47). Of these, 7 of 71 males (9.9%), 1 of 13 females (7.7%), and 2 of 17 indeterminate sex (11.8%), were affected. For males, it was most prevalent in those aged 46+ years, with 3 individuals affected (42.8%), however the 26-35 and 36-45 year age groups both had two individuals affected (28.6%). It presented unilaterally in all but one case (85.7%). The female individual was aged 26-35 years and was affected unilaterally. The two indeterminate sex individuals were 'adult', with one affected unilaterally (50%). There was no pattern for the indeterminate sex individuals.

5.2.6.5.2 Winchester

At Winchester, 7 individuals displayed carpal/tarsal disintegration, of 112 where this could be assessed (6.3%). Of these, 5 of 60 males (8.3%), and 2 of 26 females (7.7%), were affected. For males, both the 36-45 and 46+ year age groups had two individuals affected (16.7% of males in each of those age groups respectively). There was also a single 26-35 year old affected (3.7% of males that age). It presented bilaterally in all cases. The two female individuals were aged 26-35 years (50% of females that age), with the 26-35 year old affected unilaterally.

Table 5.59: Summary of male and female individuals affected by tarsal disintegration in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	M		F		M		F	
Age group	N	%	N	%	N	%	N	%
26-35	2	9.1	1	20	1	3.7	2	50
36-45	2	10.5	-	-	2	16.7	-	-
46+	3	13.3	-	-	2	16.7	-	-
Total	**7**		**1**		**5**		**2**	

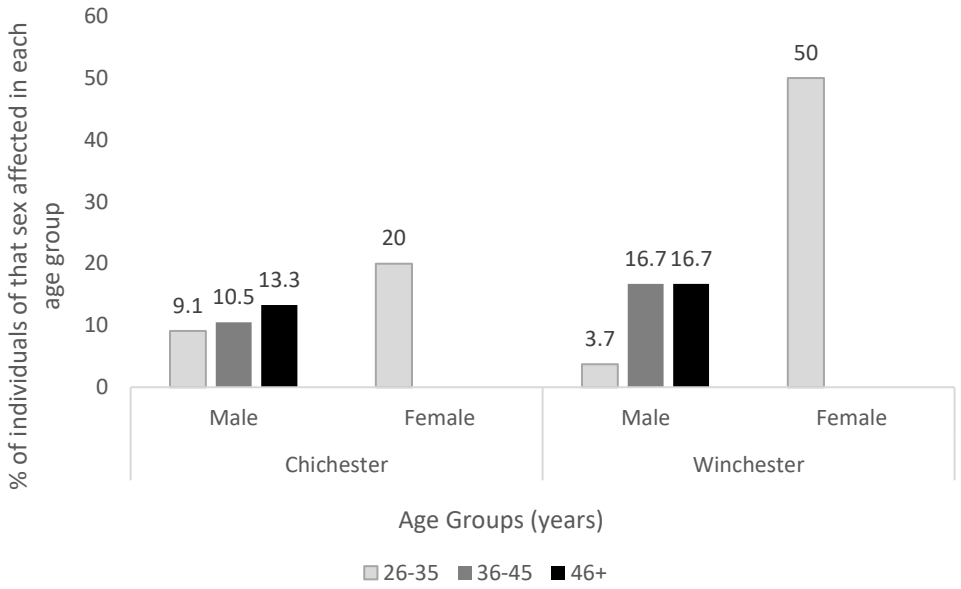


Fig. 5.47: Proportion (%) of individuals within sex and age groups affected by tarsal disintegration at Chichester and Winchester.

5.2.6.5.3 Lepro-C and Tarsal Disintegration

Of the 17 individuals across the two assemblages displaying this lesion, 12 were *consistent* (70.6%) with leprosy, 4 were *highly consistent* (23.5%) and 1 *diagnostic* (5.9%). The most prevalent age group, where an age could be determined, for each Lepro-C category got progressively younger as evidence for leprosy increased, with 46+, 36-45, and 26-35 years being the most prevalent age group for *consistent* (9.1%)*, highly consistent* (4.7%) and *diagnostic* (1.9%) respectively. Lepro-C and tarsal disintegration in relation to age of individuals is summarised in Table 5.60 and Fig. 5.48.

Table 5.60: Overall summary of Lepro-C categories of individuals affected by tarsal disintegration by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories					
	Consistent		*Highly Consistent*		*Diagnostic*	
Age group	N	%	N	%	N	%
26-35	3	5.9	1	1.9	1	1.9
36-45	3	6.9	2	4.7	-	-
46+	4	9.1	1	2.3	-	-
Adult	2	11.8	-	-	-	-
Total	**12**		**4**		**1**	

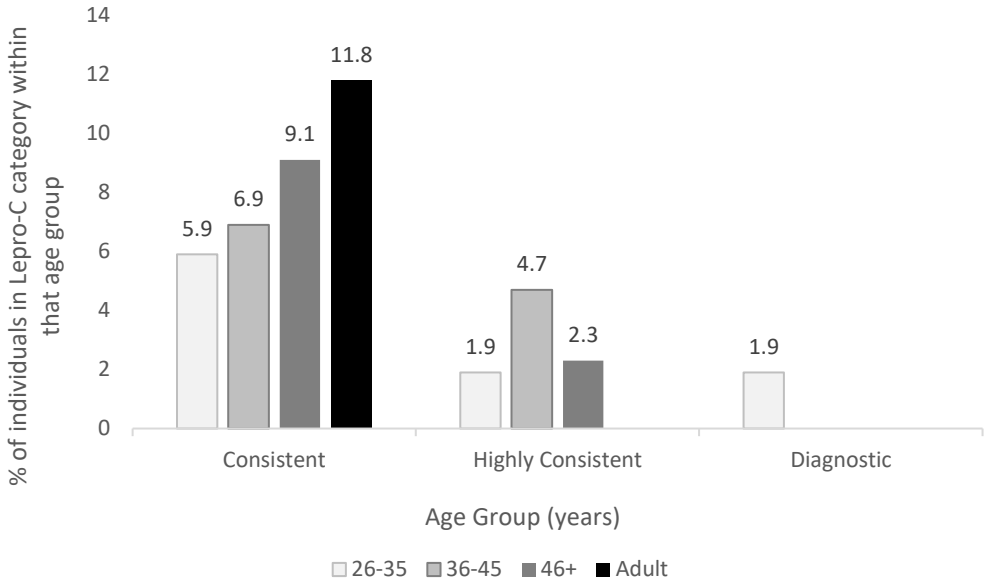


Fig. 5.48: Proportion (%) of individuals within age groups affected by tarsal disintegration in each Lepro-C category.

5.2.6.6 Ossification of Interosseous Membrane

5.2.6.6.1 Chichester

At Chichester, 13 individuals presented with ossification of the interosseous membrane, of 109 where this could be assessed (11.9%) (Table 5.61; Fig. 5.49). Of these, 10 of 78 males (12.8%), and 3 of 18 indeterminate sex individuals (16.7%), were affected. For males, ossification of the interosseous membrane was most prevalent in the 36-45 year age group, with 8 individuals affected (36.4% of males that age). The other two males were aged 26-35 (4.5%) and 46+ years (4%). Six

males were affected bilaterally (75%). There was no pattern for the indeterminate sex individuals, and no cases of this lesion in the female individuals in the dataset.

5.2.6.6.2 Winchester

In Winchester, 16 individuals presented with this lesion, of 113 where it could be assessed. Of these 13 of 61 males (21.3%), and 3 of 27 females (11.1%) were affected. For males where an age could be determined, this lesion was most prevalent in the 26-35 year age group, with 7 individuals affected (46.7% of males that age). The most commonly affected age group for females was 26-35 years, with two individuals affected (50% of females that age).

Table 5.61: Summary of male individuals affected by ossification of interosseous membrane in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	M		F		M		F	
Age group	N	%	N	%	N	%	N	%
17-25	-	-	-	-	1	14.3	-	-
26-35	1	4.5	-	-	7	46.7	2	50.0
36-45	8	36.4	-	-	1	8.3	1	25.0
46+	1	4.0	-	-	2	15.4	-	-
Adult	-	-	-	-	2	66.7	-	-
Total	**10**		**0**		**13**		**3**	

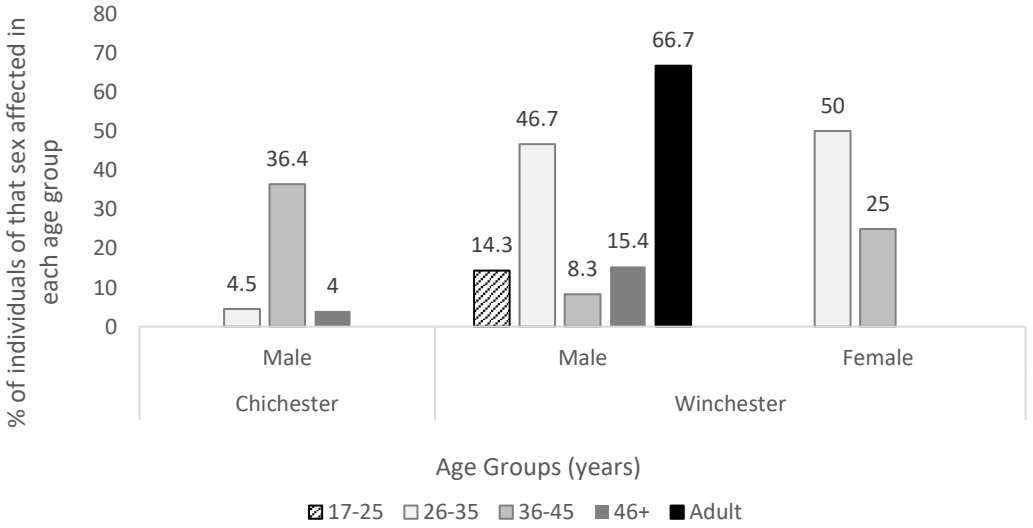


Fig. 5.49: Proportion (%) of individuals within sex and age groups affected by ossification of interosseous membrane at Chichester and Winchester.

5.2.6.6.3 Lepro-C and Ossification of Interosseous Membrane

Of the 29 individuals across the two assemblages displaying this lesion, 18 were *consistent* (62%), 7 *highly consistent* (24.1%) and 4 *diagnostic* (13.8%). Where and age could be determined, the most prevalent age group was 26-35 years as evidence for leprosy increased, with 9.6% and 5.8% of individuals that age that displayed the lesion falling into the *highly consistent* and *diagnostic* categories respectively. This contrasts with *consistent*, where 36-45 years is the most prevalent age category (38.9% of individuals that age displaying the lesion and falling into that Lepro-C category), followed by 46+ years (6.4%). Lepro-C and ossification of interosseous membrane in relation to age is summarised in Table 5.62 and Fig. 5.50.

Table 5.62: Overall summary of Lepro-C categories of individuals affected by ossification of interosseous membrane by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories					
	Consistent		*Highly Consistent*		*Diagnostic*	
Age group	N	%	N	%	N	%
17-25	1	4.2	-	-	-	-
26-35	2	3.8	5	9.6	3	5.8
36-45	7	15.2	2	4.3	1	2.2
46+	3	6.4	-	-	-	-
Adult	5	29.4	-	-	-	-
Total	**18**		**7**		**4**	

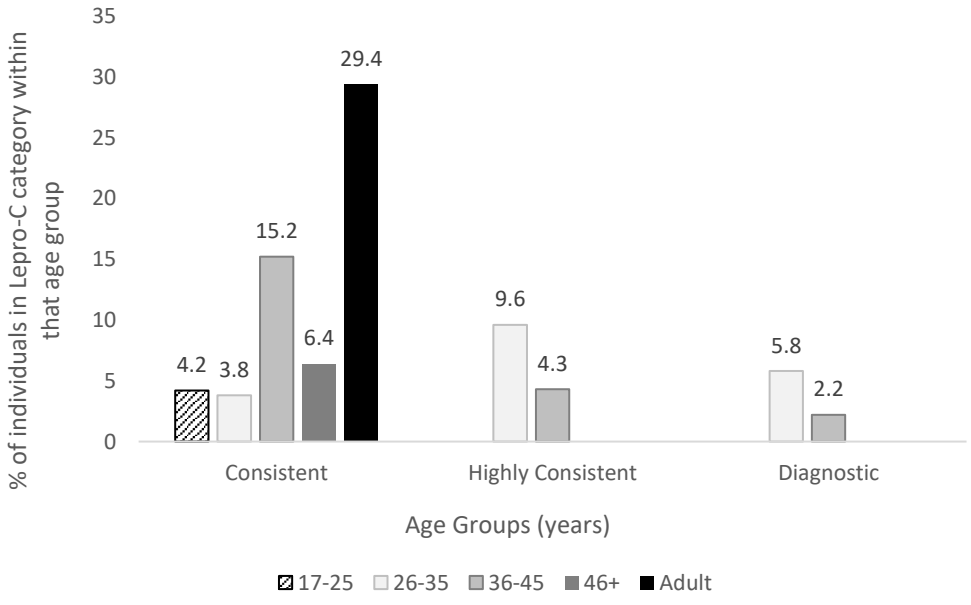


Fig. 5.50: Proportion (%) of individuals within age groups affected by ossification of interosseous membrane in each Lepro-C category.

5.2.6.7 Absorption of Foot Phalanges and Metatarsals

5.2.6.7.1 Chichester

In Chichester, 11 individuals displayed absorption of foot phalanges, of 102 where this could be assessed (10.8%). Of these, 9 of 70 males (12.9%), and 2 of 18 indeterminate sex individuals (11.1%) were affected (Table 5.63; 6.71; Fig. 5.51). For males, absorption of foot phalanges was most common in the 26-35 year age group, with 4 individuals affected (19% of males that age). Rates were reduced in the 36-45 years age group, with two individuals affected (10%), but then increased 46+ year age group, with 3 individuals affected (14.3%). Six individuals were affected unilaterally (66.7%). There was no pattern in the indeterminate sex individuals.

5.2.6.7.2 Winchester

In Winchester, 17 individuals displayed absorption of foot phalanges, of 107 where this could be assessed (15.9%). Of these, 11 of 58 males (18.9%), 4 of 23 females (17.4%) and 2 of 26 indeterminate sex individuals (7.7%), were affected. For males, this lesion was most prevalent in the 26-35 and 46+ year age groups, with 3 individuals affected in each group (21.4% and 23.1% of males those ages, respectively). Six males were affected bilaterally (50%). For females, both the 26-35 year and 36-45 year age groups were equally represented, with two individuals in each group (66.7% of females in each of those age groups. The females were all affected bilaterally. There was no pattern for the indeterminate sex individuals.

Table 5.63: Male and female individuals affected by absorption of foot phalanges/metatarsals in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	Male		Female		Male		Female	
Age group	N	%	N	%	N	%	N	%
17-25	-	-	-	-	1	16.7	-	-
26-35	4	19.0	-	-	3	21.4	2	66.7
36-45	2	10.0	-	-	2	18.2	2	66.7
46+	3	14.3	-	-	3	23.1	-	-
Adult	-	-	-	-	2	66.6	-	-
Total	**9**		**0**		**11**		**4**	

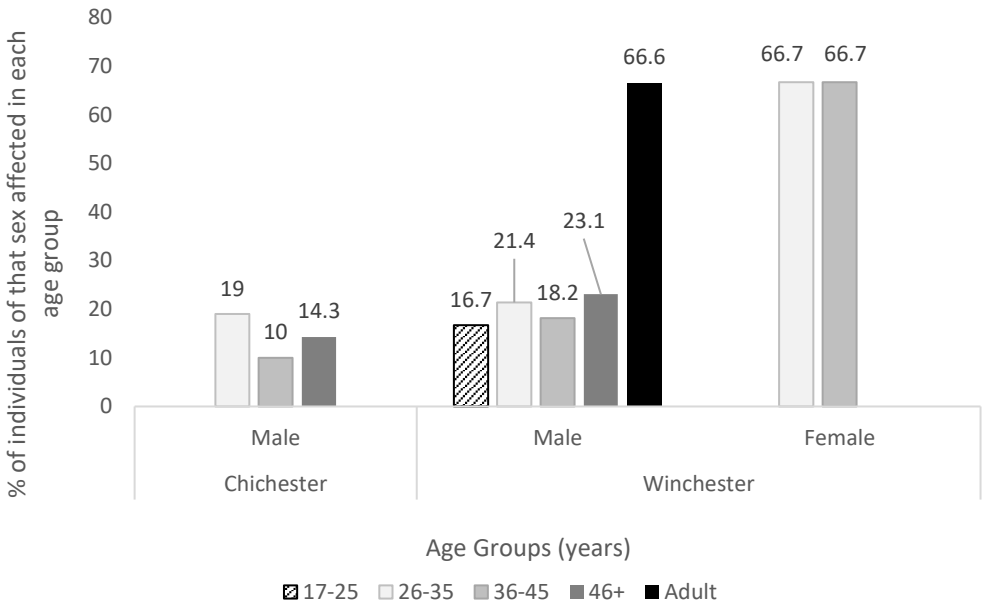


Fig. 5.51: Proportion (%) of individuals within sex and age groups affected by absorption of foot phalanges/metatarsals at Chichester and Winchester.

5.2.6.7.3 Lepro-C and Absorption of Foot Phalanges and Metatarsals

Of the 28 individuals across the two assemblages displaying this lesion, 1 was *not consistent* (3.6%), 15 *consistent* (53.6%), 9 *highly consistent* (32.1%) and 3 *diagnostic* (10.7%). Where an age could be determined, the most prevalent age groups became younger as evidence for leprosy increased, with 46+ years the most prevalent age group, with 2.3% and 11.6% of individuals that age displaying the lesion and falling into the *not consistent* (2.3%) and *consistent* categories respectively. The 26-35 year age group became the most prevalent *highly consistent* and *diagnostic* categories with 10.2% and 4.1% of individuals that age displaying the lesion and falling into those Lepro-C categories.. Lepro-C and absorption of foot phalanges and metatarsals in relation to age is summarised in Table 5.64 and Fig. 5.52.

Table 5.64: Overall summary of Lepro-C categories of individuals affected by absorption of foot phalanges/metatarsals by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories							
	Not Consistent		*Consistent*		*Highly Consistent*		*Diagnostic*	
Age group	N	%	N	%	N	%	N	%
17-25	-	-	1	4.8	-	-	-	-
26-35	-	-	3	6.1	5	10.2	2	4.1
36-45	-	-	1	2.5	4	10.0	1	2.5
46+	1	2.3	5	11.6	-	-	-	-
Adult	-	-	5	23.8	-	-	-	-
Total	**1**		**15**		**9**		**3**	

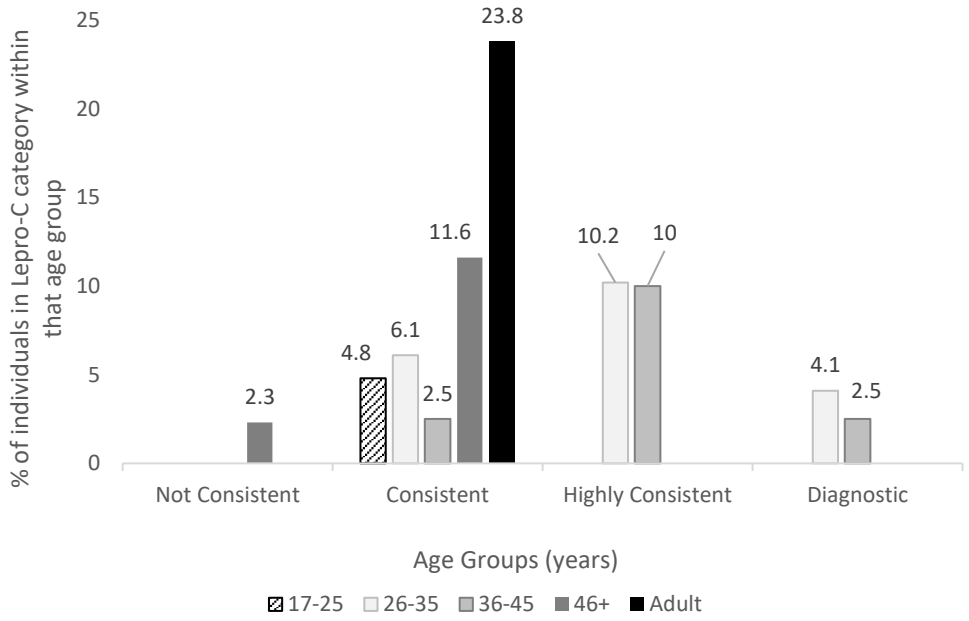


Fig. 5.52: Proportion (%) of individuals within age groups affected by absorption of foot phalanges/metatarsals in each Lepro-C category.

5.2.6.8 Concentric Remodelling of Metatarsals

5.2.6.8.1 Chichester

At Chichester, 12 individuals presented with concentric remodelling of metatarsals/phalanges, of 104 where this could be assessed (11.5%) (Table 5.65; Fig. 5.53). Of these, 8 of 72 males (11.1%), 3 of 14 females (21.4%) and 1 of 18 indeterminate sex individuals (5.6%), were affected. For males where an age could be determined, concentric remodelling of foot bones was most prevalent in the 26-35 year age group, with three individuals affected (14.3% of males that age). There was a reduction in rates in the 36-45 and 46+ year age groups, with two individuals affected in each (9.5%

and 8.7% of males those ages, respectively). Concentric remodelling was unilateral for males in all instances, predominantly on the right-hand side (75%). For females, 17-25 years was the most affected age group, with 1 individual affected (50% of females that age), although the percentages for females reflect the low numbers. All three females were affected unilaterally. The single indeterminate sex individual was 'adult'.

5.2.6.8.2 Winchester

At Winchester, 14 individuals presented with concentric remodelling of metatarsals/phalanges, of 113 where this could be assessed (12.4%). Of these, 7 of 61 males (11.5%), 4 of 26 females (15.4%), and 2 of 26 indeterminate sex individuals (7.7%), were affected. For males, concentric remodelling of metatarsals/phalanges was most prevalent in the 26-35 year age group, with 3 individuals affected (20% of males that age). Rates then reduced in the 36-45 and 46+ year age groups, with 2 (16.7%) and 1 (7.7%) individuals affected respectively. Four male individuals were affected unilaterally (66.6%). The most affected age group for females was 36-45 years, with two individuals affected (50% of females that age). Three females were affected unilaterally (75%). There was no pattern in the indeterminate sex individual.

Table 5.65: Summary of male and female individuals affected by concentric remodelling of metatarsals in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	M		F		M		F	
Age group	N	%	N	%	N	%	N	%
17-25	-	-	1	50.0	1	14.3	1	16.7
26-35	3	14.3	2	40.0	3	20.0	1	25.0
36-45	2	9.5	-	-	2	16.7	2	50.0
46+	2	8.7	-	-	1	7.7		
Adult	1	33.3	-	-	-	-	-	-
Total	**8**		**3**		**7**		**4**	

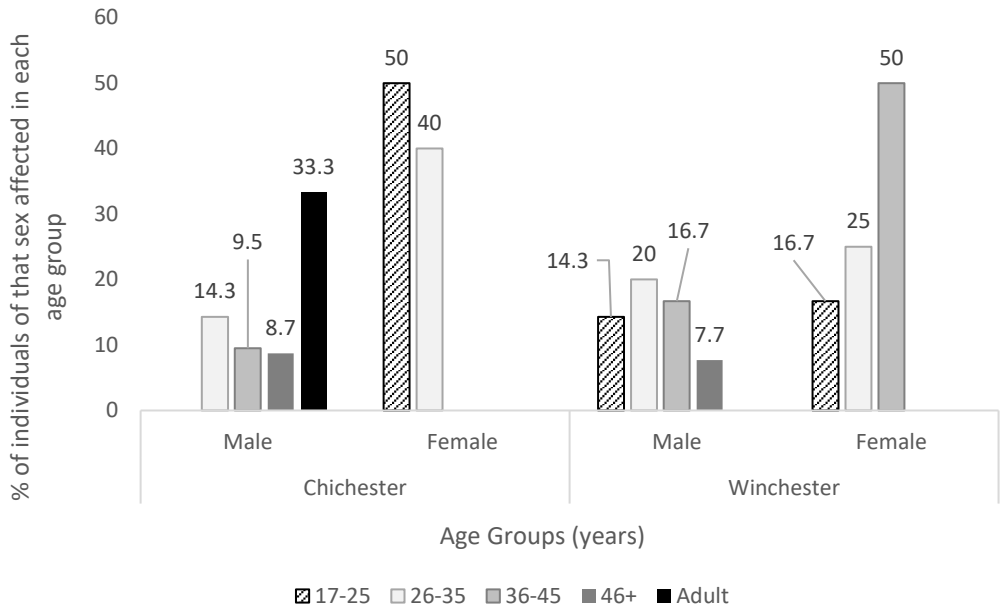


Fig. 5.53: Proportion (%) of individuals within sex and age groups affected by concentric remodelling of metatarsals at Chichester and Winchester.

5.2.6.8.3 Lepro-C and Concentric Remodelling of Metatarsals

Of the 26 individuals across the two assemblages displaying this lesion, 1 was *not consistent* (3.8%), 14 were *consistent* (53.8%) and 10 *highly consistent* (38.5%) and 1 *diagnostic* (3.8%). The 26-35 year age group became more dominant as evidence for leprosy increased, with 4 *consistent* (7.8%) individuals being of this age displaying the lesion and falling into that Lepro-C category, increasing to 5 in the *highly consistent* category (9.8%), and the diagnostic individual displaying this lesion being of this age (1.9%). Lepro-C and absorption of hand phalanges and metacarpals in relation to age is summarised in Table 5.66 and Fig. 5.54.

Table 5.66: Lepro-C categories for all individuals affected by concentric remodelling of metatarsals by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

Age group	Lepro-C Categories							
	Not Consistent		*Consistent*		*Highly Consistent*		*Diagnostic*	
	N	%	N	%	N	%	N	%
17-25	-	-	2	9.1	1	4.5	-	-
26-35	-	-	4	7.8	5	9.8	1	1.9
36-45	-	-	2	4.5	4	9.1	-	-
46+	-	-	3	6.7	-	-	-	-
Adult	1	5	3	15	-	-	-	-
Total	**1**		**14**		**10**		**1**	

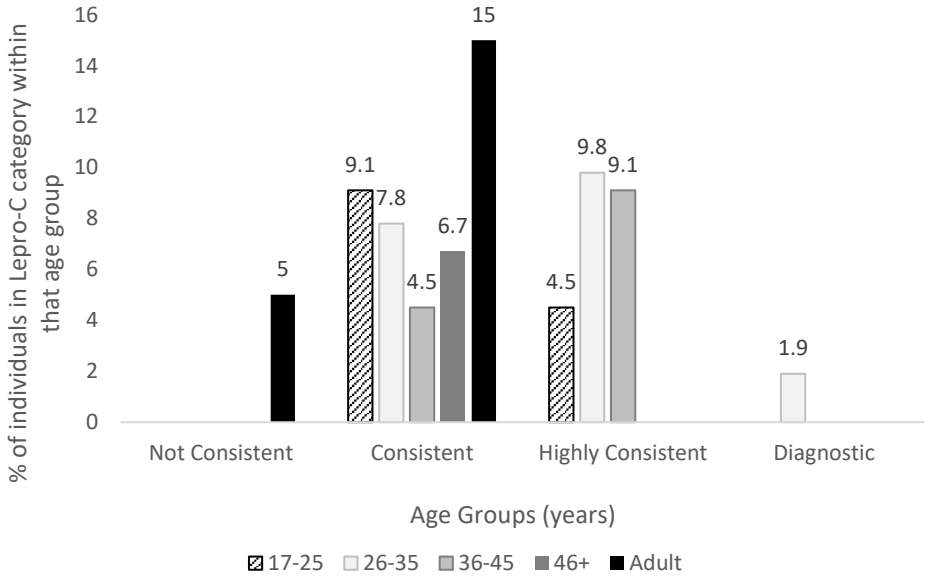


Fig. 5.54: Proportion (%) of individuals within age groups affected by concentric remodelling of metatarsals in each Lepro-C category.

5.2.6.9 Knife-Edge Remodelling of Metatarsals

5.2.6.9.1 Chichester

At Chichester, 8 individuals displayed knife-edge remodelling of metatarsals, of 105 where this could be assessed (7.6%) (Table 5.67; Fig. 5.55; 6.70). Of these, 5 of 72 males (6.9%), 2 of 14 females (14.3%), and 1 of 19 indeterminate sex individuals (5.3%), were affected. For males this was most prevalent in the 36-45 year age group, with 3 affected (14.3% of males that age). The remaining two

males were aged 46+ years (8.7% of males that age). Knife-edge remodelling was unilateral in for all males. The two females affected were aged 17-25 (50% of females that age) and 26-35 years (20% of females that age), the former bilaterally and latter unilaterally. The 'adult' indeterminate sex individual was affected unilaterally.

5.2.6.9.2 Winchester

At Winchester, four individuals presented with knife-edge remodelling of metatarsals, of 112 where this could be assessed (3.6%). Of these, 2 of 60 males (50%), 1 of 26 females (3.8%) and 1 of 26 indeterminate sex individuals (3.8%), were affected. The two males were aged 26-35 and 46+ years respectively, with the 46+ years individual showing unilateral lesions only. The female was aged 17-25 years, and was affected unilaterally. There was no pattern for the indeterminate sex individual.

Table 5.67: Summary of male and female individuals affected by knife-edge remodelling of metatarsals in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	Male		Female		Male		Female	
Age group	N	%	N	%	N	%	N	%
17-25	-	-	1	50	-	-	1	16.7
26-35	-	-	1	20	1	6.7	-	-
36-45	3	14.3	-	-	-	-	-	-
46+	2	8.7	-	-	1	7.7	-	-
Total	5		2		2		1	

Fig. 5.55: Proportion (%) of individuals within sex and age groups affected by knife-edge remodelling of metatarsals at Chichester and Winchester.

5.2.6.9.3 Lepro-C and Knife-Edge Remodelling of Metatarsals

Of the 12 individuals across the two assemblages displaying this lesion, 9 were *consistent* (75%) and 3 *highly consistent* (25%). Younger age groups became more prevalent as evidence for leprosy increased, with 46+ years being the most prevalent for *consistent* individuals (6.7%), yet *highly consistent* contained individuals aged 17-25, 26-35 and 36-45 years only (only 1 in each group, however, but 17-25 was the most affected age group overall in that Lepro-C category (4.8%)). Lepro-C and knife-edge remodelling of metatarsals in relation to age is summarised in Table 5.68 and Fig. 5.56.

Table 5.68: Overall summary of Lepro-C categories of individuals affected by knife-edge remodelling of metatarsals by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories			
	Consistent		*Highly Consistent*	
Age group	N	%	N	%
17-25	1	4.8	1	4.8
26-35	2	3.7	1	3.9
36-45	2	4.5	1	2.3
46+	3	6.7	-	-
Adult	1	4.8	-	-
Total	**9**		**3**	

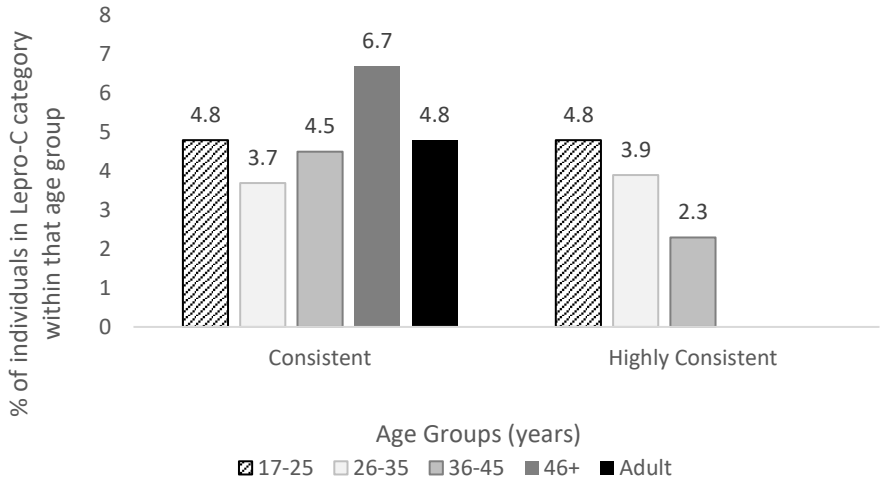


Fig. 5.56: Proportion (%) of individuals within age groups affected by knife-edge remodelling of metatarsals in each Lepro-C category.

5.2.7 Lower Extremity Lesions Statistics

5.2.7.1 Lower Extremity Lesions and Age

5.2.7.1.1 Phi Coefficient

Lower extremity lesions were tested against adult age groups using Phi coefficient. The most significant coefficients related to periosteal new bone formation on the distal tibiae and fibulae, with both lesions showing significant positive phi values to the 26-35 year age group (phi = 0.216, *p* = .005, and phi = 0.278, *p* = <.001, respectively), and significant negative relationships to the 46+ year age group (phi = -0.317 and phi = -0.313, respectively, *p* for both: <.001), in all cases significant to the 0.01 level. Navicular squeezing, absorption of foot phalanges/metatarsals, and concentric remodelling of metatarsals also showed positive phi values with the 26-35 year age group, with values of 0.147, 0.131 and 0.137 respectively. All phi relationships to age group are summarised in Table 5.69 below.

Table 5.69: Summary of Phi coefficients between lower postcranial lesions and age groups.

Lesion	Age group							
	17-25		26-35		36-45		46+	
	Phi	Sig.	Phi	Sig.	Phi	Sig.	Phi	Sig.
Distal Tibia	0.129	.098	0.216*	.005	-0.004	.959	-0.317*	<.001
Distal Fibula	0.076	.330	0.278*	<.001	-0.020	.794	-0.313*	<.001
Dorsal Tarsal Exostoses	-0.080	.311	0.029	.717	-0.100	.205	0.139	.078
Navicular Squeezing	-0.067	.403	0.147	.037	-0.089	.270	-0.014	.865
Tarsal Disintegration	-0.128	.107	0.013	.872	0.058	.466	0.034	.670
Ossfication Interosseous Membrane	-0.117	.130	0.097	.206	0.145	.060	-0.148	.055
Absorption (proximal foot phalanges/MCs	-0.119	.143	0.131	.104	-0.003	.968	-0.040	.623
Concentric remodelling (foot)	-0.045	.571	0.137	.081	0.025	.755	-0.124	.116
Knife-edge Remodelling (Foot)	0.042	.596	-0.023	.768	0.008	.917	-0.010	.896

* significant at the 0.01 level

5.2.7.1.2 Binomial Logistic Regression

Binomial logistic regression was used as it allows to test the affect that multiple independent variables had on the presence/absence of lesions. The analysis included adult individuals where a year age group could be determined. Individuals aged 46+ were automatically excluded from the analysis when running the regression model on SPSS due to redundancy (i.e. the presence/absence values could be predicted from the other three adult age categories). Therefore, the regression models test the effect that individuals age (17-25, 26-35, and 36-45 year age groups) had on the presence and absence of lesions. These were also the adult age groups most affected by lesions overall, so it is interesting to see their effect on the regression models. The effects of sex and site were also tested. Only lesions where there were 10 or more individuals affected were tested, as recommended for regression testing (van Smeden et al., 2016).

For independent variables, age was found to have a significant effect on the model for the periosteal new bone formation on the distal tibia, particularly individuals aged 17-25 (Wald = 11.917, p = <.001) and 26-35 years (Wald = 17.963, p = <.001). This was also the case for PNBF on the distal fibula with individuals aged 17-25 (Wald = 12.184, p = <.001) and 26-35 years (Wald = 22.178, p = <.001) having a strong effect on the model. However, all ages had a significant effect for these two lesions in their respective models. Males were also more likely to display PNBF on the distal fibula than females (Wald = 6.820, p = .009). The regression analysis indicates that age, sex and site did not have a strong influence on the presence of the other lower postcranial lesions. The details of the binomial logistic regressions for these lesions are in Table 5.70.

Table 5.70: Binomial logistic regression for lower postcranial lesions.

	Independent variables					
Lesion		**Age**				
PNBF Distal Tibia	**17-25**	**26-35**	**36-45**	**Site**	**Sex**	**P value of overall model**
Wald/Chi	11.917	17.963	8.171	.788	2.204	25.592
Sig (p)	<.001*	<.001*	.004*	.375	.138	<.001
Odds ratio	9.647	8.240	3.975	1.401	2.011	
PNBF Distal Fibula	**17-25**	**26-35**	**36-45**	**Site**	**Sex**	
Wald/Chi	11.150	22.178	8.366	.245	6.820	32.520
Sig (p)	<.001*	<.001*	.004*	.621	.009	<.001
Odds ratio	8.843	12.245	4.449	1.210	3.584	
Dorsal Tarsal Exostoses	**17-25**	**26-35**	**36-45**	**Site**	**Sex**	
Wald/Chi	1.060	.706	1.714	2.525	1.308	5.724
Sig (p)	.303	.401	.190	.112	.253	.334
Odds ratio	.494	.675	.515	1.861	1.822	
Tarsal Disintegration	**17-25**	**26-35**	**36-45**	**Site**	**Sex**	
Wald/Chi	.000	.059	.001	.146	.039	4.366
Sig (p)	.998	.807	.974	.702	.843	.498
Odds ratio	.000	.848	1.022	1.240	.870	
Ossification Interosseous Membrane	**17-25**	**26-35**	**36-45**	**Site**	**Sex**	
Wald/Chi	.089	3.794	4.672	4.087	1.334	13.204
Sig (p)	.766	.051	.031	.043	.248	.022
Odds ratio	.698	3.962	4.649	2.625	2.199	
Absorption Foot Phalanges	**17-25**	**26-35**	**36-45**	**Site**	**Sex**	
Wald/Chi	1.133	1.052	.055	4.135	.071	7.350
Sig (p)	.287	.305	.815	.042	.790	.196
Odds ratio	.297	1.821	1.161	2.672	1.181	
Concentric Remodelling of Metatarsals	**17-25**	**26-35**	**36-45**	**Site**	**Sex**	
Wald/Chi	.008	2.355	1.037	.083	2.842	6.138
Sig (p)	.929	.125	.309	.773	.092	.293
Odds ratio	1.092	2.996	2.155	1.158	.393	
Knife-Edge Remodelling of Metatarsals	**17-25**	**26-35**	**36-45**	**Site**	**Sex**	
Wald/Chi	.224	.482	.009	1.723	.823	3.309
Sig (p)	.636	.487	.923	.189	.364	.652
Odds ratio						

*significant at .008

5.2.7.2 Lower postcranial lesions and Lepro-C

Lower postcranial lesions were tested against Lepro-C categories using Phi coefficient. All of the lesions were negatively related to the *not consistent* category, with all but navicular squeezing significantly so to the 0.01 level. The strongest negative relationships to the *not consistent* category were PNBF to the distal tibiae and fibulae, with values of -0.588 and -0.529 respectively. PNBF to the distal tibiae and fibulae were also significantly positively related to the *consistent* (0.274 and 0.253), *highly consistent* (0.334 and 0.286) and *diagnostic* (0.141 & 0.158) categories, significant to the 0.01 level. For the *diagnostic* category, the other strongest positive relationships were for navicular squeezing (0.235), ossification of the interosseous membrane (0.349), and absorption of foot phalanges/metatarsals (0.301), significant to the 0.01 level. All coefficients are summarised in Table 5.71 below.

Table 5.71: Summary of Phi coefficient between lower extremity lesions and Lepro-C categories.

	Lepro C category							
Lesion	NC		C		HC		D	
	Phi	Sig	Phi	Sig	Phi	Sig	Phi	Sig
Distal Tibia	-0.588*	<.001	0.274*	<.001	0.334*	<.001	0.141	.036
Distal Fibula	-0.529*	<.001	0.253*	<.001	0.286*	<.001	0.158	.018
Dorsal Tarsal Exostoses	-0.270*	<.001	0.235*	<.001	-0.003	.967	0.090	.191
Navicular Squeezing	-0.103	.141	0.089	.203	-0.071	.313	0.235*	<.001
Tarsal Disintegration	-0.219*	.001	0.160*	.020	0.032	.643	0.087	.207
Ossfication Interosseous Membrane	-0.257*	<.001	0.133*	.048	0.057	.401	0.349*	<.001
Absorption (proximal foot phalanges/MCs	-0.281*	<.001	0.090	.194	0.140	.043	0.301*	<.001
Concentric remodelling (foot)	-0.209*	.002	0.048	.279	0.211*	.008	-0.061	.003
Knife-edge Remodelling (Foot)	-0.187*	.006	0.157*	.021	0.41	.548	-0.033	.627

*significant at the .01 level

5.2.8 Lesions that Could Occur on Upper or Lower Extremities

5.2.8.1 Acroosteolysis

5.2.8.1.1 Chichester

At Chichester, 13 individuals displayed acroosteolysis, of 76 where this could be assessed. Of these, 12 of 58 males (20.7%), and 1 of 7 females (14.3%), were affected (Table 5.72; Fig. 5.57). For males, acroosteolysis was most prevalent in the 46+ year age group (23.5% of males that age), although the 26-35 and 36-45 year age group were affected similarly also, with 21.7% and 23.1% of males that age affected respectively. The female individual was aged 17-25 years, and presented unilaterally on the left side. This was the only female of that age at Chichester where this lesion could be assessed.

5.2.8.1.2 Winchester

At Winchester, 34 individuals displayed acroosteolysis, of 112 where this could be assessed (30.4%). Of these, 21 of 58 males (36.2%), 10 of 26 females (38.5%), and 3 of 28 indeterminate sex individuals (10.7%). For males where an age could be determined, acroosteolysis was most prevalent in the 26-35 year age group, with 10 individuals affected (66.7% of males that age), 3 unilaterally (30%). Rates declined in the 36-45 year age group, with three individuals affected (27.3%), before increasing again the 46+ years age group, where 4 individuals were affected (36.3%). All individuals in the 36-45 year age group were affected bilaterally, with two individuals affected unilaterally in the 46+ years age group (50%). For adult females, acroosteolysis was equally prevalent in the 17-25 and 26-35 year age groups, with 66.7% of females that age affected in each category. Two non-adult females were aged 12-14 and 14-16. All acroosteolysis was bilateral for females at Winchester. The two indeterminate sex individuals were aged 46+ years.

Table 5.72: Summary of male and female individuals affected by acroosteolysis in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	Male		Female		Male		Female	
Age (years)	N	%	N	%	N	%	N	%
12-14	-	-	-	-	-	-	1	33.3
14-16	-	-	-	-	-	-	1	100
17-25	-	-	1	100	2	28.6	4	66.7
26-35	5	21.7	-	-	10	66.7	2	66.7
36-45	3	23.1	-	-	3	27.3	2	50
46+	4	23.5	-	-	4	36.3	-	-
Adult	-	-	-	-	2	66.7	-	-
Total	**12**		**1**		**21**		**10**	

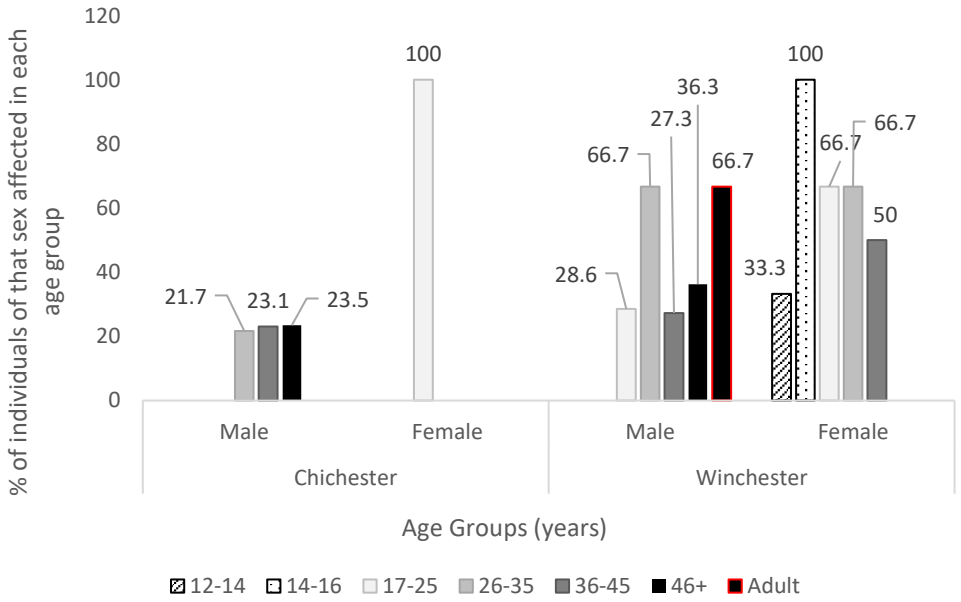


Fig. 5.57: Proportion (%) of individuals within sex and age groups affected by acroosteolysis at Chichester and Winchester.

5.2.8.1.3 Lepro-C and Acroosteolysis

Of the 47 individuals across the two assemblages displaying this lesion, 1 was *not consistent* (2.1%), 27 *consistent* (57.4%), 16 *highly consistent* (34%) and 3 *diagnostic* (6.4%). The most prevalent age group for adults became younger as evidence for leprosy increased, with 46+ years the most prevalent age group for *not consistent* (2.9% of individuals that displayed the lesion being of that age and falling into that Lepro-C category) and *consistent* (25.7%), and 17-25 years the most

prevalent age group for *highly consistent* (15%) and 26-35 for *diagnostic* (6.3%). Lepro-C and acroosteolysis in relation to age is summarised in Table 5.73 and Fig. 5.58.

Table 5.73: Overall summary of Lepro-C categories of individuals affected by acroosteolysis by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories							
	Not Consistent		*Consistent*		*Highly Consistent*		*Diagnostic*	
Age (years)	N	%	N	%	N	%	N	%
12-14	-	-	-	-	1	14.3	-	-
14-16	-	-	-	-	1	20.0	-	-
17-25	-	-	4	20.0	3	15.0	-	-
26-35	-	-	7	14.6	7	14.6	3	6.3
36-45	-	-	4	11.8	4	11.8	-	-
46+	1	2.9	9	25.7	-	-	-	-
Adult	-	-	3	20	-	-	-	-
Total	**1**		**27**		**16**		**3**	

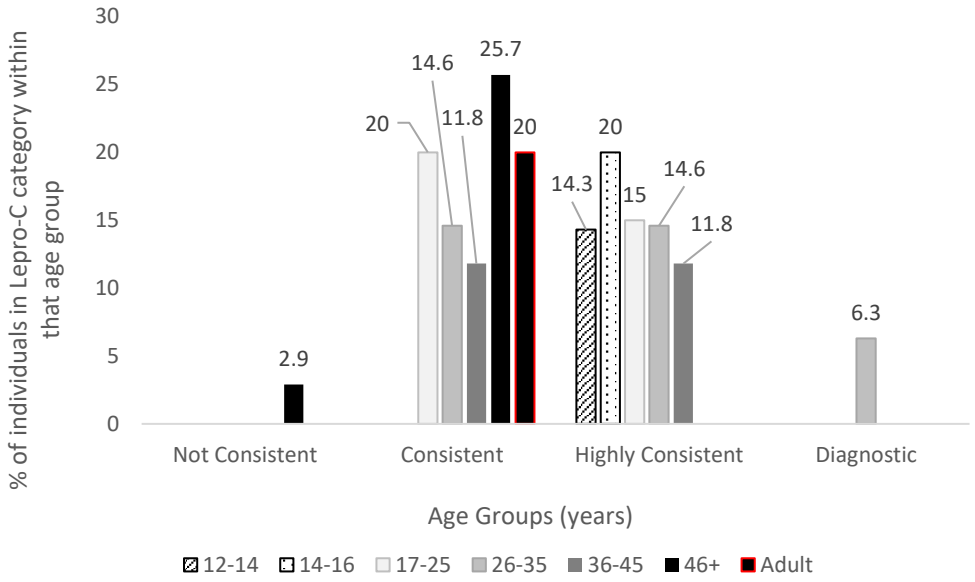


Fig. 5.58: Proportion (%) of individuals within age groups affected by acroosteolysis in each Lepro-C category.

5.2.8.2 Lytic (peri-)articular Lesions

5.2.8.2.1 Chichester

At Chichester, 21 individuals displayed articular or peri-articular lytic lesions, of 124 where these could be assessed (16.9%). Of these, 16 of 84 males (19.1%), 1 of 17 females (5.9%) and 4 of 23 indeterminate sex individuals (17.4%), were affected (Table 5.74; Fig. 5.59). For males, the most affected age group displaying these lesions was aged 46+ years, with 9 individuals affected (36.0% of males that age). Ten males were affected bilaterally (62.5%). The female displaying these lesions was aged 26-35 years (16.7% of females that age), and was affected bilaterally. There was no pattern for the indeterminate sex individuals.

5.2.8.2.2 Winchester

At Winchester, 28 individuals displayed articular or peri-articular lytic lesions, of 116 where these could be assessed (24.1%). Of these, 20 of 61 males (32.9%), 5 of 27 females (18.5%), and 3 of 28 indeterminate sex individuals (10.7%), were affected. For males where an age could be determined, these lesions were most prevalent in the 26-35 year age group, with 9 individuals affected (60% of males that age). Rates of these lesions then decreased in older age groups, with 4 individuals aged 36-45 years affected (33.3%), and three aged 46+ years (23.1%). Thirteen males were affected bilaterally (65%). For females, 36-45 years was the most affected age group (75% of females that age). Four females were affected bilaterally (80%). There was no pattern for the indeterminate sex individuals.

Table 5.74: Male and female individuals affected by lytic articular lesions in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	M		F		M		F	
Age group	N	%	N	%	N	%	N	%
17-25	-	-	-	-	2	28.6	1	16.7
26-35	2	7.7	1	16.7	9	60.0	1	25
36-45	4	19.1	-	-	4	33.3	3	75
46+	9	36.0	-	-	3	23.1	-	-
Adult	1	16.7	-	-	2	66.6	-	-
Total	**16**		**1**		**20**		**5**	

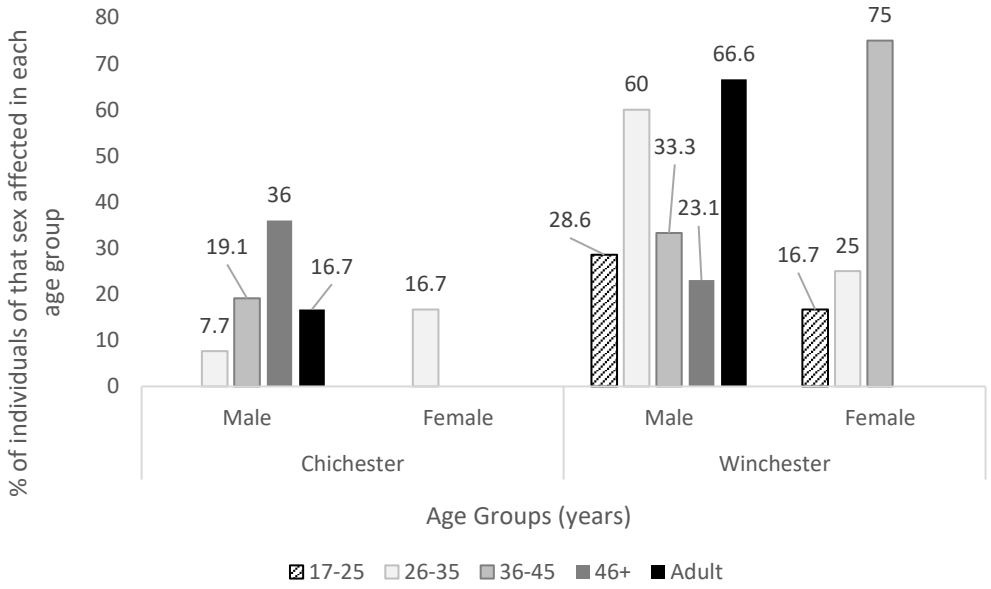


Fig. 5.59: Proportion (%) of individuals within sex and age groups affected by (peri)articular lytic lesions at Chichester and Winchester.

5.2.8.2.3 Lepro-C and Lytic (peri)articular Lesions

Of the 49 individuals across the two assemblages displaying this lesion, 6 were *not consistent* (12.2%), 27 *consistent* (55.1%), 13 *highly consistent* (26.5%) and 3 *diagnostic* (6.1%). The most prevalent age group for *highly consistent* was 36-45, with 5 (10.9%) individuals of this age displaying the lesion and falling into that Lepro-C category and the most prevalent for *diagnostic* was 26-35 years with 2 (3.4%) individuals displaying the lesion and falling into that Lepro-C category. The most common age group displaying this lesion and categorised as *consistent* with leprosy were 46+ (19.1%). Lepro-C and palmar grooving in relation to age are summarised in Table 5.75 and Fig. 5.60.

Table 5.75: Overall summary of Lepro-C categories of individuals affected by lytic (peri)articular lesions by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories							
	Not Consistent		*Consistent*		*Highly Consistent*		*Diagnostic*	
Age group	N	%	N	%	N	%	N	%
12-14	-	-	-	-	1	14.3	-	-
17-25	-	-	2	8.0	1	4.0	-	-
26-35	-	-	7	12.1	6	10.3	2	3.4
36-45	3	6.5	4	8.7	5	10.9	1	2.3
46+	3	6.4	9	19.1	1	2.1	-	-
Adult	-	-	5	18.5	-	-	-	-
Total	**6**		**27**		**13**		**3**	

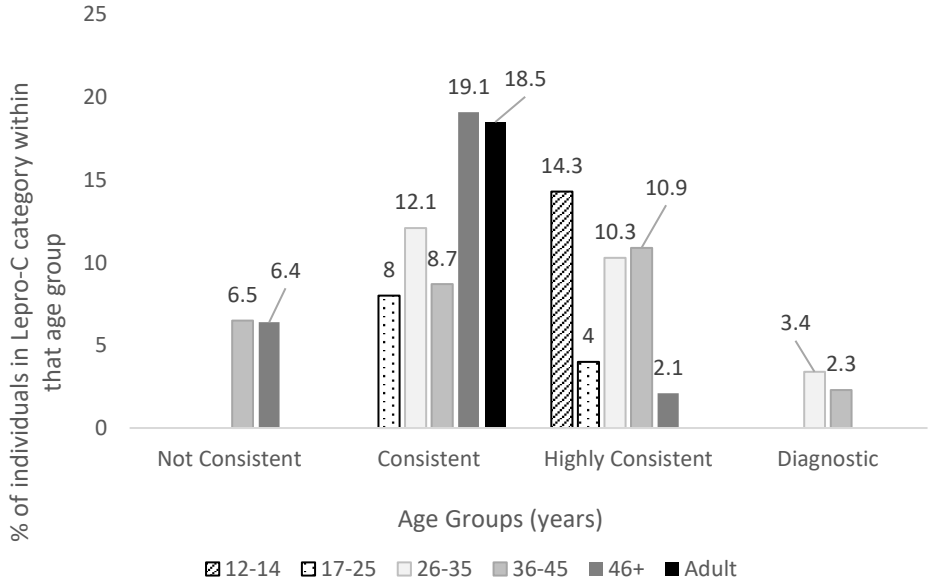


Fig. 5.60: Proportion (%) of individuals within age groups affected by lytic (peri)articular lesions in each Lepro-C category.

5.2.8.3 (Peri)articular osteophyte formation

5.2.8.3.1 Chichester

At Chichester, 39 individuals displayed articular or peri-articular osteophyte formation, of 124 where this could be assessed (31.5%) (Table 5.76; Fig. 5.61). Of these, 27 of 84 males (32.1%), 4 of 17 females (23.5%), and 8 of 24 indeterminate sex individuals (33.3%), were affected. For males, articular or peri-articular osteophyte formation was most prevalent in the 46+ years age group, with 17 males affected (68% of males that age). Twenty-four individuals were affected bilaterally (88.9%). For females, the most affected age group was 26-35 years, with 3 individuals affected (60% of females that age). Three females were affected bilaterally (75%). There was no pattern for the indeterminate sex individuals.

5.2.8.3.2 Winchester

At Winchester, 40 individuals displayed articular or peri-articular osteophyte formation, of 117 where this could be assessed (34.2%). Of these, 26 of 61 males (42.6%), 8 of 27 females (29.6%), and 6 of 29 indeterminate sex individuals (20.7%) were affected. For males where an age could be determined, 46+ years was the most affected age group, with 10 individuals affected (76.9% of males that age), with 26-35 years the next most prevalent group (23.1%). Twenty males were affected bilaterally (76.9%). The most affected age group for females was 36-45 years (75% of

females that age). All females were affected bilaterally. There was no pattern for the indeterminate sex individuals.

Table 5.76: Summary of male and female individuals affected by (peri)articular osteophyte formation in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	M		F		M		F	
Age group	N	%	N	%	N	%	N	%
14-16	-	-	-	-	-	-	1	100
17-25	-	-	-	-	3	42.9	-	-
26-35	5	19.2	1	16.7	6	40.0	2	50.0
36-45	4	19.1	3	60	5	41.7	3	75.0
46+	17	68.0	-	-	10	76.9	2	40
Adult	1	16.7	-	-	2	66.6	-	-
Total	**27**		**4**		**26**		**8**	

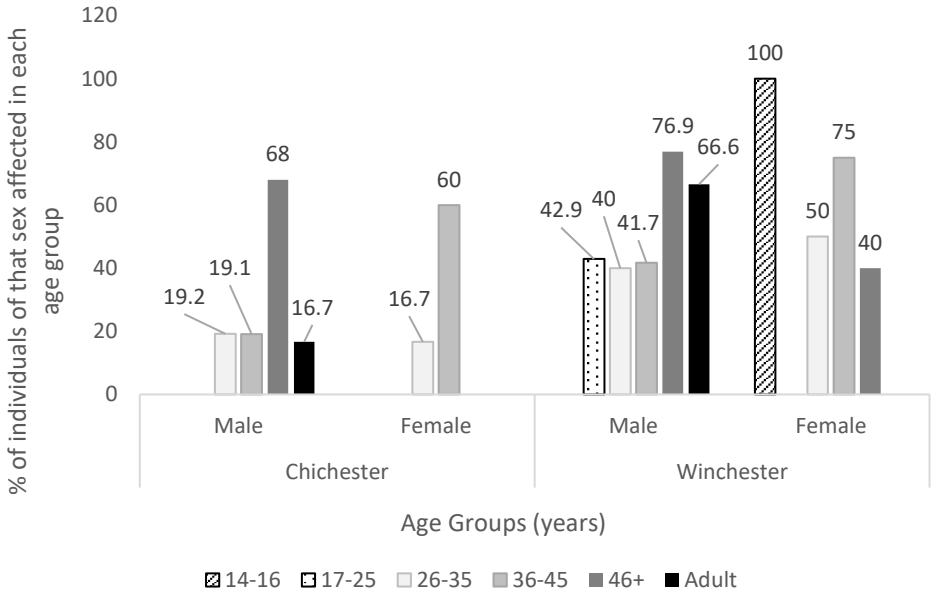


Fig. 5.61: Proportion (%) of individuals within sex and age groups affected by (peri)articular osteophyte formation at Chichester and Winchester.

5.2.8.3.3 Lepro-C and (Peri)articular Osteophyte Formation

Of the 79 individuals across the two assemblages displaying this lesion, 25 were *not consistent* (31.6%), 37 *consistent* (46.8%), 15 *highly consistent* (19%) and 2 *diagnostic* (2.5%). The most prevalent adult age group became younger as evidence for leprosy increased, with 46+ years the most prevalent age group for *not consistent* (34% of individuals that age displaying the lesion falling into that Lepro-C category) and *consistent* (29.8%), and 26-35 years the most prevalent group for

highly consistent (12.1%) and *diagnostic* (3.4%). Lepro-C and (peri)articular osteophyte formation in relation to age is summarised in Table 5.77 and Fig. 5.62.

Table 5.77: Lepro-C categories for all individuals affected by (peri)articular osteophyte formation by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories							
	Not Consistent		*Consistent*		*Highly Consistent*		*Diagnostic*	
Age group	N	%	N	%	N	%	N	%
12-14	-	-	-	-	1	14.3	-	-
14-16	-	-	-	-	1	20	-	-
17-25	-	-	3	12.0	-	-	-	-
26-35	-	-	6	10.3	7	12.1	2	3.4
36-45	6	13.0	8	17.4	4	8.7	-	-
46+	16	34.0	14	29.8	2	4.3	-	-
Adult	3	10.3	6	20.7	-	-	-	-
Total	**25**		**37**		**15**		**2**	

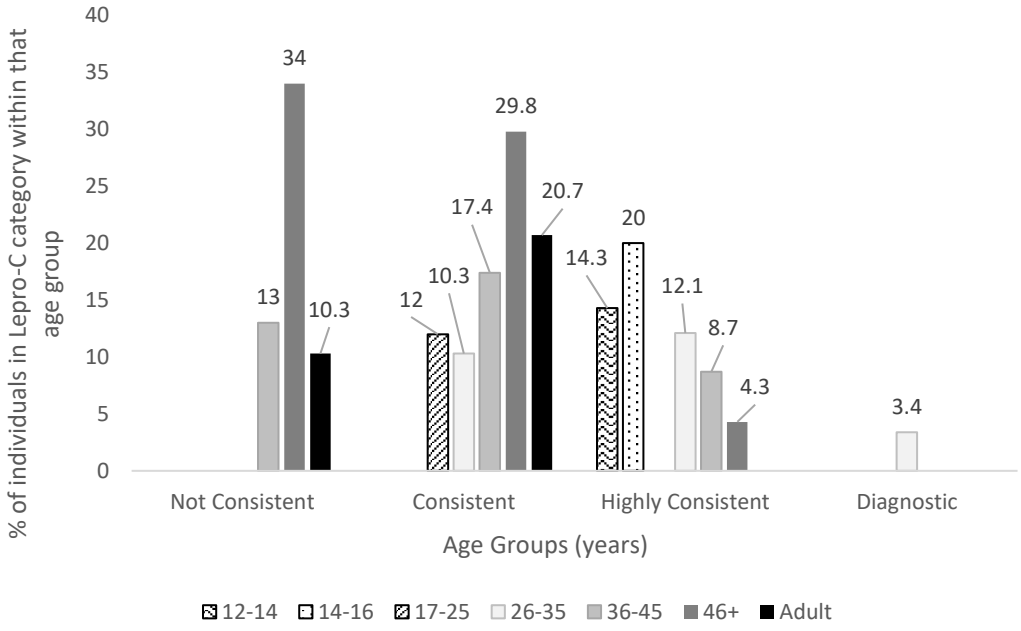


Fig. 5.62: Proportion (%) of individuals within age groups affected by (peri)articular osteophyte formation by percentage of age group affected.

5.2.8.4 Periosteal New Bone Formation Around Nutrient Foramen

5.2.8.4.1 Chichester

At Chichester, 14 individuals displayed periosteal new bone formation (PNBF) around nutrient foramen, of 127 where this could be assessed (11%) (Table 5.78; Fig. 5.63). Of these, 10 of 85 males

(11.8%), 2 of 16 females (12.5%) and 2 of 26 indeterminate sex individuals (7.7%). For males, the three age groups displaying this lesion were similarly affected, with three individuals in the 26-35, 36-45, and 46+ year age groups, however 36-45 year age group was most prevalent, with 13.6% of males that age affected. The lesion presented unilaterally in 8 individuals (80%). The two females were aged 26-35 and 36-45 years, the former bilaterally, and the latter unilaterally. There was no pattern for the indeterminate sex individuals.

5.2.8.4.2 Winchester

At Winchester, 18 individuals displayed PNBF around nutrient foramen, of 118 where this could be assessed (15.3%). Of these, 11 of 61 males (18%), 6 of 27 females (22.2%) and 1 of 30 indeterminate sex individuals (3.3%), were affected. For males, PNBF around nutrient foramen were most prevalent in the 26-35 year age group, with 6 individuals affected (40.0% of males that age). Rates then reduced in the 36-45 and 46+ year age groups, with 1 individual affected in each group (8.3-7.8% of those age groups respectively). Seven males were affected unilaterally (63.6%). For females, 36-45 year olds were most affected (50%). Four females were affected bilaterally (66.7%).

Table 5.78: Summary of male and female individuals affected by periosteal new bone formation around nutrient foramen in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	M		F		M		F	
Age group	N	%	N	%	N	%	N	%
12-14	-	-	-	-	-	-	1	33.3
17-25	-	-	-	-	2	28.6	2	33.3
26-35	3	11.5	1	2.6	6	40.0	-	-
36-45	3	13.6	1	3.3	1	8.3	2	50
46+	3	12.0	-	-	1	7.8	1	20
Adult	1	10	-	-	1	33.3	-	-
Total	**10**		**2**		**11**		**6**	

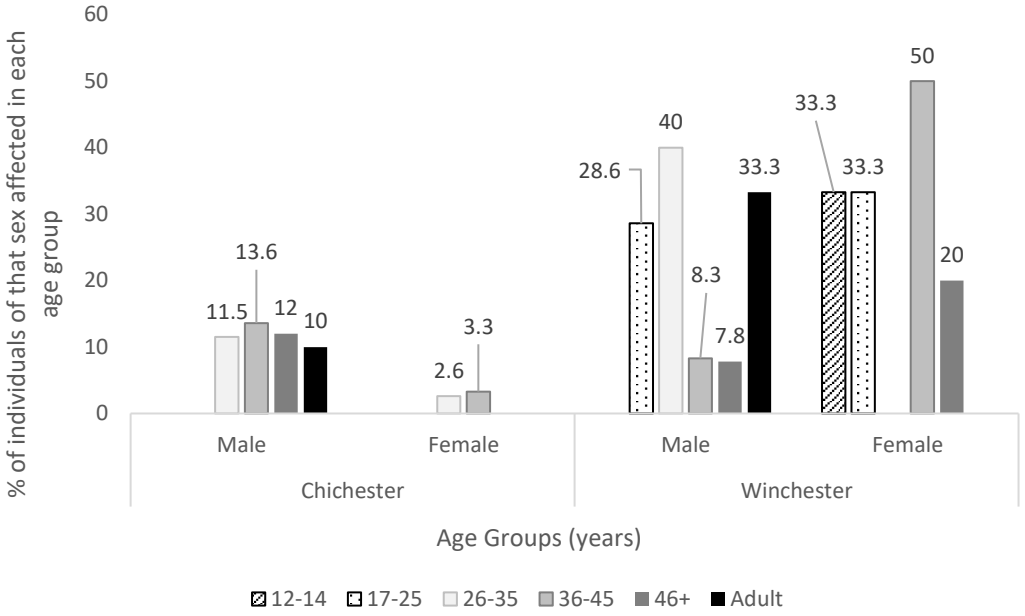


Fig. 5.63: Proportion (%) of individuals within sex and age groups affected by periosteal new bone formation around nutrient foramen at Chichester and Winchester.

5.2.8.4.3 Lepro-C and Periosteal New Bone Formation Around Nutrient Foramen

Of the 32 individuals across the two assemblages displaying this lesion, 21 were *consistent* (65.6%) and 11 *highly consistent* (34.4%). For *consistent*, 17-25 year old individuals were most prevalent, with 16% of individuals that age displaying the lesion and falling into that Lepro-C category. Older adult age groups became more dominant as evidence for leprosy increased, with 26-35 and 36-45 year old individuals most prevalent for *highly consistent*, with 8.5% of individuals displaying the lesion being of that age and falling into that Lepro-C category. Lepro-C and lesions to the periosteal new bone formation around nutrient foramen in relation to age is summarised in Table 5.79 and Fig. 5.64.

Table 5.79: Overall summary of Lepro-C categories of individuals affected by periosteal new bone formation around nutrient foramen by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories			
	Consistent		*Highly Consistent*	
Age group	N	%	N	%
12-14	-	-	1	14.3
17-25	4	16.0	1	4.0
26-35	5	8.5	5	8.5
36-45	4	8.5	4	8.5
46+	5	10.6	-	-
Adult	3	9.7	-	-
Total	**21**		**11**	

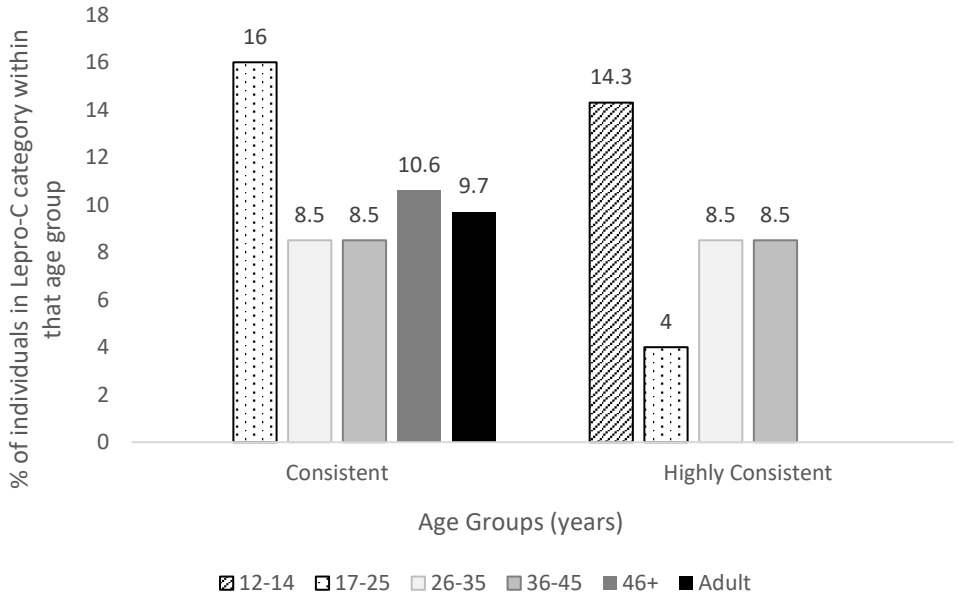


Fig. 5.64: Proportion (%) of individuals within age groups affected by periosteal new bone formation around nutrient foramen in each Lepro-C category.

5.2.8.5 Enlargement of Nutrient Foramen

5.2.8.5.1 Chichester

At Chichester, 16 individuals were displayed enlargement of nutrient foramen, of 127 where this was assessed (12.6%) (Table 5.80; Fig. 5.65). Of these, 13 of 85 males (15.3%), 2 of 16 females (12.5%) and 1 of 26 indeterminate sex individuals (3.8%), were affected. For males, enlargement of nutrient foramen was most prevalent in the 26-35 year age group, with 5 individuals affected (19.2%

of males that age), with a reduction in rates into the 36-45 and 46+ year age groups with four individuals affected in each of these age groups (18.2% and 16% of males that age respectively). Ten males were affected unilaterally (76.9%). There was no pattern in the female or indeterminate sex individuals.

5.2.8.5.2 Winchester

At Winchester, 16 individuals presented with this lesion, of 118 where this was assessed (13.6%). Of these, 10 of 61 males (16.4%), 5 of 27 females (18.5%) and 1 of 30 indeterminate sex individuals (3.3%). For males, enlargement of nutrient foramen was most prevalent in the 26-35 year age group, with 7 individuals affected (46.7% of males that age). There was a reduction in rates in the 36-45 and 46+ year age groups, with 2 (16.7%) and 1 (7.7%) individuals affected. Nine males were affected unilaterally (90%). For females, 26-35 years was the most affected age group, with two individuals affected (50% each). Four females were affected unilaterally (80%).

Table 5.80: Summary of male and female individuals affected by enlargement of nutrient foramen in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	M		F		M		F	
Age group	N	%	N	%	N	%	N	%
12-14	-	-	-	-	-	-	1	33.3
17-25	-	-	-	-	-	-	2	33.3
26-35	5	19.2	1	16.7	7	46.7	2	50
36-45	4	18.2	-	-	2	16.7	-	-
46+	4	16.0	-	-	1	7.7	-	-
Adult	-	-	1	25.0	-	-	-	-
Total	**13**		**2**		**10**		**5**	

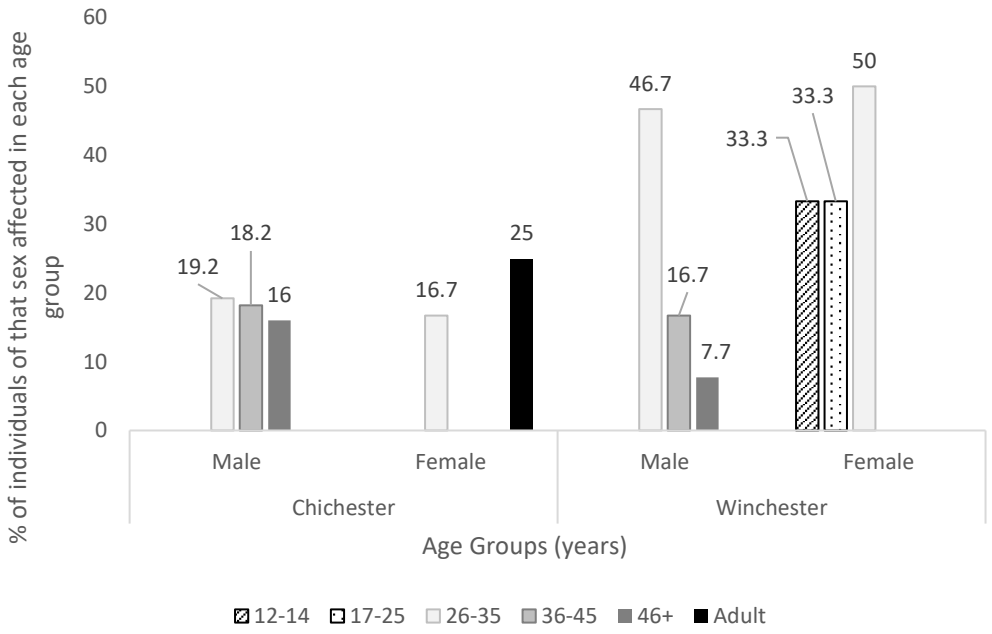


Fig. 5.65: Proportion (%) of individuals within sex and age groups affected by enlargement of nutrient foramen Chichester and Winchester.

5.2.8.5.3 Lepro-C and Enlargement of Nutrient Foramen

Of the 32 individuals across the two assemblages displaying this lesion, 3 were *not consistent* (13.6%), 21 *consistent* (65.6%) and 8 *highly consistent* (25%). Younger age groups became more dominant as evidence for leprosy increased, with 26-35 years being the most prevalent age group for *consistent* with 10 individuals affected (16.9% of that age displaying the lesion falling into that Lepro-C category) and 12-14 for *highly consistent* (14.3%). This is in contrast to *not consistent* individuals, where 36-45, 46+ and 'adult' are the only year age groups represented, with an individual in each group. Lepro-C and enlargement of nutrient foramen in relation to age is summarised in Table 5.81 and Fig. 5.66.

Table 5.81: Overall summary of Lepro-C categories of individuals affected by enlargement of nutrient foramen by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories					
	Not Consistent		*Consistent*		*Highly Consistent*	
Age group	N	%	N	%	N	%
12-14	-	-	-	-	1	14.3
17-25	-	-	-	-	2	8.0
26-35	-	-	10	16.9	5	8.5
36-45	1	2.1	7	14.9	-	-
46+	1	2.1	4	8.5	-	-
Adult	1	3.2	-	-	-	-
Total	**3**		**21**		**8**	

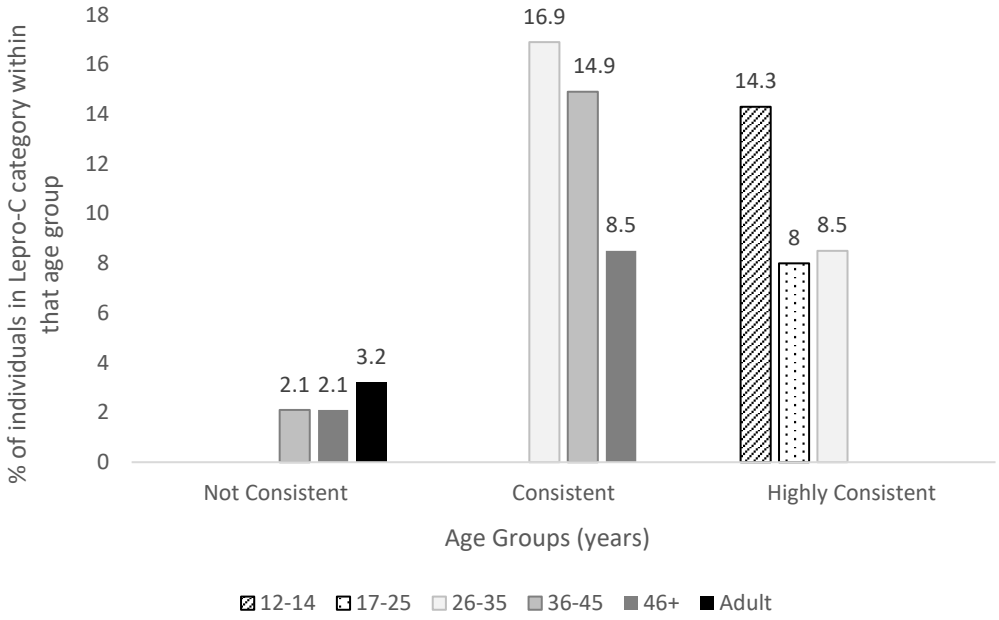


Fig. 5.66: Proportion (%) of individuals within age groups affected by enlargement of nutrient foramen aperture in each Lepro-C category.

5.2.8.6 Dactylitis

5.2.8.6.1 Chichester

At Chichester, 1 individual displayed evidence of dactylitis, of 110 where this could be assessed (0.9%) (Table 5.82; Fig. 5.67). The individual was male and aged 26-35 years.

5.2.8.6.2 Winchester

In Winchester, 2 individuals displayed evidence of dactylitis, of 114 where this could be assessed (1.8%). The individuals were both male and aged 26-35 and 46+ years respectively.

Table 5.82: Summary of male and female individuals affected by dactylitis in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	M		F		M		F	
Age group	N	%	N	%	N	%	N	%
26-35	1	4.0	-	-	1	6.7	-	-
46+	-	-	-	-	1	7.7	-	-
Total	**1**		**0**		**2**		**0**	

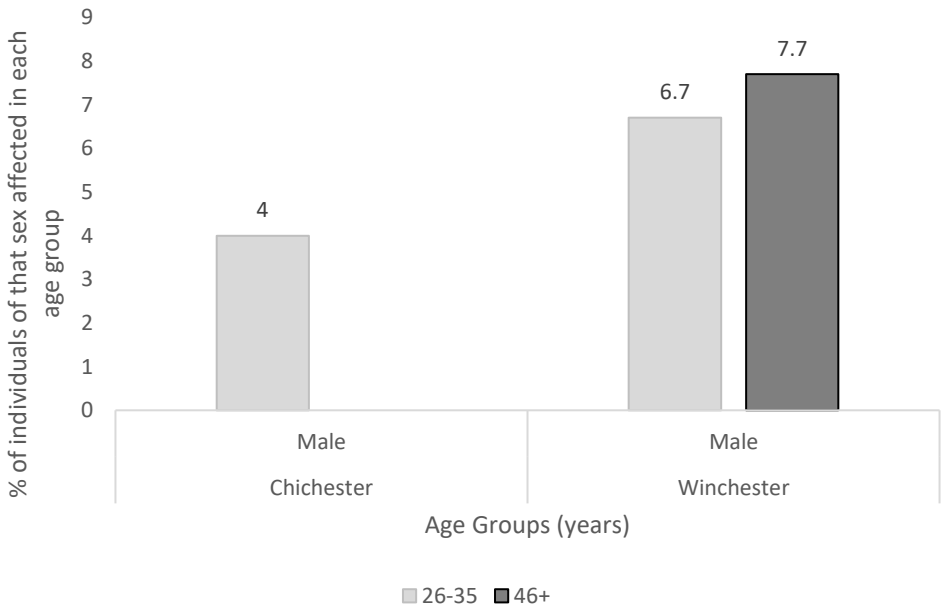


Fig. 5.67: Proportion (%) of individuals within sex and age groups affected by dactylitis at Chichester and Winchester.

5.2.8.6.3 Lepro-C and Dactylitis

Of the 3 individuals across the two assemblages displaying this lesion, 2 were *highly consistent* (66.7%) and 1 *diagnostic* (33.3%). Individuals aged 26-35 years were present in the *highly consistent* and *diagnostic* categories, with an individual in each. The remaining individual was aged 46+ years and was *highly consistent*. Lepro-C and dactylitis in relation to age is summarised in Table 5.83 and Fig. 5.68.

Table 5.83: Overall summary of Lepro-C categories of individuals affected by dactylitis by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories			
	Highly Consistent		*Diagnostic*	
Age group	N	%	N	%
26-35	1	4.2	1	4.2
46+	1	2.2	-	-
Total	2		1	

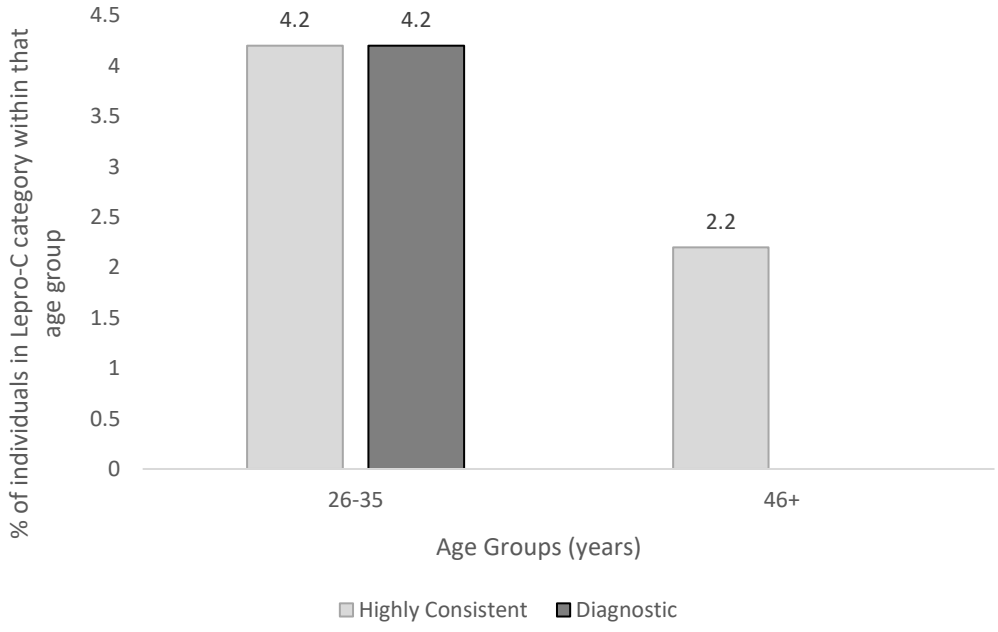


Fig. 5.68: Proportion (%) of individuals within age groups affected by in each Lepro-C category.

5.2.8.7 Osteomyelitis

5.2.8.7.1 Chichester

At Chichester, 12 individuals displayed osteomyelitis, of 127 where this was assessed (9.5%) (Table 5.84; Fig. 5.69). Of these, 9 of 85 males (10.6%), 1 of 17 females (5.9%) and 2 of 25 indeterminate sex individuals (8%) were affected. For males, osteomyelitis was most prevalent in 36-45 year age group, with three individuals affected (13.6% of males that age). Rates then reduced in the 46+ years age group, with 2 individuals affected (8%). Five males were affected bilaterally (55.6%). The female individual was aged 26-35 years and affected unilaterally. There was no pattern in the indeterminate sex individuals.

5.2.8.7.2 Winchester

At Winchester, 5 individuals displayed osteomyelitis, of 118 where this could be assessed (4.2%). All 5 were male, of 61 males where this could be assessed (8.2%). Where an age could be determined, the 46+ year age group was most affected, with two individuals affected (15.4% of males that age). Three individuals were affected bilaterally.

Table 5.84: Summary of male and female individuals affected by osteomyelitis in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	M		F		M		F	
Age group	N	%	N	%	N	%	N	%
26-35	3	11.5	1	16.7	2	13.4	-	-
36-45	3	13.6	-	-	-	-	-	-
46+	2	8.0	-	-	2	15.4	-	-
Adult	1	16.7	-	-	1	33.3	-	-
Total	**9**		**1**		**5**		**0**	

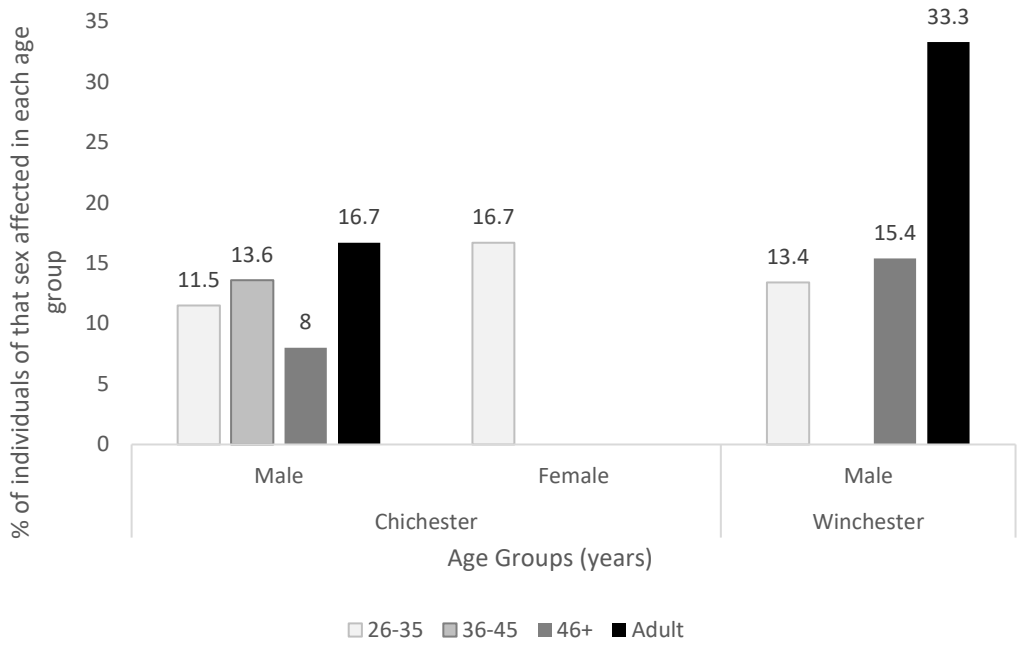


Fig. 5.69: Proportion (%) of individuals within sex and age groups affected by osteomyelitis at Chichester and Winchester.

5.2.8.7.3 Lepro-C and Osteomyelitis

Of the 17 individuals across the two assemblages displaying this lesion, 1 was *not consistent* (5.9%), 12 were *consistent* (70.6%), 3 *highly consistent* (17.6%) and 1 *diagnostic* (5.9%). While 26-35 years was the most prevalent age groups for those in the *consistent* (6.9% of individuals that age displaying the lesion and being in that Lepro-C category) and *highly consistent* categories (3.5%), the *diagnostic* individual was aged 36-45 (2.1%). Lepro-C and osteomyelitis in relation to age is summarised in Table 5.85 and Fig. 5.70.

Table 5.85: Overall summary of Lepro-C categories of individuals affected by osteomyelitis by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories							
	Not Consistent		*Consistent*		*Highly Consistent*		*Diagnostic*	
Age group	N	%	N	%	N	%	N	%
9-10	-	-	1	3.3	-	-	-	-
26-35	-	-	4	6.9	2	3.5	-	-
36-45	1	2.1	2	4.3	-	-	1	2.1
46+	-	-	3	6.4	1	2.1	-	-
Adult	-	-	2	6.5	-	-	-	-
Total	**1**		**12**		**3**		**1**	

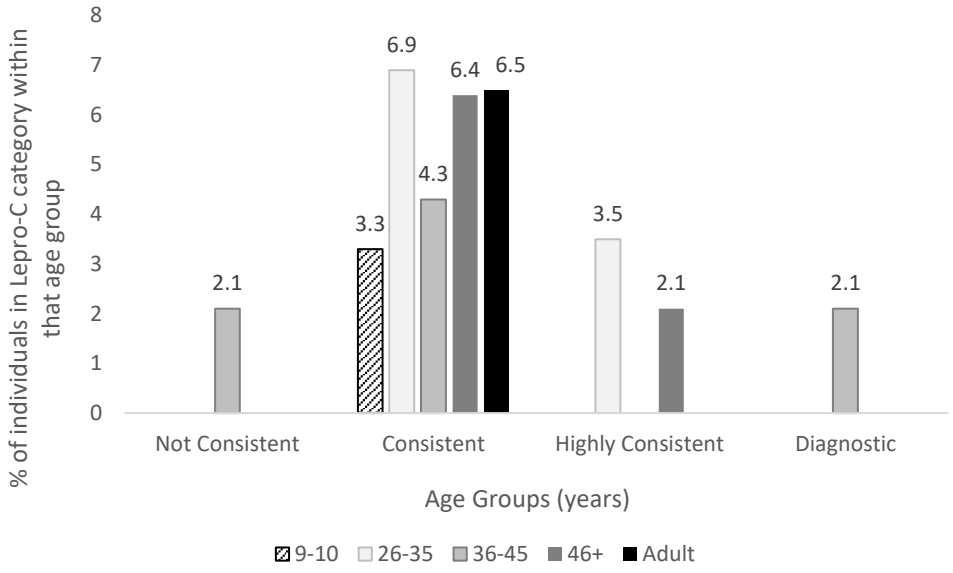


Fig. 5.70: Proportion (%) of individuals within age groups affected by osteomyelitis in each Lepro-C category.

5.2.8.8 Osteitis

5.2.8.8.1 Chichester

At Chichester, 12 individuals displayed osteitis, of 127 where this was assessed (9.5%) (Table 5.86; Fig. 5.71). Of these, 9 of 85 males (10.6%) and 3 of 25 indeterminate sex individuals (12%), were affected. For males, osteitis was most prevalent in the 36-45 year age group, with 4 individuals affected (18.2% of males that age). Five males were affected unilaterally (55.5%). There was no pattern in the indeterminate sex individuals.

5.2.8.8.2 Winchester

At Winchester, 9 individuals displayed osteitis, of 119 where this was assessed (7.6%). Of these, 4 of 61 males (6.6%), 3 of 28 females (10.7%), and 2 of 30 indeterminate sex individuals (6.7%), were affected. For males where an age could be determined, osteitis was most prevalent in the 26-35 year age group, with 2 individuals affected (13.3% of males that age). Three males were affected unilaterally (75%). The female individuals were aged 17-25 and 36-45 years old respectively, with most female individuals displaying osteitis being aged 36-45 (50% of females that age), bilaterally in all cases.

Table 5.86: Summary of male and female individuals affected by osteitis in Chichester and Winchester by age group. Percentage shows the proportion of individuals of that age and sex that were affected by the lesion.

	Chichester				Winchester			
	M		F		M		F	
Age group	N	%	N	%	N	%	N	%
17-25	-	-	-	-	-	-	1	16.7
26-35	3	11.6	-	-	2	13.3	-	-
36-45	4	18.2	-	-	-	-	2	50.0
46+	1	4.0	-	-	1	7.7	-	-
Adult	1	16.7	-	-	1	33.3	-	-
Total	**9**		**0**		**4**		**3**	

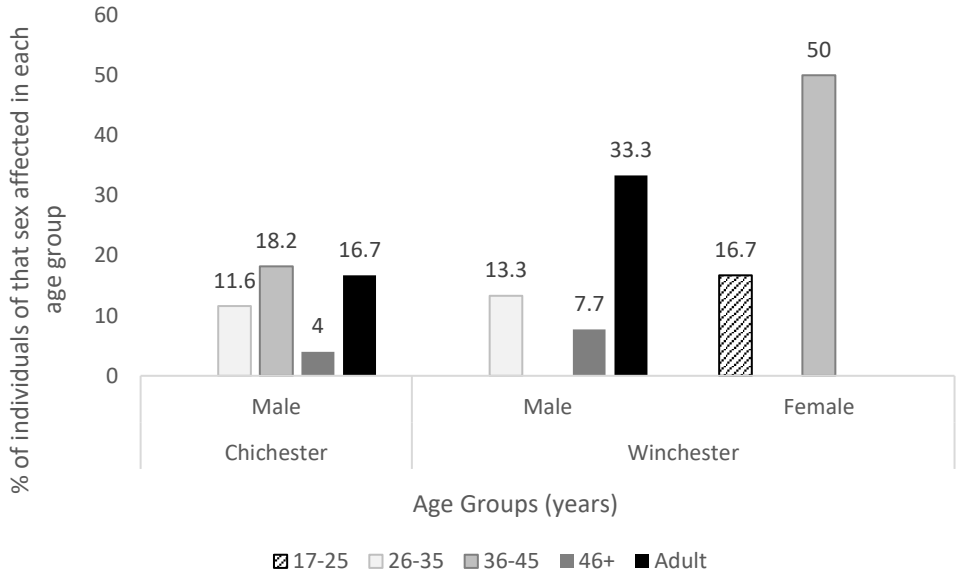


Fig. 5.71: Proportion (%) of individuals within sex and age groups affected by osteitis at Chichester and Winchester.

5.2.8.8.3 Lepro-C and Osteitis

Of the 21 individuals across the two assemblages displaying this lesion, 1 was *not consistent* (4.8%), 14 were *consistent* (66.6%) and 6 *highly consistent* (28.6%). For age groups, 17-25, 26-35 and 36-45 years became dominant as evidence for leprosy increased, although there were no *diagnostic* individuals displaying this lesion. Lepro-C and osteitis in relation to age is summarised in Table 5.87 and Fig. 5.72.

Table 5.87: Overall summary of Lepro-C categories of individuals affected by osteitis by age group. Percentage shows the proportion of individuals within that age group that were in that Lepro-C category.

	Lepro-C Categories					
	Not Consistent		*Consistent*		*Highly Consistent*	
Age group	N	%	N	%	N	%
17-25	-	-	1	4.0	1	4.0
26-35	-	-	2	3.5	3	5.2
36-45	-	-	4	8.5	2	4.3
46+	-	-	3	6.4	-	-
Adult	1	3.1	4	12.5	-	-
Total	**1**		**14**		**6**	

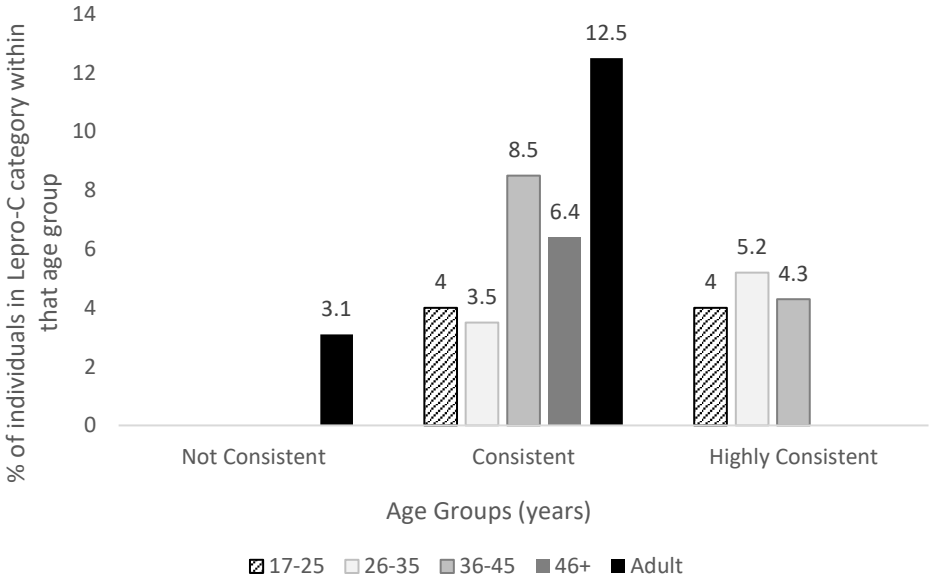


Fig. 5.72: Proportion (%) of individuals within age groups affected by osteitis by Lepro-C category of affected individuals.

5.2.9 Statistics of Lesions that Could Occur on the Upper or Lower Extremities

5.2.9.1 Age

5.2.9.1.1 Phi Coefficient

Lesions that could occur on the upper or lower extremities were tested against adult age groups using Phi coefficient. (Peri)articular osteophyte formation showed the strongest relationship to age groups, with negative (phi = -.220, p = .003) and positive (phi = .342, p = <.001) Phi values to the 17-25 year age group, and 46+ year age group respectively, in each case significant to the 0.01 level. Enlargement of nutrient foramina was also positively related to the 26-35 year age group (Phi = 0.164). The Phi coefficients are summarised in Table 5.88 below.

Table 5.88: Summary of Phi coefficient between lesions that could occur on the upper or lower postcranial skeleton and age groups of individuals displaying these lesions.

	Lesion							
Age group		Lytic (Peri)articular Lesions	(Peri)articular Osteophyte Formation	PNBF Nutrient Foramen	Enlargement Nutrient Foramen	Dactylitis	Osteomyelitis	Osteitis
17-25	Phi	-0.116	-0.220*	0.048	-0.094	-0.054	-0.118	-0.014
	Sig.	.123	.003	.521	.208	.483	.116	.853
26-35	Phi	0.028	-0.177	0.027	0.164	0.097	0.065	-0.008
	Sig.	.714	.018	.721	.028	.206	.387	.918
36-45	Phi	0.040	0.029	0.034	0.016	-0.07	0.022	0.043
	Sig.	.598	.697	.651	.834	.314	.769	.567
46+	Phi	0.032	0.342*	-0.092	-0.108	0.016	0.007	-0.018
	Sig.	.670	<.001	.221	.151	.839	.928	.814

* = significant at .01

5.2.9.1.2 Binomial Logistic Regression

Binomial logistic regression was used as it allows to test the affect that multiple independent variables had on the presence/absence of lesions. The analysis included adult individuals where a year age group could be determined. Individuals aged 46+ were automatically excluded from the analysis when running the regression model on SPSS due to redundancy (i.e. the presence/absence values could be predicted from the other three adult age categories). Therefore, the regression

models test the effect that individuals age (17-25, 26-35, and 36-45 year age groups) had on the presence and absence of lesions. These were also the adult age groups most affected by lesions overall, so it is interesting to see their effect on the regression models. The effects of sex and site were also tested. Only lesions where there were 10 or more individuals affected were tested, as recommended for regression testing (van Smeden et al., 2016).

For independent variables, age was found to have a significant effect on the model for the (peri)articular osteophyte formation, particularly individuals aged 17-25 (Wald = 13.423, p = <.001) and 26-35 years (Wald = 13.182, p = <.001). However, all ages had a significant effect for this lesion in the regression model. The regression indicated also that individuals at Winchester were much more likely to display acroosteolysis (Wald = 6.455, p = .011) and lytic (peri)articular lesions (Wald = 7.634, p = .006) at Winchester than in Chichester. The regression analysis indicates that age, sex and site did not have a strong influence on the presence of the other lesions that could occur on the upper and lower extremities. The details of the binomial logistic regressions for these lesions are in Table 5.89.

Table 5.89: Binomial logistic regressions for lesions that could occur on the upper and lower extremities

	Independent variables					
Lesion		**Age**				
Acroosteolysis	**17-25**	**26-35**	**36-45**	**Site**	**Sex**	**P value of overall model**
Wald/Chi	.589	2.494	.038	6.455	.013	10.303
Sig (p)	.443	.114	.845	.011	.908	.067
Odds ratio	1.669	2.321	1.124	2.993	.941	
Lytic (peri-)articular lesions	**17-25**	**26-35**	**36-45**	**Site**	**Sex**	
Wald/Chi	1.554	.012	.001	7.634	1.260	9.826
Sig (p)	.213	.912	.981	.006*	.262	.080
Odds ratio	.398	.948	.988	2.970	1.798	
(Peri)articular osteophyte formation	**17-25**	**26-35**	**36-45**	**Site**	**Sex**	
Wald/Chi	13.423	13.812	8.006	4.630	.014	27.708
Sig (p)	<.001*	<.001*	.005*	.031	.907	.463
Odds ratio	.066	.179	.265	2.247	1.057	
PNBF Nutrient Foramen	**17-25**	**26-35**	**36-45**	**Site**	**Sex**	
Wald/Chi	.289	1.172	.474	2.629	.328	4.630
Sig (p)	.591	.279	.491	.105	.567	.498
Odds ratio	1.503	1.916	1.553	2.075	.744	
Enlargement of Nutrient Foramen	**17-25**	**26-35**	**36-45**	**Site**	**Sex**	
Wald/Chi	.067	4.441	.173	1.533	.166	8.274
Sig (p)	.796	.035	.677	.216	.683	.142
Odds ratio	.792	3.335	1.312	1.724	1.259	
Osteomyelitis	**17-25**	**26-35**	**36-45**	**Site**	**Sex**	
Wald/Chi	.000	.217	.099	.233	.795	5.733
Sig (p)	.998	.641	.753	.629	.373	.333
Odds ratio	.000	1.378	.777	.736	2.614	
Osteitis	**17-25**	**26-35**	**36-45**	**Site**	**Sex**	
Wald/Chi	.001	.862	2.004	.055	.004	2.868
Sig (p)	.980	.353	.157	.815	.947	.720
Odds ratio	1.032	2.235	3.334	1.146	.955	

*significant at .008

5.2.9.2 Lepro-C

Most of the lesions in this group were negatively related to the *not consistent* category, and mostly significantly so (see Table 5.92 below). All lesions in this group were also positively related with the *consistent* category, except for dactylitis, which was negatively related with a Phi value of -0.101 (p = .132). The strongest positive Phi value for the *consistent* category was PNBF around nutrient foramen and enlargement of nutrient foramen, both with a Phi value of 0.210 (p = .001) – significant to the 0.01 level. Lytic (peri)articular lesions and dactylitis were strongly positively related to the

diagnostic category, with Phi values of 0.222, 0.324 respectively, all significant to the 0.01 level (p = .001 for both). All Phi coefficients are summarised in Table 5.90 below.

Table 5.90: Summary of Phi coefficient between lesions that could occur on the upper or lower postcranial skeleton and Lepro-C categories of individuals displaying these lesions.

		Lesion						
Lepro-C		Lytic (Peri)articular Lesions	(Peri)articular Osteophyte Formation	PNBF Nutrient Foramen	Enlargement Nutrient	Dactylitis	Osteomyelitis	Osteitis
NC	Phi	-0.254*	-0.105	-0.314*	-0.215*	-0.089	-0.155	-0.217*
	Sig.	.000	.103	.000	.001	.183	.015	.001
C	Phi	0.171*	0.082	0.210*	0.210*	-0.101	0.158	0.180*
	Sig.	.008	.207	.001	.001	.132	.013	.005
HC	Phi	0.060	0.044	0.140	0.044	0.140	0.001	0.051
	Sig.	.356	.497	.029	.492	.036	.991	.427
D	Phi	0.222*	0.001	-0.043	-0.043	0.324*	0.116	-0.34
	Sig.	.001	.984	.501	.501	.000	.071	.596

* = significant at 0.01

5.2.10 Summary of Adult Age Groups Most Affected

The most affected adult age groups for each of the individual lesions is detailed in Table 5.91. Only adult age groups are considered as the non-adult age groups affected by lesions tended to contain just a single individual, inflating the percentages of individuals affected so are not representative. There were also relatively few females, but these have been included see whether there were any patterns compared to the adult males. For adults, the most affected individuals by each lesion tended to be aged 26-35 for males and females. For rhinomaxillary lesions overall, females aged 17-25 years were most affected at Chichester, with females aged 26-35 most affected at Winchester. Males aged 26-35 years were most affected overall at Winchester, whereas males aged 26-35 and 36-45 were jointly most-affected at Chichester across the 5 rhinomaxillary lesions. However, the most affected age group varied for specific lesions for these two age groups at Chichester

For postcranial lesions, males and females aged 26-35 years were most affected overall, although at Winchester females aged 36-45 years were most affected by lesions to the upper limbs, and lytic (peri)articular lesions, (peri)articular osteophyte formation and osteitis.

Table 5.91: Age of individuals most -commonly affected for each lesion.

	Site and Adult Age Group Most Affected (Years)			
	Chichester		Winchester	
Lesion	Male	Female	Male	Female
Cranial – RMS				
Nasal Aperture	26-35	17-25	26-35	17-25/26-35
Anterior Nasal Spine	26-35	17-25	26-35	36-45
Anterior Maxillary Alveolus	36-45	17-25	26-35	17-25/26-35
Oral Palatine Pitting	26-35/36-45	17-25	26-35	26-35
Nasal Palatine Pitting	36-45	17-25	26-35	17-25/26-35
Summary	**26-35/36-45 (60%)**	**17-25 (100%)**	**26-35 (100%)**	**26-35 (80%)**
Cranial - other				
Maxillary Sinusitis	26-35	-	26-35	-
Root malformation	26-35	-	-	-
Summary	**26-35 (100%)**	**-**	**26-35 (100%)**	**-**
Upper lesions				
Palmar Grooving	26-35	26-35	36-45	-
Acroosteolysis	46+	17-25	26-35	17-25/26-35
Absorption of Hand Phalange/MCs	26-35	26-35	17-25	36-45
Concentric Remodelling of Hand Phalanges/MCs	-	-	-	36-45
Distal Humerus	46+	46+	46+	-
Proximal Ulna	26-35	-	26-35	36-45
Summary	**26-35 (60%)**	**26-35 (50%)**	**26-35 (40%)**	**36-45 (75%)**
Lower lesions				
Distal Tibia	36-45	26-35	26-35	17-25
Distal Fibula	26-35	36-45	26-35	17-25
Dorsal Tarsal Exostoses	46+	36-45	36-45/46+	26-35
Navicular Squeezing	46+	26-35	26-35	26-35
Tarsal Disintegration	46+	26-35	36-45/46+	26-35
Ossification of Interosseous Membrane	36-45	-	26-35	26-35
Absorption of Foot Phalanges/MTs	26-35	-	46+	-
Concentric Remodelling of Foot Phalanges/MCs	26-35	17-25	26-35	36-45
Knife-edge Remodelling of Metatarsals	36-45	17-25	46+	17-25
Summary	**26-35;36-45; 46+ (33.3% each)**	**26-35 (43%)**	**26-35 (56%)**	**26-35 (50%)**
Other				
Lytic (peri)articular Lesions	46+	26-35	26-35	36-45
(Peri)articular Osteophyte Formation	46+	36-45	46+	36-45
PNBF Nutrient Foramen	36-45	36-45	26-35	-
Enlargement of Nutrient Foramen	26-35	26-35	26-35	26-35
Dactylitis	26-35	-	46+	-
Osteomyelitis	36-45	26-35	46+	-
Osteitis	36-45	-	26-35	36-45
Summary	**36-45 (43%)**	**26-35 (60%)**	**26-35 (57%)**	**36-45 (75%)**

5.2.11 Intraobserver Error Testing

To test intraobserver agreement and the replicability of identifying the lesions in the Lepro-C method, 20 individuals at Winchester were recorded twice. The first recording took place in two phases in September 2020 and July 2021, with the second recording taking place in December 2023. The second recording was conducted blind. This was done to see if lesions were being consistently identified to test replicability. Testing the agreement can also provide insight into future improvements for the lesions assessed when applying Lepro-C to skeletal remains.

Cohen's kappa was used to test the intraobserver error rates for the lesions under consideration in this study on a subset of 20 individuals from Winchester. The presence and absence of each lesion from the first and second recordings were tested against each other. This was done to test the replicability of the method by seeing if lesions were being identified consistently. Cohen's kappa gives a value of -1 to 1, with -1 being strong disagreement between observers, and 1 being strong agreement. The alpha value for significance was 0.05, as only 1 comparison was made for each test – the presence/absence rate of the lesion each recording, so Bonferroni Correction was not required. (Emerson, 2020).

5.2.11.1 Rhinomaxillary lesions

For RMS lesions, there was agreement on the presence and absence of lesions for both recordings of the 20 individuals at Winchester. There was very strong, and significant, agreement for all RMS lesions apart from absorption of the nasal aperture, in which the agreement was not as strong, but there was still agreement overall. The Cohen's kappa results for intraobserver error testing for rhinomaxillary lesions are available in Table 5.92, and are discussed in section 7.6.5.1.

Table 5.92: Cohen's kappa results for intraobserver error testing of rhinomaxillary lesions

Lesion	**Kappa**	**Significance**
Absorption of Nasal Aperture	.446	.058
Absorption of Anterior Nasal Spine	.865	<.001
Absorption of Anterior Maxillary Alveolus	.852	<.001
Oral Pitting	.780	<.001
Nasal Pitting	.692	.001

5.2.11.2 Postcranial lesions

For postcranial lesions, most had a very strong and significant agreement, suggesting that the assessment of lesions overall was highly consistent, and the method is replicable overall. Several lesions, such as concentric remodelling of metacarpals, were logged as absent for all 20 individuals in both recordings, so no kappa could be calculated. This does demonstrate that the recording of these lesions is replicable, as they were being consistently logged as absent and not erroneously scored as present, but a statistical value cannot be ascribed. The Cohen's kappa results for intraobserver error testing for postcranial lesions are available in Table 5.93. There were two lesions where there was a slight disagreement in the recordings, PNBF around nutrient foramen (kappa = -.071), and osteitis (kappa = -.154).

Table 5.93: Cohen's kappa results for intraobserver error testing of postcranial lesions

Lesion	Kappa	Significance
Palmar Grooving	.459	.015
Lytic (peri-)articular lesions	.800	<.001
(Peri)articular osteophyte formation	.687	001
Acroosteolysis	.222	.317
Absorption of hand phalanges	.640	.004
Absorption of foot phalanges	.821	<.001
Concentric Remodelling of Metacarpals	-	-
Concentric Remodelling of Metacarpals	.692	.001
Knife-Edge Remodelling of Metacarpals	-	-
Knife-Edge Remodelling of Metatarsals	1.000	<.001
Leprogenic odontodysplasia	-	-
Distal Humerus	-	-
Proximal Ulna	.769	<.001
PNBF nutrient foramen	-.071	.732
Enlargement of nutrient foramen	.828	<.001
PNBF Distal Tibia	1.000	<.001
PNBF Distal Fibula	.573	.011
Dorsal Tarsal Exostoses	.400	.068
Navicular Squeezing	-	-
Carpal Tarsal Disintegration	.444	.047

Ossification of Interosseous Membrane	.529	.015
Dactylitis	-	-
Maxillary Sinusitis	-	-
Osteomyelitis	.459	.015
Osteitis	-.154	.456

'-' = the lesion was recorded as absent for all 20 individuals for both recordings, so a kappa value cannot be calculated due to this constant.

5.3 Overall Relationship of Lesions

Phi coefficient was used to test relationships between lesions in the dataset. This test was chosen as it allows us to assess the nature of relationships between variables (e.g., presence/absence of a lesion vs individuals being of a specific age or not), not just whether they are significant or not. The full data of the phi tests, including significance values, are included in Appendix C.

5.3.1 Cranial vs Postcranial

The occurrence of cranial and postcranial lesions overall (i.e., were cranial lesions present - yes/no, were postcranial lesions present – yes/no), which revealed a relationship of 0.345 (p = <.001) that was also significant at 0.01 confidence interval, indicating there was a significant positive relationship between the presence of cranial and post cranial lesions observed in this research, i.e. individuals with cranial lesions tended also to have postcranial lesions, and *vice versa*.

5.3.2 Relationships of Rhinomaxillary Lesions

All five RMS lesions were strongly positively related to each other, with each being significant at the 0.01 level (p = <.001 in all tests). For context, the lowest relationship value was 0.363 for the relationship between nasal pitting and absorption of the anterior maxillary alveolus. All RMS phi relationships are summarised in Table 5.94 below.

Table 5.94: Detail of Phi coefficient between RMS lesions.

Age group	RMS Lesion				
	Nasal Aperture	Anterior Nasal Spine	Anterior Maxillary Alveolus	Oral Pitting	Nasal Pitting
Nasal Aperture	-	0.665*	0.386*	0.377*	0.406*
Anterior Nasal Spine	0.665*	-	0.421*	0.509*	0.425*
Anterior Maxillary Alveolus	0.386*	0.421*	-	0.415*	0.363*
Oral Pitting	0.377*	0.509*	0.415*	-	0.567*
Nasal Pitting	0.406*	0.425*	0.363*	0.567*	-

* = significant at 0.01

5.3.3 Relationship of Rhinomaxillary Lesions with Individual Postcranial Lesions

For postcranial lesions, RMS lesions showed the strongest relationships with tibial and fibular PNBF and lesions to the proximal ulna, with all five RMS lesions being significantly positively related to the 0.01 level, with the lowest value at this significance being 0.204 for the relationship between nasal pitting and proximal ulna lesions. The exception to this was the relationship between oral PNBF on the distal fibula and absorption of the anterior maxillary alveolus (phi = 0.192).

Of the new lesions analysed in this research, lesions to the proximal ulna showed significant positive relationships at the .01 level with all five RMS lesions. Periosteal new bone formation and enlargement of nutrient foramen showed no relationship with RMS lesions, with the exception of oral pitting of the palatine surface, where there was a positive relationship in both cases (phi = 0.172 and 0.150), but not significant. Lesions to the humerus showed no relationship with RMS. The positive relationships for PNBF around nutrient foramen was much stronger for postcranial lesions, with positive relationships between this lesion and PNBF of the distal tibia and fibula, ossification of the interosseous membrane, acroosteolysis, knife-edge and concentric remodelling (foot). PNBF and enlargement of nutrient foramen were positively related as they tended to appear together. Lesions to the distal humerus did not appear at all with RMS lesions, so no coefficient could be calculated, and the only other lesion it showed any relationship to with was the proximal ulna.

There were several other significant relationships between RMS and postcranial lesions, with all phi coefficient values detailed in Table 5.95.

Table 5.95: Detail of phi coefficient between RMS lesions and postcranial lesions.

PC Lesion		RMS Lesion				
		Nasal Aperture	Anterior Nasal Spine	Anterior Maxillary Alveolus	Oral Pitting	Nasal Pitting
Palmar Grooving	Phi	0.043	0.116	0.091	0.032	0.101
	Sig.	.580	.144	.240	.682	.192
Acroosteolysis	Phi	0.155	0.207	0.240*	0.093	0.156
	Sig.	.062	.014	.003	.259	.058
Absorption of Hand Phalanges	Phi	0.234*	0.143	0.112	-0.048	-0.042
	Sig.	.002	.070	.146	.539	.590
Concentric Remodelling of Hand Phalanges	Phi	0.136	0.176*	0.064	-0.091	-0.062
	Sig.	.079	.026	.407	.240	.420
Proximal Ulna	Phi	0.241*	0.239*	0.334*	0.207*	0.204*
	Sig.	.002	.002	<.001	.007	.008
Distal Tibia	Phi	0.328*	0.485*	0.302*	0.409*	0.299*
	Sig.	<.001	<.001	<.001	<.001	<.001
Distal Fibula	Phi	0.302*	0.449*	0.192	0.335*	0.247*
	Sig.	<.001	<.001	.014	<.001	.002
Dorsal Tarsal Exostoses	Phi	0.052	0.202	0.087	-0.065	-0.010
	Sig.	.516	.012	.270	.410	.896
Navicular Squeezing	Phi	0.064	0.024	0.099	0.043	0.093
	Sig.	.460	.773	.216	.592	.247
Tarsal Disintegration	Phi	0.109	0.163	0.057	-0.092	-0.075
	Sig.	.173	.045	.473	.248	.344
Ossification of Interosseous Membrane	Phi	0.232*	0.164	0.229*	0.119	0.077
	Sig.	.003	.040	.003	.127	.324
Absorption of Foot Phalanges	Phi	0.296*	0.289*	0.111	0.044	0.093
	Sig.	<.001	<.001	.171	.586	.250
Concentric Remodelling of Foot Phalanges	Phi	0.151	0.257*	0.082	-0.020	0.050
	Sig.	.055	.001	.301	.803	.525
Knife-edge Remodelling of Foot Phalanges	Phi	0.071	0.056	-0.021	-0.093	-0.032
	Sig.	.372	.488	.786	.238	.685
Lytic (peri)Articular Lesions	Phi	0.170	0.216*	0.069	-0.017	-0.002
	Sig.	.025	.005	.367	.821	.977
(Peri)articular Osteophyte Formation	Phi	-0.021	0.021	0.012	-0.047	-0.085
	Sig.	.781	.784	.873	.536	.264
Periosteal New Bone Formation Around Nutrient Foramen	Phi	0.110	0.089	0.038	0.172	-0.027
	Sig.	.146	.253	.618	.023	.727
Enlargement of Nutrient Foramen	Phi	-0.079	-0.024	-0.050	0.150	0.023

	Sig.	.297	.756	.512	.048	.759
Dactylitis	Phi	0.238*	0.174	0.182	0.007	0.053
	Sig.	.002	.026	.017	.948	.493
Osteomyelitis	Phi	0.010	0.070	0.067	-0.034	-0.007
	Sig.	.895	.366	.375	.651	.922
Osteitis	Phi	0.135	0.116	0.016	0.082	-0.120
	Sig.	.076	.136	.833	.282	.113

* significant to the .01 level

5.3.4 Relationship of the Individual Postcranial Lesions to Each Other

The strongest positive relationship between post cranial lesions were between tibial and fibular PNBF, with a value of 0.780, which was significant to the 0.01 level (p = <.001). PNBF on the distal tibia and fibula were also showed strong positive phi values with postcranial absorptive lesions, particularly acroosteolysis (phi = 0.303 and 0.255), which was significant to the 0.01 level (p = <.001 for both). PNBF on the distal tibia was also strongly positively related to concentric remodelling of metatarsals (phi = 0.203, p = .003) and knife-edge remodelling (phi = 0.182, p = .009), which were significant to the 0.01 level.

For the new lesions assessed in this research, lesions to the proximal ulna showed several significant positive phi values to the 0.01 level, particularly with acroosteolysis (phi = 0.333, p = <.001), PNBF of the distal tibia (phi = 0.196, p = .006) and ossification of the interosseous membrane (phi = 0.287, p = <.001). Periosteal new bone formation around nutrient foramen, while not related with RMS lesions according to the phi values, did show a positive phi value with PNBF of the distal tibia and fibula (phi = 0.267 and 0.299 (p = <.001 in both instances)), respectively. It was also positively related with tarsal disintegration (phi = 0.237, p = <.001) and ossification of the interosseous membrane, (phi 0.183, p = .006), significantly to the 0.01 level, but showed the strongest relationship with enlargement of the nutrient foramen (phi = 0.317, p = <.001).

There are examples of positive phi values between inflammatory/proliferative lesions such as PNBF on the distal tibia and absorptive lesions such as concentric remodelling and knife-edge remodelling, which is encouraging given the mix of lesions of these aetiologies being present in leprosy. All postcranial phi values are detailed in Appendix C.

5.3.5 Unilateral/Bilateral Lesion Relationships

Rates of unilateral and bilateral lesions in the upper and lower extremities were tested against each other using phi coefficient. The rates of no upper extremity lesion being present was positively related with rates of no lower extremity lesions being present (phi = 0.260, p = <.001), i.e. when

lesions did not occur, this tended to be the across the whole postcranial skeleton. Unilateral upper extremity lesions did not show any relationship with unilateral lower extremity lesions (phi = 0.008, p = .902), i.e. there is no pattern to the co-occurrence (or not) of unilateral lesions in the upper and lower postcranial skeleton. Bilateral upper and bilateral lower extremity lesions were significantly positively related (to the 0.01 level) with each other, with a phi value of 0.236 (p = <.001), i.e. they tended to be either both present or both absent. Unilateral upper extremity lesions were also positively related to bilateral lower extremity lesions, with a value of 0.115 (p = .083). This tentatively suggests that bilateral upper extremity lesions develop later, but the phi value was not significant.

5.3.6 Summary

All rhinomaxillary syndrome lesions showed a strong positive association with each other, suggesting that they are related. This is not entirely surprising given that they are known as the key indicators of leprosy. However, some interesting patterns are present when considering rhinomaxillary lesions with other lesions, particularly the positive relationship shown between rhinomaxillary lesions and lesions to the proximal ulna, a novel lesion tested in this research. Lesions to the proximal ulna also showed several significant positive relationships to other postcranial lesions, particularly with acroosteolysis, PNBF of the distal tibia, and ossification of the interosseous membrane. Periosteal new bone formation of the tibia and fibula was also shown to be positively related, but is not a specific indicator of leprosy in and of itself. The phi values indicate that when postcranial lesions occur, they tend to occur bilaterally.

Chapter 6: Lepro-C Applied to Previously Published Papers

The following applies the Lepro-C criteria devised in this research to individuals assessed in nine previously published papers, to demonstrate how Lepro-C can be useful for consistent and rigorous assessment of leprosy in skeletal remains in future research. Specific examples from six of these papers that characterise some of the key issues are discussed in the text. All cases from the nine papers and their Lepro-C determination are summarised in Table 5.1. The lesions and Lepro-C assessment for all individuals from each paper are also summarised in Appendix D. The papers are presented in chronological order, covering a period from 2008-2019. Papers from this time were chosen as a decade seemed a reasonable timescale to consider whether the assessment of leprosy had developed, or if key issues were present throughout. These papers were also the most prolific publications that consistently occurred when searching for previous papers concerning leprosy in skeletal remains. It had also been over a decade since key criteria were established by Andersen and Manchester, and even longer since Møller-Christensen published his work. Therefore, it was interesting to see how leprosy was being described and considered in these papers long after the publication of previous diagnostic criteria to assess the improvements to replicability and rigour that Lepro-C addresses. Papers on leprosy continue to be published (see Filipek et al., 2022; Spekker et al. 2022, for recent examples). The Lepro-C criteria applied is based on the revised version of the criteria as detailed in Chapter 7.

6.1 Gilmore, J. K. (2008) Leprosy at the Lazaretto on St Eustatius, Netherlands Antilles. *International Journal of Osteoarchaeology*, 18(1), pp.72–84.

Gilmore (2008) considers the macroscopic lesions of three individuals (skeletons 2, 4 and 5) from the Lazaretto on St Eustatius, Netherlands Antilles, which operated from 1866 to 1923. Gilmore (2008: 80) concludes that the three individuals display lesions that are 'strongly suggestive of the presence of multibacillary leprosy'. This is after a considering differential diagnoses such as infectious disease (mucormycosis, cryptococcus, actinomycosis, sarcoidosis, syphilis, tuberculosis, treponemal disease), endocrine disorders (diabetes), and arthropathy (septic and psoriatic).

The descriptions of the pathology are divided into sections for cranial, upper extremity and lower extremity lesions, not by individual, so it is not always clear when reading Gilmore (2008) what pathology the individuals display as the text provides inconsistent detail and moves back and forth between individuals. For example, the knife-edge remodelling is reported to be present in 'the

metatarsal diaphysis and proximal phalanges of skeletons 2, 4 and 5' (Gilmore, 2008: 77), but only details for lesions affecting skeletons 4 and 5 are subsequently provided, and skeleton 2 is not included in the discussion any further. This is compounded in that there is no summary table of the lesions displayed by the individuals to clearly communicate what skeletons displayed which lesions.

This makes the application of Lepro-C challenging. On a broad level, Skeleton 2 is *highly consistent* with leprosy, as there are two RMS lesions present, as well as bilateral postcranial absorptive lesions to the metatarsals (in this case knife-edge remodelling), and bilateral PNBF on the tibiae and fibulae. The evidence is strengthened further by the reported nodular bone formation focussed on the interosseous border of the tibiae and fibulae, suggesting ossification of the interosseous membrane. The descriptions of RMS would have been strengthened by the use of images to aid in assessing the morphology and variability of these lesions. The individual should be assessed again in-person using Lepro-C before a final category can be assigned, as the precise morphology of the lesions are not clear enough to make a firm assessment otherwise. It is accepted that journals have limits on the number of images for articles, however.

While individual skeleton 4 had no cranial lesions due to post-mortem damage, the postcranial evidence is *consistent* with leprosy, as multiple absorptive and proliferative/inflammatory lesions are present, such as concentric remodelling and distal absorption of the phalanges and metacarpals, and PNBF on the tibiae and fibulae. Interestingly, this individual shows lesions to the ulna, radius, medial humerus that may indicate hypertrophy of the ulnae nerve (Donaghy, 2003; Payne et al., 2015; Fonseca et al., 2018). This individual would benefit from reassessment using Lepro-C to gain insight into the precise morphology of all of the lesions. For example, this individual is a mature adult, so the humerus and ulna lesions could also be age-related degeneration.

Skeleton 5 (Fig. 6.1 and 6.2) is an interesting case, as from Gilmore's (2008) descriptions there are four RMS lesions present (with pitting of the nasal aperture appearing to be absent). There are no images for RMS lesions, and there is limited detail provided for the absorption the anterior nasal spine, and oral pitting (see, Gilmore, 2008: 76). Therefore, the Lepro-C category given is tentative, and reassessment of the individual, or at least provision of the images of RMS lesions, would be beneficial. This highlights the importance of including appropriate images to support descriptions where publication constraints allow. Appropriate images of RMS should be a standard going forward. Reassessment of this individual may also show nasal pitting (particularly as there is inflammatory pitting of the left inferior nasal concha), which with the extensive absorptive and proliferative/inflammatory postcranial evidence, would make this individual *diagnostic* of leprosy if the other four RMS lesions were also confirmed, but at present the individual is *highly consistent*

with leprosy. Gilmore (2008) also suggests that lesions to the hyoid and cervical vertebra may be due to leprosy, due to the apparent spread of leprosy to the larynx in clinical cases.

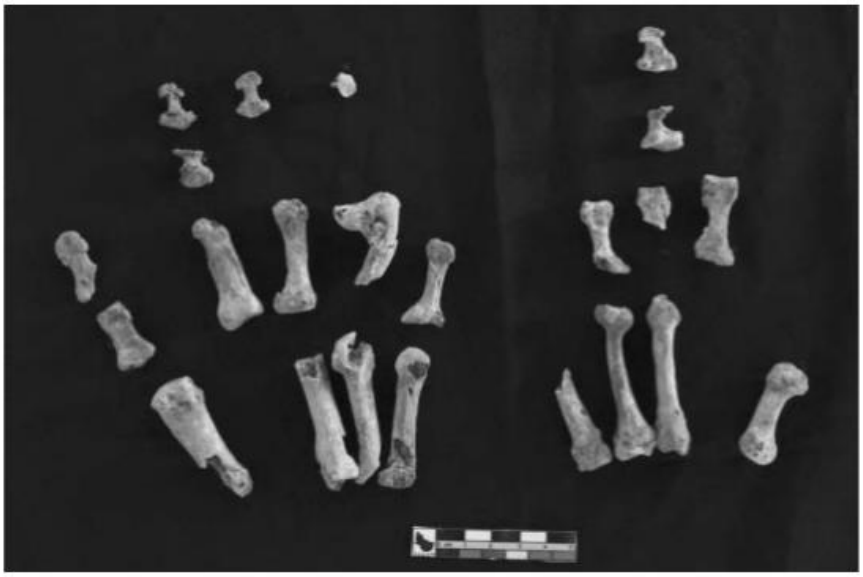


Fig. 6.1: Palmar view of hands of skeleton 5. The left 4th proximal interphalangeal joint is ankylosed. The right MC4 shows some concentric remodelling. There are also destructive lesions to the proximal articular surfaces of the proximal phalanges (Gilmore, 2008: 76).

Fig. 6.2: Dorsal view of feet of Skeleton 5. The left proximal phalanges show some diaphyseal thinning. The phalanges of the left MT1 also shows some destructive remodelling of the articular surfaces. The distal phalanges of the right foot also show some acroosteolysis (Gilmore, 2008: 78).

6.2 Rubini, M. and Zaio, P. (2009) Lepromatous leprosy in an early mediaeval cemetery in Central Italy (Morrione, Campochiaro, Molise, 6th-8th century AD. *Journal of Archaeological Science*, 36, pp. 2771-79.

Rubini and Zaio (2009) present two individuals from a 6-9th century cemetery in Morrione, Italy (grave nos. 68 and 108). They determine that these individuals have a 'most likely diagnosis of lepromatous leprosy' (p. 2776). Their conclusion is based on the evidence for rhinomaxillary syndrome in both individuals, with individual skeleton 108 also displaying some postcranial lesions to the hand and foot phalanges. Individual skeleton 68, female, '40-46 years', displays rounding of the nasal aperture and absorption of the anterior nasal spine, with Rubini and Zaio (2009: 2775) also ascribing exposure of the anterior maxillary dental roots to an 'erosive process' (Fig. 6.3). Individual skeleton 108, male, '50-55 years', also displays rounding of the nasal aperture and absorption of the anterior nasal spine, with Rubini and Zaio (2009: 2775) also observing absorption of the maxillary alveolar process, and distal absorption of hand and foot phalanges and metacarpals with 'erosion' present.

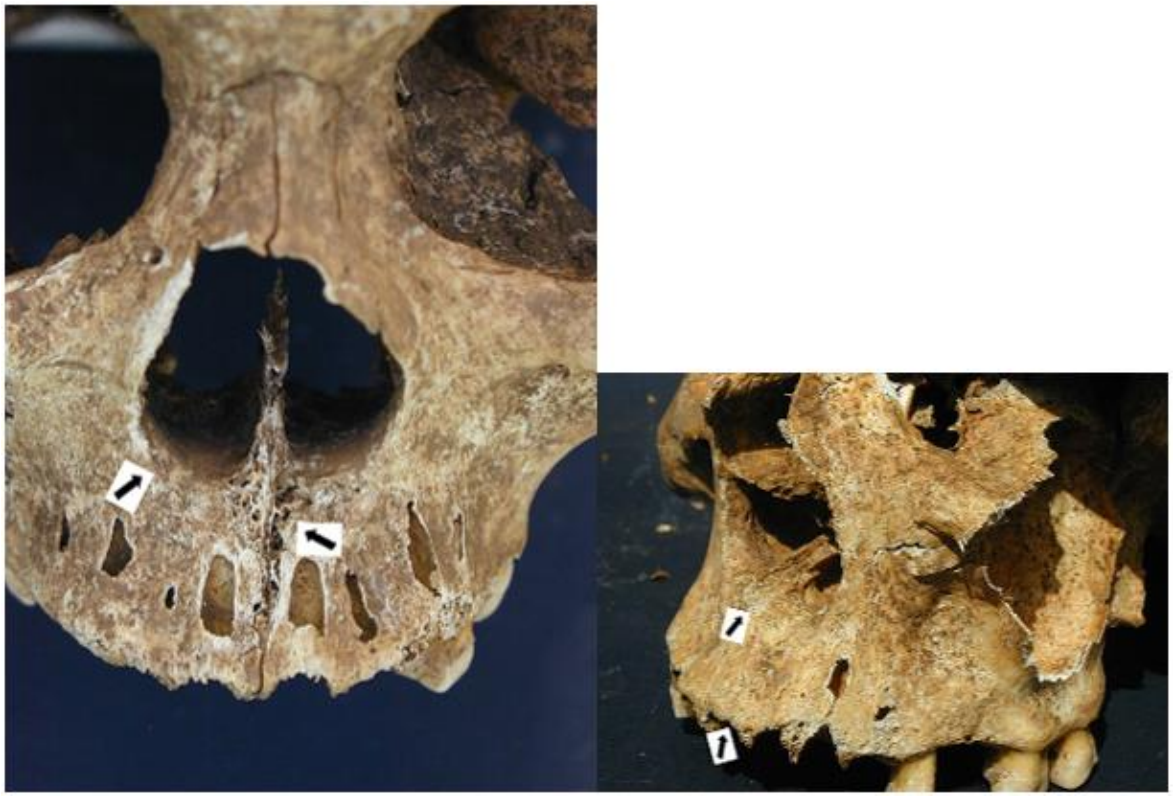


Fig. 6.3: Left - grave no 68, Right – grave no 108, both from Rubini and Zaio (2009: 2775, their arrows) with both showing rounding of the nasal aperture, absorption of anterior nasal spine, and absorption of maxillary alveolar process.

The rounding of the nasal aperture and absorption of the anterior nasal spine are questionable for both individuals. The postmortem damage to the anterior nasal spine means absorption is difficult

to diagnose grave SK68, and the remodelling of the nasal aperture for grave SK108 may be reflective of other factors, such as the ancestry of the individual. The nasal region can vary morphologically depending on ancestry, which present-day forensic research shows is due to complex population histories (Plemons and Hefner, 2016). This is a relevant concern for this period, as Heath et al. (2021) show that the Mediterranean in the Medieval period was a culturally heterogenous space with significant opportunities for the mobility and movement of individuals, so individuals of varying ancestry in the same place is possible. Rubini & Zaio (2009) do not consider ancestry in their differential diagnosis and focus only on infectious disease that might affect the nasal aperture. For the other lesions, the morphology of the 'erosive process' they ascribe as absorption of the alveolar maxillary process for skeleton 68 seems more taphonomic in character. This is due to the lightly coloured margins of these erosions when compared with the darker colour of the surrounding bone, suggesting post-mortem breakage (Fig. 6.3). The patchy and jagged morphology of the erosions exposing the incisor crypts are also inconsistent with the progression of lesions to the alveolar process of the maxilla in leprosy, which begins at the prosthion and gradually extends laterally and symmetrically (Andersen and Manchester, 1992: p. 123). Whether the alveolar maxillary process for skeleton 68 was predisposed to post-mortem damage due to cortical thinning resulting from leprosy cannot be discounted. The evidence is also limited for the absorption of the alveolar maxillary process for skeleton 108, as the lesion present cannot be specifically linked to leprosy above other conditions that affect the alveolar margins (see Chapter 3) - non-specific periodontal disease could be a differential diagnosis. The pencilling Rubini and Zaio (2009: 2775) report for the fifth metatarsal of skeleton 108 is difficult to determine from the angle provided in the figure presented (Fig. 6.4). The 'remodelling' and 'erosion' of the metatarsal and foot phalanx displayed are also consistent with post-mortem damage due to the lighter colouring of the margins of any breaks and exposed trabeculae compared to the surrounding bone. This may also apply to the distal 'erosive process' of the hand phalanges also (Fig. 6.4)(Rubini and Zaio, 2009: 2775).

When Lepro-C was applied to these individuals, both display lesions 'not consistent' with leprosy – this is because they display only one absorptive RMS lesion, and the other lesions reported could be caused by other means, such as periodontal disease, ancestry or taphonomic damage. The recommendation for future publications is that front *and* side views are provided where possible, particularly for cranial lesions, as this will help the assessment of differential diagnoses.

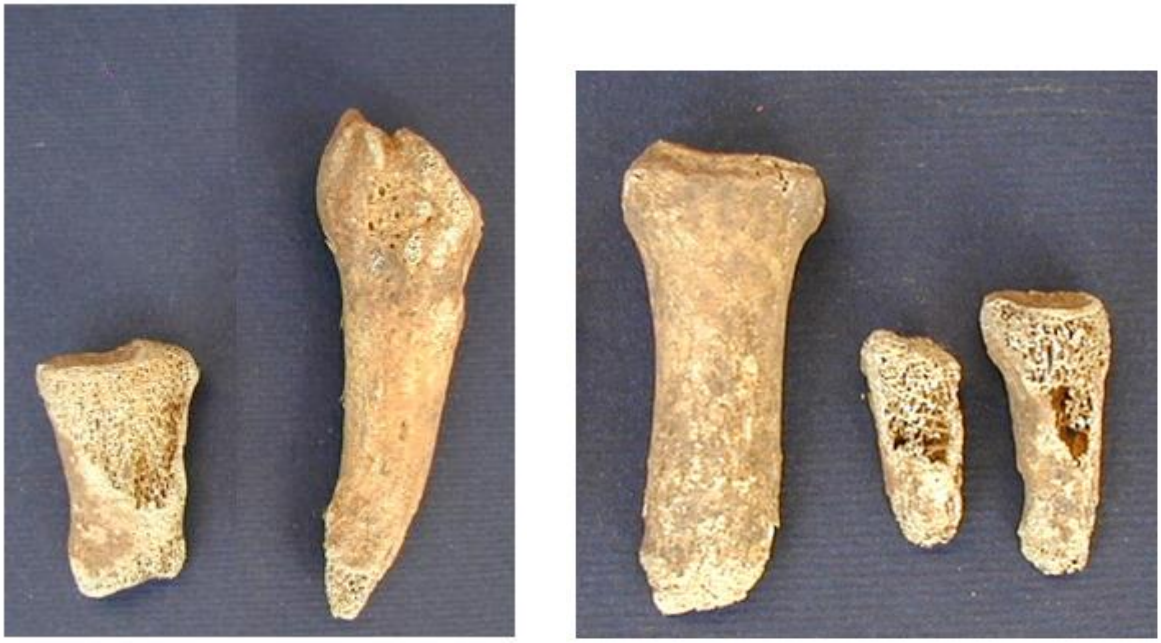


Fig. 6.4: The postcranial lesions from Rubini and Zaio (2009: 2775). Left: 5th metatarsal and phalanx, right: hand phalanges.

6.3 Kjellstrom, A. (2012) Possible cases of leprosy and tuberculosis in medieval Sigtuna, Sweden. *International Journal of Osteoarchaeology*, 22: 261-283.

Kjellstrom (2012) analyses six cases of possible leprosy, including one with a potential co-morbidity with tuberculosis, from a wider population of 227 individuals from the site of a medieval church in Sigtuna, Sweden, dating to AD 1100-1300. Kjellstrom (2012) provides a thorough analysis of each case, with descriptive detail of the lesions, even where figures are not provided. The differential diagnosis is also detailed and considered. Kjellstrom (2012) diagnoses lepromatous leprosy in one individual (case 5), and notes possible leprosy in five other individuals, with case 4 described as displaying signs of tuberculosis and leprosy. Therefore, despite the analysis Kjellstrom (2012) provides, recategorization of these individuals in the context of Lepro-C is appropriate. The below discusses case 4 and 5, as they display co-morbidity and diagnostic signs of non-adult leprosy respectively. All 6 individuals are summarised in Table 5.1 and Appendix D.

6.3.1 Case 4

Individual case 4 is an 'adult individual of unknown sex', displaying destructive lesions with no concurrent bone formation in the T4-T12 vertebrae, along with destruction of the vertebral bodies and sharp angular kyphosis and ankylosis of the L1-L3 vertebrae (Fig. 6.5), with large smooth-walled lytic lesions in the remaining lumbar vertebrae. There were also severe lytic lesions on the upper

ventral surface of the sacrum (Kjellstrom, 2012: 267), and longitudinally striated PNBF on the distal lateral tibiae, and on the diaphysis of the fibulae (although Kjellstrom (2012) does not specify which aspects). Both first metacarpophalangeal joints were ankylosed (Fig. 6.6), with the proximal phalanx 'pointed in an axial direction' (Kjellstrom, 2012: 268). The right ankylosed proximal phalanx also shows some concentric remodelling. The right second metatarsal had also fused with the medial cuneiform, and also displayed a cloaca. There is also absorption of the distal end of the intermediate phalanx with anklyosis to the proximal phalanx of the second metatarsal.

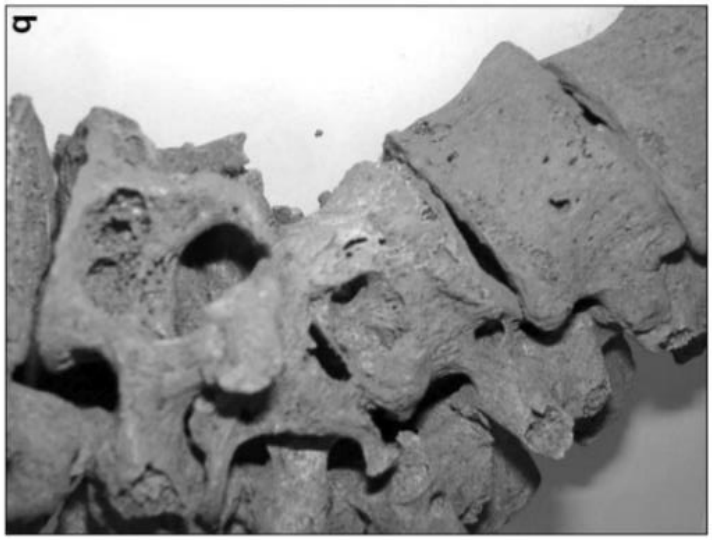


Fig. 6.5: Lytic lesions in thoracic vertebral bodies of Case 4, with sharp angle kyphosis (Kjellstrom, 2012: 269).

Case 4 presents with a curious set of lesions. There is strong evidence of tuberculosis, which Kjellstrom (2012: 277) suggests were responsible for the destructive lesions of the spine and sacrum, and also possibly the non-specific proliferative changes seen in the lower extremities. However, the absorptive processes, ankylosis, and evidence of secondary infection seen in the foot bones are suggestive of leprosy, and points to co-morbidity with tuberculosis (Kjellstrom, 2012). Evidence of advanced lesions for both diseases in Case 4 suggests that the interaction of leprosy and tuberculosis was/is complex, and that eradication of leprosy simply due to cross-immunity or co-infection with tuberculosis may be simplistic, as this individual evidently survived for some time for lesions of this extent to develop, suggesting that leprosy and tuberculosis co-infection can be chronic (see Crespo et al. (2019); Kilpatrick et al. (2017) and Kama et al. (2019) also for further discussion). Of the lesions potentially attributable to leprosy, however, this individual is *consistent* leprosy, as there are at least two bilateral proliferative postcranial lesions, and at least one

absorptive lesion, albeit unilateral, which may be indicative of a borderline case due to the mix of bilateral and unilateral lesions. RMS is required to be categorised higher.

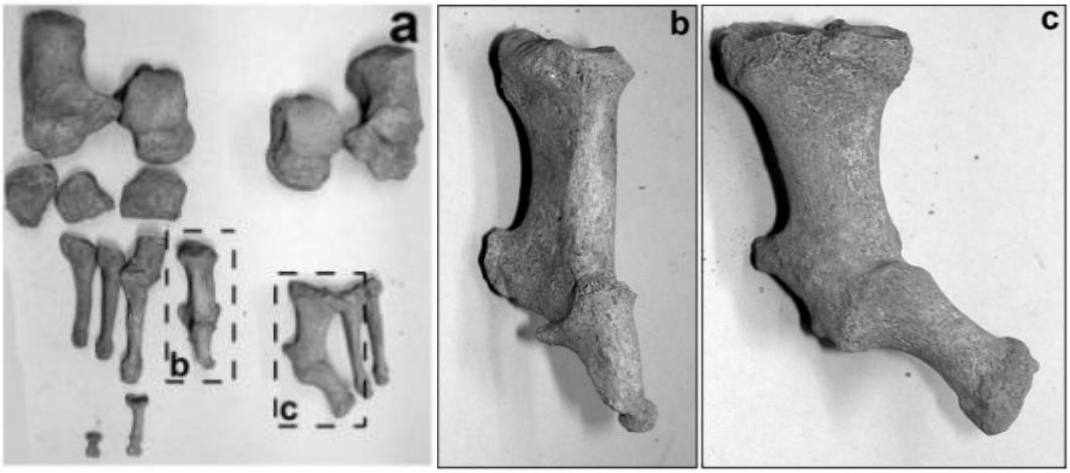


Fig. 6.6: The feet of Case 4. b) and c) show angled ankylosis of the right and left MT1 and proximal phalanx respectively (Kjellstrom, 2012: 270).

6.3.2 Case 5

Case 5 is the well-preserved skeleton of an 11-12-year-old child (Kjellstrom, 2012: 268), displaying absorption of the anterior nasal spine, rounding of the nasal aperture, absorption of the anterior maxillary alveolar process (Fig. 6.7) and constriction of the dental roots of the central maxillary incisors, and pitting of the oral surface of the palatine process. Postcranially, the individual displayed fine striated PNBF on the distal left fibula, and a 15mm long and 4.5mm deep lytic lesion on the distal right fibula (Fig. 6.8). The first distal phalanx, the only one preserved, showed concentric atrophy of the distal end, causing it to taper.

Kjellstrom (2012: 278) states that the lesions displayed in Case 5 'imply that the individual suffered from lepromatous leprosy'. When viewed using Lepro-C, the evidence presented shows this individual is *highly consistent* with leprosy, as four of five RMS lesions are present. Reanalysis of the individual may show some pitting of the nasal surfaces, the RMS lesion not accounted for in this individual. No figures are provided of the oral pitting, so reanalysis would clarify the nature of that lesion. That this evidence of leprosy is found in an individual of only 11-12 years old is interesting, given the length of time for lesions to develop in leprosy generally, and the presence of RMS lesions that you might only expect to see in adults. The evidence of LOD (Fig. 6.8) is also interesting, as the occurrence of this with evidence of RMS lends support to malformation of this kind being leprogenic in origin, which has been controversial in palaeopathology, and not often observed (see Matos and

Santos, 2013). This individual should be reassessed to include radiographs of the hands and feet, as osteoporosis/ostepenia in these regions is the most common expression of leprosy in children (Lewis, 2017), and would not be picked up macroscopically. This, along with further assessment of the inflammatory pitting of the palatine process in RMS as noted above, means that this individual could yet be *diagnostic* with leprosy.

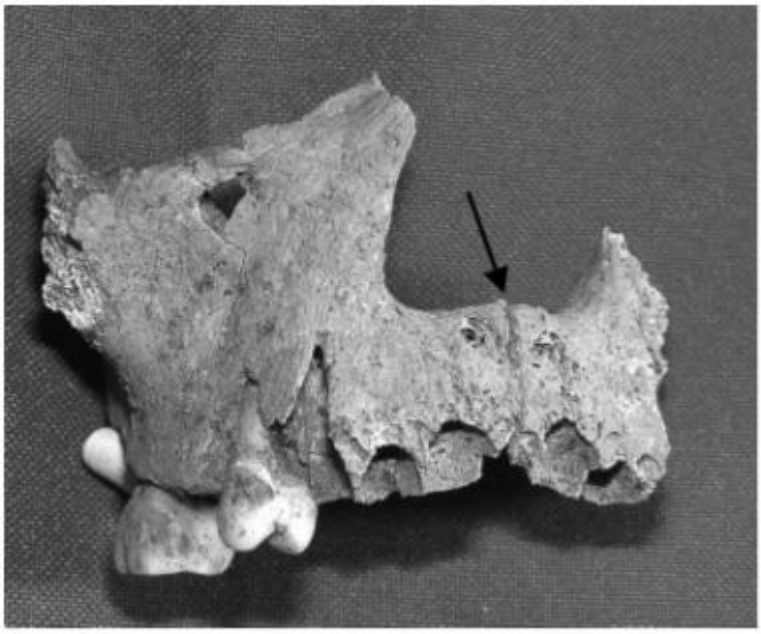


Fig. 6.7: Atrophy of the anterior nasal spine of Case 5 (Kjellstrom, 2012: 270).

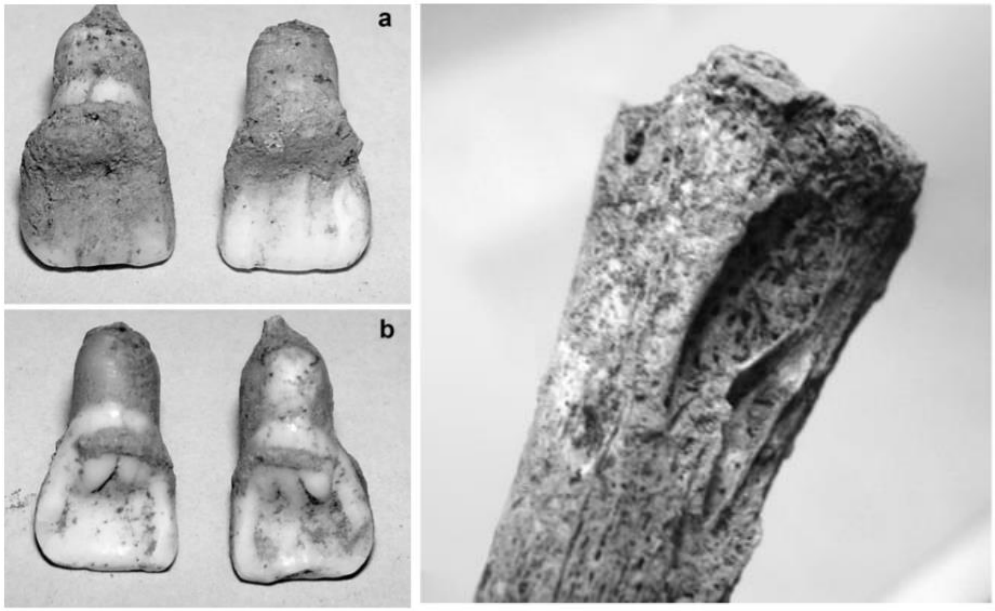


Fig. 6.8: Left: shortened roots of central incisors; right: erosive lesion of right fibula, in Case 5 (Kjellstrom, 2012: 271).

6.4 Kohler et al. (2017) Possible cases of leprosy from the late Copper Age (3780-3650 cal BC) in Hungary. *PLoS ONE* 12(10): e0185966

Kohler et al. (2017) consider possible leprosy in a single individual (SK 257 S20, 18-22 year old male), determining that SK 257 S20 'shows strong evidence for the bony manifestation of advanced leprosy' (Kohler et al. 2017: 13). They determine this primarily on the presence of absorption of the anterior nasal spine, rounding of the nasal aperture, and pitting of the nasal and oral surfaces of the palate found in conjunction with PNBF on the tibiae and fibulae. It is not clear how complete the individual is, with Kohler et al. (2017: 10) noting that 'the postcranial bones are fragmentary and partially missing'.

Assessing RMS (and then applying Lepro-C) on the evidence they present alone is difficult. There is clear evidence of the absorption of the anterior nasal spine, as there is smooth remodelled cortical bone in the region where the ANS would once have been (although porosity remains on the right side). The remaining RMS lesions are more difficult to assess, however. For example, the smooth rounding of the margins of the nasal aperture they report is patchy and inconsistent, and seems to morphologically differ from one image to the next, with images (a) and (b) (Fig. 6.9) suggesting that relatively sharp margins remain in much of the aperture, particularly adjacent to the ANS, while appearing smooth and rounded in image (c). The images are not supported by sufficiently detailed descriptions of the absorption in the text (see Kohler et al., 2017: 10). For example, the lateral left margin of the nasal aperture seems to be rounded in (b), however the next image (c) gives the impression that a sharp margin remains in that region. The relatively symmetrical appearance of the aperture, both where smoothness and sharpness of the bone remain, may suggest that ancestry (Plemons and Hefner, 2016) is a reason for the observed morphology, and not necessarily pathology. That is to say it is not clear-cut that a nasal aperture of this morphology is leprous by default. However, even if we accept that some rounding/remodelling is present, issues remain with the remaining RMS lesions reported. The magnified picture of the oral pitting (e) does not seem to be a magnified picture of the photo above (d), despite the arrow. In any case, the pitting in (e) does not seem be pitting centred around the midline of the oral or nasal surface of the maxilla, making the link to leprosy tenuous. The missing sections of the palate from (d) could be post-mortem damage, which is supported by the lack of porosity around the margins of the remaining bone. There is no evidence of lunate absorption of the anterior maxillary alveolus that you expect from leprosy.

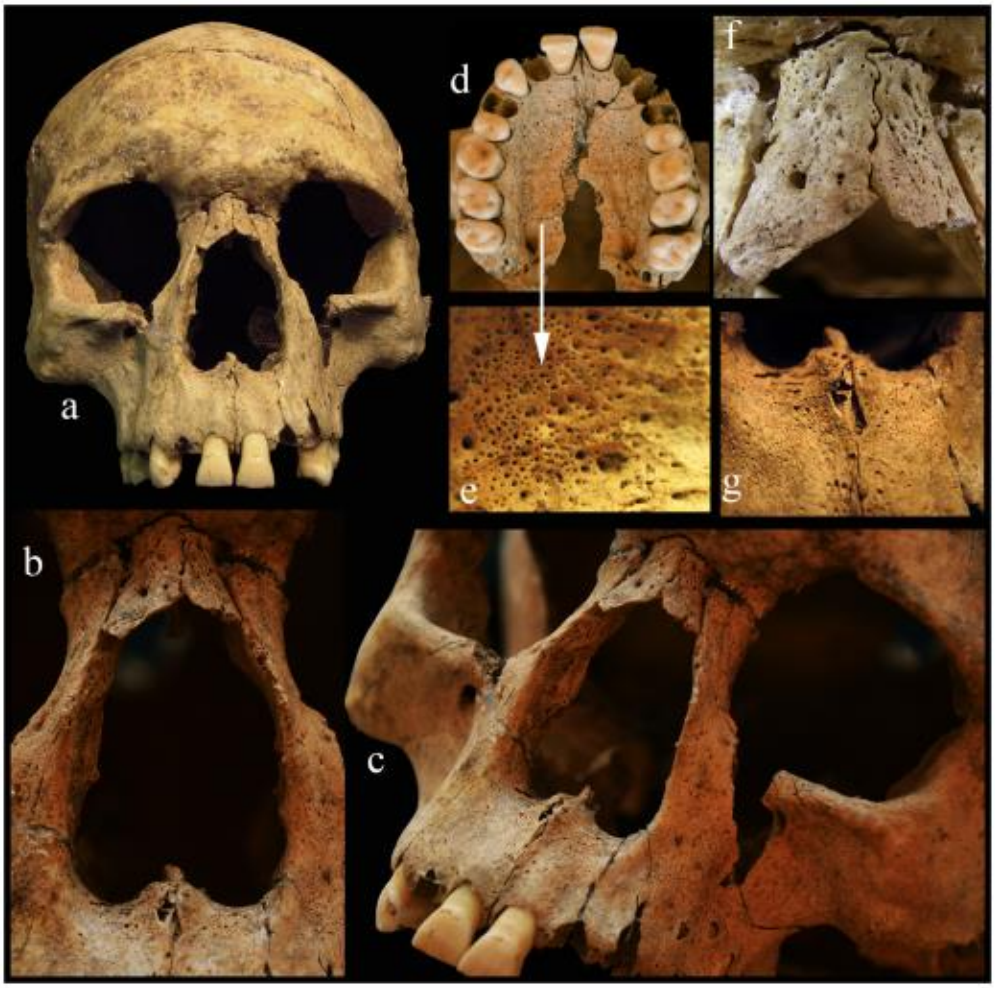


Fig. 6.9: Evidence of rhinomaxillary syndrome as presented by Kohler et al. (2017: 10 – their notation and arrows).

The photographic evidence of the postcranial lesions (Fig. 6.10) are limited to sections of the right tibia and fibula, and right 1st metatarsal. The tibia shows a combination of longitudinally striated and porous and disorganised PNBF on the lateral and medial aspects of the midshaft, extending proximally (the distal portions are missing), with an overall delicate and fine morphology. There is also an apparent peri-articular cyst on the proximal 1st metatarsal. The pathology to the fibula that Kohler et al. (2017) report is not readily apparent from the photo. The posterior proximal nutrient foramen of the tibia seems to be enlarged, which is interesting as enlargement of foramina is being assessed by the author in this thesis. The tibia also appears to be bowed. All told, given the limitations of the descriptions and photographs as presented, this individual is *consistent* with leprosy as per Lepro-C, as two RMS lesions are present at best, both absorptive in nature, with the postcranial lesions being inflammatory/proliferative in nature, but not in the primary location you may expect to find them in leprosy. Kohler et al. (2017: 11) report 'serious inflammation, periostitis and resorption of the nasal bones', however the precise nature of this is not described any further, and the image provided (f)(Fig. 6.9), while showing some pitting, does not appear to be resorbed,

with the lighter coloured inferior margins (particularly of the right side), suggesting post-mortem damaged.

Fig. 6.10: Post cranial lesions for SK 257 S20 from Kohler et al. (2017: 11 - their notation and arrows).

This is not the whole picture, however, as SK 257 S20 displays PNBF in other regions of the skeleton not associated with leprosy, suggesting some co-morbidity. The bone formation appears mainly in the ribs, humeri, and distal ulnae, as well as cortical porosity of the occipital bone, and healed antemortem trauma of the frontal bone. Kohler et al. (2017) also report porotic vertebral bodies and mandibular incisor crypts. Kohler et al. (2017) note evidence of high rates of interpersonal violence in this assemblage, surmising that these additional lesions could be evidence of this individual being abused, particularly given the location of the PNBF on the ribs, humeri, ulnae and femora. However, the presence of cribra orbitalia in the left orbit also suggest that these additional lesions, along with apparent tibial bowing, could be due to long-standing metabolic deficiencies, which may also be indicative of a poor standing in society for this individual. This may also be suggestive of the poor immune function required for lepromatous leprosy lesions to develop (even if the overall evidence for the disease is limited here). However, the descriptions of these additional lesions are limited to single sentences that do not shed any light on the precise morphology of the lesions so it is impossible to assess them further without looking at the skeleton in-person.

6.5 Taylor, G et al. (2018) Leprosy at the edge of Europe—biomolecular, isotopic and osteoarchaeological findings from medieval Ireland. *PloS One*, 13(12), p.e0209495.

Taylor et al. (2018) provide an osteological and aDNA analysis (as well as isotope analysis) for five individuals from two sites in Ireland (Ardreigh and Golden Lane, Dublin) and one in Northern Ireland (St Patrick's Church, Armoy). The individuals date from the 9th-14th centuries, and display 'probable leprosy'. The four individuals from Golden Lane and Armoy have previously been published in Murphy and Manchester (1998) and Buckley (2008). It is still appropriate, however, to assess the summaries that Taylor et al. (2018) provide, as the information provided in studies such as these should still be appropriately detailed, particularly given the complex variability and presentation of leprosy lesions, and potential issues over access to previous studies.

6.5.1 Golden Lane and Armoy Individuals

Taylor et al. (2018: 11) state that SkCXLVIII is a '13-18' year old 'probable male' displaying 'diaphyseal remodelling', 'destruction of extremities MT and P', 'Inflammatory pitting' and 'reactive new bone formation'. This is the extent of the detail provided for the lesions present for SkCXLVIII, and no images are provided in the main body of the text. In and of themselves these descriptors are not helpful for the application of Lepro-C, as the precise location and form of lesions such as 'diaphyseal remodelling' and 'inflammatory pitting' are essential, as is the nature of the destruction of 'extremities MT and P'. Without this additional detail a firm Lepro-C category cannot be given, although based on the limited descriptions the individuals would be *consistent* with leprosy, as an inflammatory and absorptive postcranial lesion are present.

These descriptive issues are present for the other three previously published individuals in the main body of the paper. For example, Sk171 displays lesions such as 'knife-edge deformity' and 'cup and peg deformity', and SkCXCV displays lesions described as 'rhinomaxillary syndrome', with no additional detail provided for which aspects of RMS are present, and 'minor destruction of extremities MT and P'. As with SkCXLVIII above, a full and earnest evaluation of these individuals using Lepro-C is not possible due to the lack of detail. At best, Sk171 and SkCXCV might be categorised as *not consistent* based on these descriptions alone due to the presence of dorsal-tarsal exostoses, but even then the precise bone affected is not disclosed. SKCXCV and SkCCXXX also tested strongly positive for *M. leprae* aDNA, but as noted previously, this is to be used cautiously when assessing leprosy, the medical condition, in skeletal remains.

There is supplementary information, however, that supplies some specific descriptions and images of the lesions. So for, SkCXLVIII, given that there are no rhinomaxillary syndrome lesions, and

concentric remodelling of the metatarsals and periosteal new bone formation on the distal tibia and fibula, makes this individual *consistent* with leprosy.

For SkCXCV, the image in the supplementary information shows that full rhino-maxillary syndrome is present, and that this individual is *diagnostic* with leprosy as per Lepro-C. This is also the case for SkCCXXX, which based on the descriptions displays full rhinomaxillary syndrome, so this individual would also be *diagnostic*. It would have been beneficial to have an anterior view of the maxilla to see the absorption of the anterior maxillary alveolus, as this is not clear from the image. If this lesions was not present then the individual would be *highly consistent* with leprosy. For Sk171, only the feet were preserved, but there is clear concentric remodelling and of the metatarsals and tarsals. So without any RMS lesions due to preservation, this individual is *consistent* with leprosy.

The disconnect between the detail provided in the main body of the text and the supplementary information, and the subsequent application of Lepro-C, demonstrates how important the level of detail is. However, the value of Lepro-C as a method is shown in that two individuals can be diagnosed with leprosy on the macroscopic evidence along, given the full rhinomaxillary syndrome present, whereas before they were said to have 'probable leprosy' only. It is clear from this paper that the macroscopic osteological evidence was not at the forefront of the investigation, so the value of Lepro-C is demonstrated in that this evidence is now able to be considered, and leprosy diagnosed, on its own merits in a rigorous and replicable way.

6.5.2 Ardeigh Individual (Sk1494)

Sk1494 is a 'possible male adult of 18-35 years' (Taylor et al. 2018: 10). The postcranial skeleton is 'largely complete' but no cranial elements survive. Diaphyseal remodelling is present in the left MT3, 4 and 5, with nodular bone formation on the dorsal surface of the shaft of MT4 (Fig. 6.11). The heads of these metatarsals have been fully absorbed, and the corresponding proximal phalanges display osteolysis and deformation of the articular surfaces. Diaphyseal remodelling is similarly present in the distal right MT3, 4 and 5, but much more extensive, with full absorption of the distal thirds of these bones, with deformation of the surviving margins. The surviving portion of the right MT4 displays cortical expansion and a possible cloaca on the dorsal surface of the proximal diaphysis. Dorsal tarsal exostoses are present on the 'majority of tarsals present', with navicular and cuboid bones most severely affected. There was also bilateral and extensive PNBF with a 'spiculed' and 'healing' appearance on all aspects of the distal half of the tibiae and fibulae. There were also visible fractures in T11 and L5 vertebrae, and right rib. Only images of the metatarsals and phalanges are provided by Taylor et al. (2018).

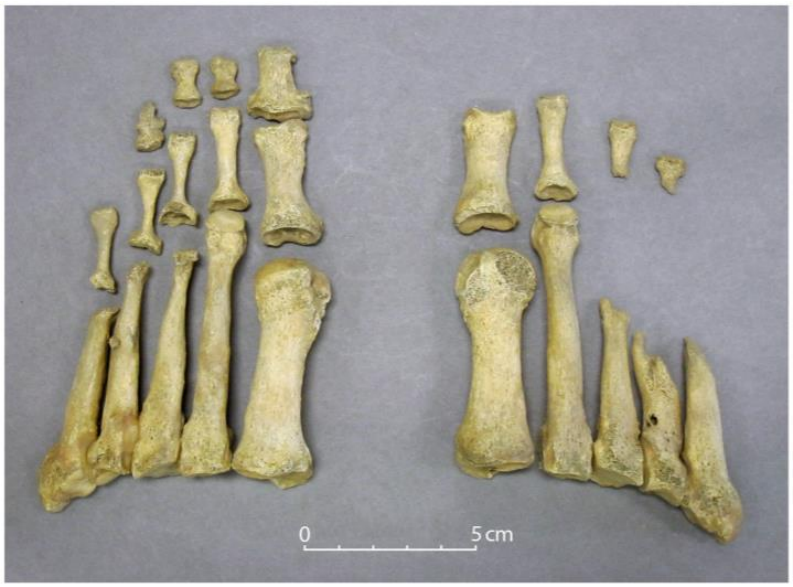


Fig. 6.11: Metatarsals and phalanges of Sk1494 (Taylor et al., 2018: 12), showing diaphyseal remodelling of distal ends of metatarsals and absorption/erosion of distal ends, most pronounced on right MT3, 4 and 5.

Based on the descriptions, this individual is *consistent* with leprosy, as there is bilateral PNBF on the tibiae and fibulae, as well as bilateral concentric remodelling of the metatarsals, with arthropathy of associated phalanges, as well as dorsal tarsal exostoses. No maxilla survives to assess RMS, however, so the individual cannot be categorised higher. In the absence of images of the tibial and fibular lesions and dorsal tarsal exostoses this is somewhat tentative, as images would aid in assessing the nature of the lesions further.

Taylor et al. (2018: 19) note that Sk1494 was negative when tested for *M. leprae* aDNA, however was positive for mitochondrial DNA. They conclude that it is unusual, as *M. leprae* aDNA tends to be more resilient than mitochondrial DNA in archaeological assemblages, suggesting that the lesions may not have been caused by leprosy. This is not easily resolved with the patterns of osteological evidence however, which do not correspond with other potential differential diagnoses such as sarcoidosis, rheumatoid arthritis, due to the patterns of the observed lesions (Taylor et al., 2018). The medieval context of the individual also makes long-term survival leading to lesions unlikely for cases of diabetes mellitus at that time (Brostoff et al., 2007). Taylor et al. (2018: 19) note that it is unfortunate that no cranial elements survive, to which this author agrees as this is a curious case. The presence or not of RMS or not might have had interesting implications for the presence or not of *M. leprae* aDNA and how that relates to osteological evidence of leprosy.

6.6 Bedic, Z., Slaus, M. & Donoghue, H.D. (2019) The earliest recorded case of lepromatous leprosy in continental Croatia. *Journal of Archaeological Science*, 25: 47-55.

Bedic et al. (2019) consider the skulls of two adult individuals from a site called Bijelo Brdo in mainland Croatia, dating to the 10-11th centuries AD. No postcranial bones were present. Bedic et al. (2019: 52) determine that the 'diagnosis of lepromatous leprosy is the most probable one', after considering evidence of rhinomaxillary syndrome against the differential diagnoses of aspergillosis, mucormycosis, actinomycosis, tuberculosis, sarcoidosis and treponemal disease.

Skull 83 shows some post-mortem damage to the maxilla, with the superior left nasal aperture missing, however enough survives to assess most RMS lesions. The evidence Bedic et al. (2019) present for absorption of the anterior maxillary alveolus and rounding of the inferior margins of the nasal aperture is clear, however their interpretation of absorption of the anterior nasal spine and inflammatory pitting of the oral and nasal surfaces of the palatine process is less so. Bedic et al. (2019: 50) note that 'partial resorption of the anterior nasal spine is present', however the image shows that the anterior nasal spine is completely missing, either by full absorption or post-mortem damage. While it might be argued that the somewhat pitted appearance of the margins of the surviving bone immediately adjacent to the missing ANS support full absorption, the generally poor preservation of this individual cannot discount post-mortem damage. The images presented by Bedic et al. (2019) do not help make this distinction, with key elements, such as margins of lesions, out of focus (Fig. 6.12). To be counted as 'present' for Lepro-C purposes, the presence of a lesion should be clear and unambiguous, with clear images of the margins of lesions where possible, as the precise morphology is significant when assessing pathology and taphonomical processes. There is perhaps some slight pitting on the margins of the right nasal surfaces adjacent to the nasal aperture, and along the central margins of the oral palatine suture, although pitting in these regions can be normal, particularly as a person ages. So, age related changes may be a factor given the broad age range of 25-45 Bedic et al. (2019: 51) give for this individual. Bedic et al. (2019) also make broad reference to 'inflammatory pitting on the inner surface of the right nasal bone', however the main point of focus in the image provided (Fig. 6.12; top right) is the exposed trabeculae of the palatine suture, which while superficially resembling inflammatory porosity, is not. The adjacent cortical bone is also not obviously pitted when looking at the image. More specific descriptions of the location and precise morphology of the pitting would clear up this point, as the precise location and morphology of pitting is not trivial. As it stands the evidence for pitting of the nasal surface is not clear enough (although there is a lytic lesion that may be a primary granuloma). The inflammatory pitting on the oral surface is stronger, as there is evidence of inflammatory pitting close to the midline of the palatine process.

Therefore, this individual shows lesions *highly consistent* with leprosy, as absorption of the anterior nasal spine and rounding of the nasal aperture are present with inflammatory pitting of the oral surface of the palatine process, however the other differential diagnoses cannot be discounted fully, particularly taphonomic processes.

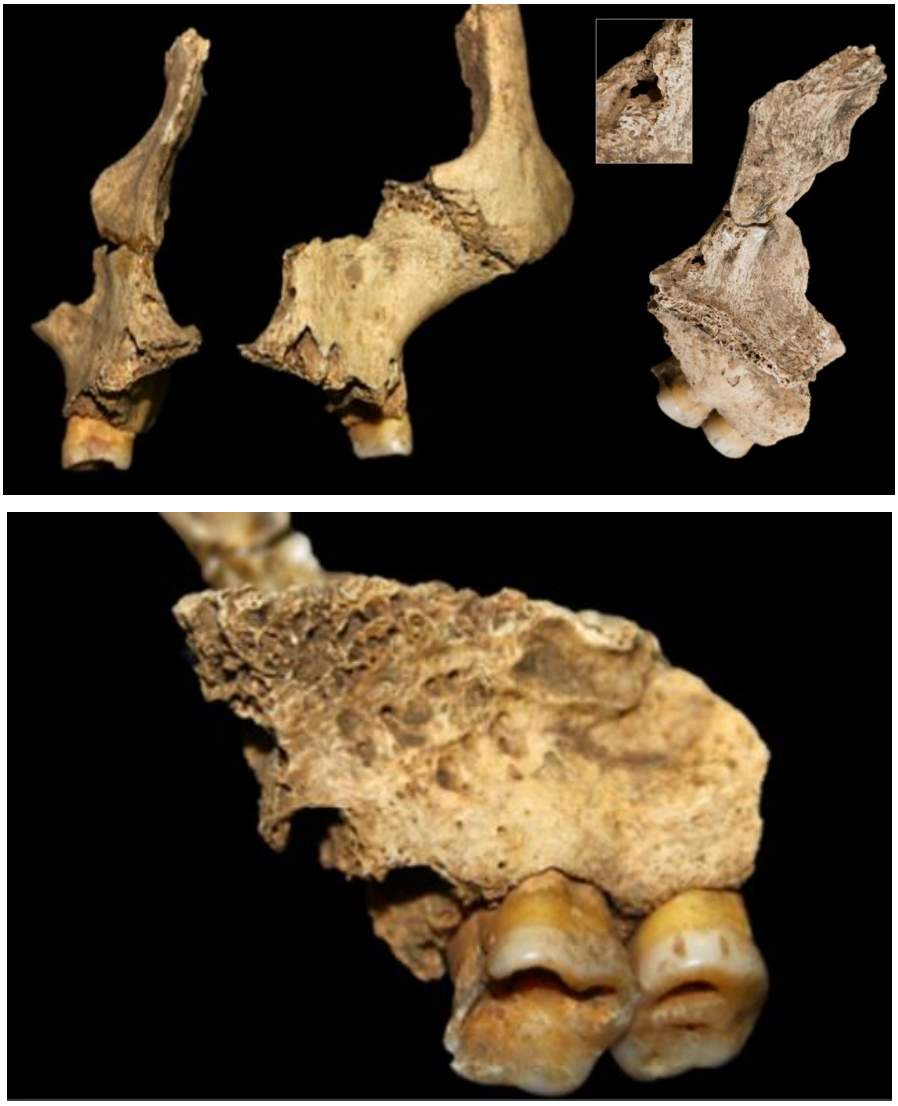


Fig. 6.12: RMS as reported in Bedic et al. (2019: 51-52).

The evidence for leprosy in the individual represented by skull 200 hundred is not as strong overall, but perhaps easier to assess. Absorption of the anterior nasal spine and remodelling of the inferior nasal aperture are present, with the image clearly showing this (Fig. 6.13). Bedic et al. (2019: 51) also note that 'slight inflammatory pitting is present on the palatine process of the maxilla'. No image is provided for this however, and the description is too vague to distinguish pitting that occurs normally from that occurring around the midline in leprosy. Some *cribra orbitalia* was also present. Therefore, skull 200 shows changes *consistent* with leprosy, as two absorptive RMS lesions are present, but the evidence of leprosy is not extensive enough overall to give a higher category. It is

not possible to assess the presence of the reported inflammatory pitting of the palatine process, confirmation of which may mean this individual could be *highly consistent* if reassessed in person using Lepro-C. This highlights the importance of detailed descriptions of lesions and images, as the precise morphology of lesions must be adequately conveyed in order to make proper assessments of disease in skeletal assemblages.

Fig. 6.13: Skull of skeleton 200 as depicted in Bedic et al. (2019: 52).

6.7 Summary

A review of publications from 2008-2019 reveals the variability of the detail and rigour in previous assessments of leprosy in skeletal remains, particularly issues surrounding depth of descriptive and illustrative detail for some lesions. The recommendation is that there should be a minimum standard of description and illustration going forward. Descriptions must be detailed enough so that the precise morphology of the lesions are clear, particularly as leprosy lesions are morphologically variable, and photographs of lesions, particularly absorption of the anterior nasal spine and remodelling of the inferior margins of the nasal aperture, should be from several angles. Two dimensional photographs of morphologically subtle lesions that exist in three-dimensional space can be inherently misleading and must be supported by appropriate descriptive detail. Lepro-C can be applied to ensure a rigid and replicable approach that allows consistent assessment of leprosy in skeletal remains while also accounting for the variability of leprosy as a disease. It exposes the previous issues while also showing a way forward. It is important that macroscopic osteological methods be improved in this way so that it can contribute effectively to studies and be a valuable

tool in archaeological investigation on the same level as aDNA and isotope analysis going forward, and the above demonstrates why we need rigorous and replicable criteria to improve consistency in research output for the macroscopic assessment of leprosy in skeletal remains, and to give the appropriate macroscopic context of the extent of leprosy displayed by an individual in wider investigations.

Table 6.1: Summary of all individuals in each paper assessed and their Lepro-C category.

Paper	Individual (age and sex)	Determination in original paper	Lepro-C category	Reason Lepro-C category given
Gilmore (2008)	Skeleton 2 ('probable female, 20-25 years old')	'showed changes that are characteristic of leprosy'	Could be *highly consistent*, but limited descriptive detail provided for pathology. Needs reassessment in person	Two RMS lesions present, as well as bilateral postcranial absorptive lesions to the metatarsals and bilateral PNBF on the tibiae and fibulae
	Skeleton 4 ('indeterminate sex, 40-50 years old)	'the changes to the rhinomaxillary area in skeleton 5, combined with the bilaterally symmetrical postcranial bone changes found in both skeletons 4 and 5 are strongly suggestive of the presence of multi-bacillary leprosy'	*Consistent*, but limited descriptive detail provided for pathology. Needs reassessment in person	No facial lesions, but absorptive and proliferative / inflammatory postcranial lesions present
	Skeleton 5 ('indeterminate sex, 40-50 years old)	*See above*	*Highly consistent* based on descriptions, but might be *diagnostic* if reassessed to check for pitting of nasal surface of palate, and to confirm RMS as no images are provided	Four RMS lesions are present
Rubini and Zaio (2009)	Skeleton 68 ('Female, 40-46 years old')	'most likely diagnosis is lepromatous leprosy' [this statement applies to both individuals]	*Not consistent*	Individuals display only one absorptive RMS lesion at best, other lesions reported could be caused by other means, (non-specific periodontal disease, ancestry or taphonomic damage

	Skeleton 108	*See above*	*Not consistent*	*See above*
Kjellstrom (2012)	Case 1 ('adult, 20-23 yeas old'); Case 2 ('female, 20-30 years old'); Case 3 (male, 20-25 years old)	'display evidence of systemic infection, possibly leprosy'	All three are *consistent*	No skull to assess RMS for these individuals, but all three display bilateral absorptive and proliferative / inflammatory, mainly of the lower extremities
	Case 4 ('adult of unknown sex')	'lesions suggestive of leprosy with tuberculosis (TB) comorbidity'	*Consistent*	No RMS, but at least two proliferative postcranial lesions, and at least one absorptive lesion. Signs of comorbidity with TB
	Case 5 (complete skeleton of '11-12 year old child')	'lesions imply that individual suffered from lepromatous leprosy'	*Highly consistent,* could be *diagnostic* if reassessed and pitting on nasal palatine surface is present	Four RMS lesions are present
	Case 6 ('male aged 35-50 years')	'the skeletal changes are diffused and could not be confidently associated with a specific disease'	*Highly consistent* based on descriptions, but *consistent* based purely on images presented - This highlights the variable conclusions to be drawn when there is disparity between descriptive and photographic evidence, and why ideally both should be equally representative of the pathology reported.	Two inflammatory RMS lesions (oral and nasal palatine pitting), and an absorptive lesion (rounding of the nasal aperture), with possible absorption of the anterior maxillary alveolus also, as well as evidence of proliferative and absorptive/destructive postcranial lesions

Christensen et al. (2013)	Burial 228 ('male, 22-32 years old')	'most likely suffered from a combination of tuberculosis and leprosy, or leprosy and lung cancer, due to the concurrent evidence of HOA, particularly on the left ilium and sacrum'	*Consistent*	PNBF on tibiae and fibulae, evidence of ossification of the interosseous membrane, some absorption of the metatarsals, absorption of the anterior nasal spine
Lunt (2013)	HH Cist 26 ('female, 34-38 years old')	'pathological bone conditions…would appear to be pathognomonic for lepromatous leprosy'	*Consistent*, could be *highly consistent* if oral pitting reassessed, as image provided does not show clear pathology	Only absorptive RMS lesions are present, and the postcranial lesions are inflammatory/proliferative (absorptive postcranial lesions would also have to be present to be *highly consistent*)
	K725A ('possible female, 25-35 years old')	'bone changes are clear evidence of facies leprosy'	*Diagnostic*	All 5 RMS lesions clearly present
Inskip et al. (2015)	GC96 ('male, 21-53 years old')	'osteological evidence is typical of leprosy'	*Consistent*	Several proliferative and absorptive/inflammatory postcranial lesions, some bilateral and symmetrical, no facial bones survive to assess lesions.
Kohler et al. (2017)	SK257 S20 ('male, 18-22 years old')	'shows strong evidence for the bony manifestation of advanced leprosy''	*Consistent*	Two RMS lesions are present at best, both absorptive in nature, with the postcranial lesions being inflammatory/proliferative in nature

Taylor et al. (2018)	SkCXLVII ('probable male, 13-18 years old'); Sk171 ('adult, indeterminate sex'); SkCXCV ('male, 35-50 years old'); SkCCXXX (male, 35-50 years old)	All individuals display 'probable leprosy'	SkCXLVII – *consistent* Sk171 – *consistent* SkCXCV – *diagnostic* SkCCXXX - *diagnostic*	SkCXLVII - no rhinomaxillary syndrome lesions, and concentric remodelling of the metatarsals and periosteal new bone formation on the distal tibia and fibula Sk171 - concentric remodelling and of the metatarsals and metacarpals, as well some tarsal disintegration. SkCXCV – full rhinomaxillary syndrome SkCCXXX – full rhinomaxillary syndrome
	SK1494 ('possible male, 18-35 years old')	*See above*	*Consistent*	No maxilla to assess RMS. Bilateral PNBF on the tibiae and fibulae present, as well as bilateral concentric remodelling of the metatarsals, with arthropathy of associated phalanges, and dorsal tarsal exostoses
Bedic et al. (2019)	Skull 83 ('female, 25-45 years old')	'diagnosis of lepromatous leprosy is the most probable one'	*Highly consistent*	Absorption of the anterior nasal spine and rounding of the nasal aperture are present with inflammatory pitting of the oral surface of the palatine process
	Skull 200 ('female, 15-17 years old')	*See above*	*Consistent*	Two absorptive RMS lesions are present

Chapter 7: Discussion

The main aim of this research for the macroscopic assessment of leprosy was to formalise the criteria for assessing leprosy in skeletal remains and to assess the nuance and variability of leprosy lesions in skeletal remains, demographically and morphologically. The following discusses some of the key salient outcomes of the results and how they relate to these aims. The first to be considered is the overall demographic patterns of the assemblage.

7.1 Demographic Profile

There were significantly more males in the combined dataset than females, with 58.3% of individuals recovered from the cemeteries being male. The disparity observed between males and females may reflect a bias towards selecting more male 'brothers' as inmates. They were certainly not places where people ended up by accident; Demaitre (2007) and Rawcliffe (2006) show that leprosaria were governed by committees comprised of a mix of inmates and other individuals closely involved with the running of the institution. Rawcliffe (2006: 144) shows that leprosaria did admit both male and female leprosy sufferers, albeit with internal segregation to keep the male and female inmates apart, and reportedly not before the 15th century. The significant representation of males compared to females at the sites may reflect the charters of the leprosarium and the entry criteria they imposed. For example, Magilton et al. (2008: 63) show that charter evidence suggests that women were not formally admitted to Chichester prior to the 15th century. This perhaps explains the disparity to an extent, with the female burials at Chichester and Winchester possibly being those of nurses that provided care to the inmates (Lewis et al., 1995; Rawcliffe, 2006). However, the evidence of leprosy in younger females at Chichester and Winchester from cemeteries that were in use before the 15th century suggests they were there as inmates. Therefore, this observation echoes the recommendation of Filipek et al. (2022) that further research is needed on the place of women in early leprosaria in medieval England. Leprosaria for female inmates only have been identified in medieval France, such as Salle-aux-Pelles in Medieval Rouen, which Brenner (2015) shows was well-funded, including receiving Royal patronage from Henry II. So, this valuable work of the place of women in leprosaria in medieval France shows that this must also be explored for Medieval England in future research. For example, Kemp (1985) shows that a priory called Maiden Bradley was a leprosarium founded in 1164 in Bradley, Wiltshire, specifically for women. Maiden Bradley has not been written about in peer-reviewed scholarship since then (it was the subject of a blog post on the National Archives in 2022), although it was the subject of a chapter in *A History of the County of Wiltshire: Volume 3* (Pugh and Crittall, 1956) which gives a broad overview

of the history of the site from its foundation in 1164 to 1545. This demonstrates that there is much more work to be done on the place of women in leprosaria in medieval England, as we know from Maiden Bradley that female-only institutions existed, they have just been neglected in scholarship. The present research is important also as it shows that females with macroscopic evidence of leprosy were present in leprosarium cemeteries prior to the 15th century, but there were evidently socio-cultural factors at play that led to males being interred at a systematically higher rate than females at Chichester and Winchester.

The disparity could also be due to female monastic institutions being in more rural areas than male monastic institutions, so may not have been excavated (Inskip, *pers. comm*). For example, Venarde (2018: 110) shows that female monastic institutions in medieval France, such as nunneries, obtained their wealth from the rural economy. However, the existence of Maiden Bradley noted above shows that female-only leprosaria in medieval England needs further research.

It may also be the case that men were biologically more susceptible to leprosy than females. Interestingly, Blondiaux et al. (2016) argued for a systematically higher mortality rate of female leprosy sufferers in the eight leprosaria they studied in northern France, comprising 852 individuals, and so perhaps females in medieval England living at a similar time were predisposed to dying before the most debilitating lesions developed, and before they could present themselves to a leprosarium, given the long time it took to formally diagnose leprosy. Modern clinical literature on leprosy rates between men and women is contradictory. Kumar et al. (2004) observe a ratio of 2:1 in leprosy rates between males and females in Nepal. However, in their study on gender differences in leprosy in Sichuan China from 2000-2015, Liu et al. (2018) demonstrate that rates of leprosy between men and women were similar, but that women displayed leprosy at younger ages than men but did not suffer any greater disability. So, even in the present day with active cases in live individuals to study, leprosy remains a confounding and inconsistent disease. Given the comparability of 'medieval' and 'modern' leprosy as shown by the Latin translations in this research, the contradictory demographic patterns seen in modern clinical research into leprosy are potentially reflective of similar patterns in medieval England. This shows the importance of this research, as the second and third aims of the thesis have been used to explore these patterns, demonstrating the importance of a multidisciplinary approach.

In terms of macroscopic evidence of leprosy and the proportion of each sex affected, males and females were similarly affected at Chichester and Winchester, suggesting that the differences in rates of males and females relates to systematic socio-culturally-driven separation, rather than males being more susceptible to leprosy. Women may have been less likely to come forward if they had leprosy. This is a pattern observed in modern clinical research where there is increased stigma

towards women with the disease (Dijkstra et al., 2017). Rawcliffe (2006: 80-86) also shows that women at times faced significant stigma as vectors of leprosy in medieval England, particularly with regards to passing on leprosy via sexual contact with a man while menstruating, or if they had associated with individuals with leprosy previously, so women suffering from leprosy may have been less likely to come forward at certain periods of time when the leprosarium cemeteries were in operation, so fewer females were interred than males over the time the cemetery was in operation. Rawcliffe (2006: 285) also shows that there was anxiety around spiritual and physical contagion if associating with women that had spiritual or physical leprosy, so this may have fed into burial practices in leprosaria. It may have been the case that females with leprosy were not routinely interred with the males in the leprosarium cemeteries at Chichester and Winchester as a result of this. However, the fact that females were buried at Chichester and Winchester shows that there was socio-cultural heterogeneity over the centuries the cemeteries were being used. This demonstrates the importance of this present research, as the macroscopic evidence of leprosy in females at Chichester and Winchester highlights this socio-cultural heterogeneity over time by proxy, it also shows the need to test Lepro-C on non-leprosarium assemblages to see if there is a higher prevalence of leprosy in females in those assemblages compared to males, to further explore the socio-cultural themes suggested in this research. Roberts (2020: 213) also notes that not all of those who experienced leprosy in the medieval period would be detected by studying only leprosarium cemeteries, so this will be an essential future direction for research. This demonstrates the importance of Lepro-C, as it allows us to consistently gauge the macroscopic evidence for leprosy displayed by an individual as a baseline to explore the impact of sociocultural burial practices where leprosy is concerned, particularly for non-leprosarium sites where only women have been identified.

An example of sites to explore where only females with evidence of leprosy have been identified this is the Collingbourne Ducis site in Wiltshire, which is an Anglo-Saxon cemetery dated to 5^{th}-7^{th} century AD, and from which 3 adult individuals displayed macroscopic evidence of leprosy, all female (Dinwiddy, 2016). Sites such as these would benefit from being reanalysed with Lepro-C to see how extensive the evidence of leprosy is for previously identified female individuals, and whether there is any other evidence for leprosy in the wider cemetery with the detailed and replicable analysis that Lepro-C allows. Roberts (2020: 323-328) details the known sites of leprosy burials from Medieval England. The sites detailed there would be an ideal starting point to explore known non-leprosarium burials and the demographic profile thereof, and apply Lepro-C to them. This should be a dedicated research project where the skeletal remains are directly reassessed, as a current difficulty with determining the sex demographics of the individuals reported by Roberts (2020: 323-328) is that when consulting the material cited, some of the resources are unpublished,

or do not detail in the full the sex of the individual skeletons. An example of this is the Ipswich, Blackfriars, Suffolk site noted on page 326, where 4 individuals with leprosy lesions are present, however Mays (1991) is unpublished, and Taylor et al. (2006 and 2011) do not provide detail of all the leprosy individuals from that site, as those papers concern aDNA evidence from a subset of the individuals only.

At Winchester, 35 children were present, aged across the spectrum from birth to 16 years old. At Chichester, while 105 children have been recovered from the whole assemblage (Lewis, 2008), only two were found in the part of the cemetery that served the leprosaria. The children at Chichester were not far apart in age, at 5-7 years and 9-10 years respectively. That each of the non-adult age groups at Winchester was similarly represented suggests there was no particular bias towards non-adults entering the cemetery in terms of age. They may also have entered the leprosarium to save them from becoming orphans (Lewis, *pers. comm.*).

7.2 Individuals with No Lesions

Given the context of the cemeteries under study, it is of note that 29.5% and 6.9% of the individuals examined displayed no macroscopic signs of leprosy at Winchester and Chichester respectively. Roffey and Tucker (2012) suggest that liminal sites such as leprosaria on the edges of town may also have served as burial sites for criminals, although later concedes this is unlikely (Roffey, 2020: 542). These 'non-affected' individuals may also represent those who entered the leprosaria with soft tissue lesions, but due to their frailty died before any skeletal lesions could manifest (Wood et al. 1992; Soltysiak, 2015; Dewitte and Stojanowski, 2015). Individuals displaying no lesions may have been suffering from a tuberculoid or borderline form of the disease, which principally manifests in the soft tissues with limited or no skeletal involvement (Spekker et al., 2022). The Latin medical texts analysed in this research shows that there was an awareness of the lesions caused by milder forms of the disease with reference to skin rashes such as impetigo and serpigo. Serpigo in particular refers to a discoid (disc-shaped) skin rash, which is a prominent feature of tuberculoid leprosy (Lastoria and Abreu, 2014). Gaddesden also refers to localised hair loss and neuropathy that remains in the affected regions even if lesions are 'cured', which strengthens the link to tuberculoid leprosy, rather than a skin condition that might mimic it. These 'leprosy reactions' are noted in modern clinical cases of tuberculoid leprosy that can flare up and recede in repeated episodes due to a granulomatous immune response in individuals with high resistance immunity (Nery et al., 2013; Kahawita and Lockwood, 2008; Walker and Lockwood, 2008; Leon et al., 2016), and enduring neuropathy and hair loss is a feature of tuberculoid leprosy (Talhari et al., 2015). This awareness of tuberculoid lesions in medieval medical literature demonstrates that there was keen observation of the variability of lesions, and that the lesions observed then are comparable to those observed

today for leprosy. It is therefore reasonable to suggest that some individuals displaying no lesions were suffering from the tuberculoid form of leprosy, as opposed to being having another disease or dying before lepromatous lesions could manifest, especially as individuals were not admitted to leprosaria lightly, as noted above.

That individuals with no lesions may have been suffering from tuberculoid leprosy needs reconciling with the inherently strong immune response required to develop tuberculoid leprosy, as this would suggest that individuals were relatively strong (at least immunologically). This is particularly so given that 73.3% of individuals displaying no lesions were aged 26-35 year old or younger, suggesting a degree of selective mortality for these individuals given the overall age distribution of individuals in the dataset. Co-morbidity may be a factor, as they were living in institutions where infectious disease could spread easily. Four individuals displayed evidence of tuberculosis (TB), displaying mainly destructive lesions to the lumbar vertebrae and thoracic ribs, so it may have been present more widely in those displaying no lesions, as skeletal tuberculosis accounts for just 6-10% of extra pulmonary tuberculosis (Fujiwara et al., 2023). Individuals could die of TB, also a *mycobacterium*, before the leprosy lesions developed as TB can manifest 2 years post-infection (Behr et al., 2018), as opposed to the 3-5 year average for leprosy (Lockwood, 2004). Donoghue et al. (2005) suggest that the low immunity associated with lepromatous leprosy would trigger latent TB, however an individual must have had an appropriately strong immune system in the first instance for the TB to become latent, and not manifest within the first two years of infection (Lin and Flynn, 2010). Therefore, perhaps social factors subsequently led to a weakening of the immune system, or maybe the contraction of *M.leprae* tipped the immune system over the edge. The former suggests that external factors predisposed them to developing leprosy *and* reactivating latent TB, rather than leprosy causing the reactivation of TB directly, *per se*. The latter suggests that an immune system is overreacting, a risk of which is cytokine storm, a potentially fatal immune response due to overactivation of immune cells and inflammatory cytokines (Teijaro et al., 2014; Yamamura et al., 1991; Bleharski et al., 2003). Increased cytokine activity in the tuberculoid form of leprosy (Barnes and Wizel, 2000), combined with acute leprosy reactions (Suzuki et al., 2012; Nascimento, 2013; Wan et al., 2016), suggests that an overly aggressive cell-mediated immune response to *M. leprae* may have been a higher risk factor in reactivating latent TB. The presence of both bacteria in the body could then possibly lead to a hyper immune response that was potentially fatal. This might also explain how someone also had a strong enough immune response for latent TB to develop in the first place, and how they subsequently died before lesions could develop. Older individuals may also have been affected by selective mortality in this way also, as only 2 individuals aged 46+ (4.2%) had three or more rhinomaxillary lesions present and fell into the *highly consistent* category. All of

the remaining individuals in this age category were *not consistent* or *consistent*, reflecting the generally low macroscopic evidence of leprosy for individuals in this age category.

Individuals with chronic TB have been identified in the cemeteries during the times the sites were operating as leprosaria, suggesting they may have been inmates. The interaction of TB and leprosy in late-medieval England remains a hot topic of debate, with cross-immunity and co-infection being prominent theories in the decline of leprosy in the UK (Crespo et al., 2019). The relationship between these bacteria is evidently complex, and the above shows that an overreactive immune response needs more consideration in the debate. This may then feed into wider syndemic discussions in bioarchaeology, where the social and economic determinants of health (as well as biological) are given due consideration when considering variable frailty in the population (Perry and Gowland, 2022). The syndemic approach may show that those co-infected by leprosy and TB may have been predisposed to this due to their socio-economic situation, so the presence of these two diseases may reveal something about the wider context they came from by proxy. This demonstrates the importance of Lepro-C, as the method allows for the consistent macroscopic assessment of leprosy in skeletal remains, so can help to highlight the impact of socio-economic factors for individuals, particularly where there is co-morbidity with TB.

7.3 Overall Evidence for Leprosy

In total, 148 individuals (58.7%) were categorised as showing lesions *consistent* with leprosy or higher (78 individuals at Chichester (59.5%), 70 at Winchester (57.8%)). As expected, rates of individuals included within Lepro-C categories got progressively fewer as the criteria become more stringent. Encouragingly however, the rates of individuals falling into each category at Chichester and Winchester were similar, suggesting that the method was being consistently applied, and that there was similar evidence for leprosy at each site. This also broadly suggests that the propensity of individuals to develop leprosy lesions or not was consistent between sites, and therefore the nature of leprosy and how it manifests was not site specific (at least for these two sites). This does not consider the minutiae of the ages and sexes of individuals affected however, and the possible differences of socio-economic background. So, the trends from the results are discussed in greater detail below.

7.3.1 Asymmetry and Areas Affected

While lesions on both sides of the skeleton were well represented, there was a trend for males to show more lesions on the right side of the body. For example, the right hand, leg and foot of males showed were more affected by lesions, with all being around 4% more affected by lesions than the left side equivalent. While individual female cases also showed a propensity for lesions to be more

on one side than another, the dominant side varied overall. At both sites, however, in both males and females the right leg was more likely to be affected by lesions. While there was a trend for females to display more facial lesions, the numbers were small, but males showed much greater propensity to display lesions in the upper limbs than females, and had a higher likelihood of more severe lesions and had a greater number of lesions overall. Overall however, the feet being affected more than the hands at Chichester and Winchester reflects a wider trend in the bioarchaeological evidence of leprosy generally, with the feet being affected more than the hands in many other sites (see Roberts, 2020: chapter 5). The hands can be seen and protected from blisters, which may explain this. The differential rates of lesions between left and right hands, and left and right legs, may reflect trends in dominant hand/legs in individuals, which may predispose them to trauma. Modern clinical studies have suggested a link between handedness and trauma (Canakci et al., 2003), so this could also explain lesions being more present on one side than the other.

7.3.2 Did Site and/or Sex Have an Influence on Lesion Expression?

The following considers whether the sex of an individual, or the site where an individual was buried, had an influence on the presence of lesions. This is done in light of the binomial logistic regression to explore whether there were any differences between the sites, or differences in distribution of lesions between individuals of varying sex, to highlight the importance of the present work for exploring these patterns across key sites for leprosy in medieval England.

7.3.2.1 Differences between Chichester and Winchester

Lytic (peri)articular lesions were significantly more common at Winchester than Chichester. (Wald = 7.634; p = .006), indicating in the binomial regression that these lesions were significantly more common at Winchester than at Chichester. This suggests that there was a greater propensity for individuals at Winchester to develop septic arthritis due to invasive pyogenic infection (Andersen et al., 1994). This tentatively suggests that there was marginally greater frailty in the Winchester individuals, due to these lesions appearing to a greater extent than at Chichester, and their septic origin suggesting a greater susceptibility to secondary infection, although this is tentative as this was the only lesion where the site had an influence on whether the lesion was present. This does however illustrate the importance of this study as it demonstrates that the macroscopic evidence of leprosy overall did not systematically occur more at one site that the other, with the exception of the lesion above. This perhaps suggests a degree of homogeneity in the socioeconomic conditions of the leprosaria over time, and the immunological status of individuals admitted. This is further supported also in that the evidence of Chapter 2 shows that the knowledge existed to diagnose leprosy in medieval England, and that leprosy presented in a manner similar to how we would

understand it in the present day. This demonstrates the nuance of leprosy lesion expression between sites, and importance of the multidisciplinary approach of this research.

7.3.2.2 Differences Between Sexes

The binomial logistic regression testing showed that whether an individual was male or female had no bearing on whether a lesion was more likely to be present, as no test between lesion and sex fell below alpha value of p = .008 after Bonferroni correction. The closest lesion to this alpha threshold was periosteal new bone formation to the distal fibula (p = .009). Ultimately, this study demonstrates that being male or female had no bearing on the specific leprosy lesions that could occur. This may have been influenced by the low numbers of females compared to males, but the importance of this research is demonstrated as now it is suggested on the evidence available that sex does not influence how likely a specific leprosy lesion is to occur.

7.4 Leprosy Lesions and Age-at-death

The following discusses the patterns observed in the results between individuals of a certain age and the lesions they displayed.

7.4.1 Rhinomaxillary Syndrome

For males, individuals aged 26-35 years were generally the most affected by rhinomaxillary lesions. However, males aged 36-45 years at Chichester were most affected by absorption to the anterior maxillary alveolus and nasal pitting, and jointly most affected with males aged 26-35 for oral pitting. Females at Chichester most affected by rhinomaxillary lesions were aged 17-25, whereas the ages of females most affected by rhinomaxillary syndrome lesions was more variable at Winchester, with individuals aged 17-25, 26-35 and 36-45 most affected depending on the lesion. For example, females aged 36-45 were most affected by absorption of the anterior nasal spine, whereas females aged 17-25 and 26-35 years were jointly most affected by remodelling of the nasal aperture. While numbers of females were small compared to males, so it is important to not overstate the patterns observed, these results at least suggest that females generally develop these lesions younger than males, reflecting the pattern observed by Liu et al., (2018). This is a valuable observation, that directly addresses the second aim of this research, which was to assess the nuance and variability in the expression of leprosy in skeletal remains, with the caveat that there were relatively low numbers of females.

When age and the prevalence of lesions was tested statistically, remodelling of the nasal aperture (phi = 0.316) and absorption of the anterior nasal spine (phi = 0.211) was most common in individuals aged 26-35 years. There was a weak relationship between RMS and those aged 36-45

years, with phi values between -0.101 and 0.057, and a significant negative relationship between all RMS lesions and individuals dying aged 46 years or older. Absorption of the anterior nasal spine was the most common RMS lesion of all, and 57.8% of adult individuals dying with *highly consistent* or *diagnostic* combinations of lesions as per Lepro-C were aged 26-35 years. This indicates that individuals aged 26-35 years were most likely to die having developed the most debilitating form of rhinomaxillary syndrome, perhaps due to contracting the disease earlier, such as in adolescence when the disease can take advantage of a transforming immune system (Lewis, 2022). This is supported further by the binomial logistic regression analysis, where being aged 26-35 was shown to be significantly linked to the presence of remodelling of the nasal aperture (Wald = 4.226, p = .001), absorption of the anterior nasal spine (Wald = 12.184, p = <.001), and oral pitting (Wald = 9.476, p = .002), with each model significant overall. These findings are more robust than those seen in the phi analysis as binomial logistic regression allows for patterns to be tested for a number of variables all at once, so these results are encouraging and demonstrate statistically that there was selective mortality for individuals displaying the most extensive evidence of leprosy.

Therefore, the results and statistical analyses indicate that full rhinomaxillary syndrome is most likely to develop by 26-35 years in individuals. Individuals of this age were more likely to be immunologically compromised and develop the most serious, lepromatous form of the disease, and die younger. The link between the higher Lepro-C categories, where more evidence of rhinomaxillary syndrome is required, and individuals aged 26-35, also demonstrates the strength of Lepro-C as a method, as it allows us to consistently gauge the extent of rhinomaxillary syndrome present and make comparisons in relation to age and sex from this consistent baseline.

The systematic lack of RMS lesions in 46+ year old individuals, and weak relationship of leprosy lesions to individuals aged 36-45 years is also of interest. It is reasonable to suggest (if tentatively so) that some older individuals in the dataset had a form of leprosy largely invisible to us skeletally, as opposed to them having another disease or having no disease at all. This may suggest that these older individuals were relatively strong immunologically, and therefore more predisposed to developing tuberculoid leprosy, as they evidently were not as frail as those that died aged 26-35 with strong evidence of lepromatous leprosy. Individuals older than 35 years developing tuberculoid leprosy is observed in modern clinical cases (Brandao et al., 2018; Liu et al., 2018), and Arunraghav and Herakal (2021) note that the most common form of leprosy in elderly patients is borderline tuberculoid, so this view is supported clinically.

These findings of rhinomaxillary syndrome lesions and how they affect adult individuals of certain ages directly addresses the second aim of this thesis, as it demonstrates the nuance and variability

of the occurrence of leprosy lesions at a lesion-by-lesion level not explored at this resolution before, illustrating the importance of the research.

Outside of this research, similar results are found in the published cases included in the Lepro-C analysis on previous papers (see Chapter 6). For the *diagnostic* individuals identified in this research, Individual K275A, from St Andrew's, Fife, Scotland, was aged 25-35 years (Lunt, 2013). Individuals SkCXCV and SkCCXXX (both male, 35-50 years old, and displaying lesions *diagnostic* of leprosy) from Golden Lane and Armoy, Ireland (Taylor et al., 2018) were potentially older, but may also have been 35 years old, which is in the range for individuals most commonly affected by leprosy lesions in this thesis. The other individual in Lunt (2018), aged 34-38 years, had less advanced RMS with absorptive lesions to the nasal spine, nasal aperture and maxillary alveolus. Of the other 5 individuals in the literature considered in Chapter 6 given a Lepro-C category of *highly consistent* or higher, all but two were under the age of 46+ years, and those 'older' than that were given ages of 35-50 and 40-50 years in their respective papers ('Skeleton 6' in Kjellstrom, 2012; Skeleton 5 in Gilmore, 2008) so still potentially younger than 46+. This perhaps mostly highlights the ongoing issues with inconsistent age categories (see Falys and Lewis, 2011) but it is nonetheless interesting that younger adults are consistently affected by the most extensive evidence of leprosy in other research also.

7.4.2 Leprogenic Odontodysplasia

Five individuals displayed root malformation that might be termed 'leprogenic odontodysplasia' (LOD), morphologically speaking (Fig. 7.1). At Chichester, the teeth affected were the right maxillary canine for skeleton C32 and C31, maxillary central incisors for skeleton C367. At Winchester, the right maxillary central incisor of SK28, and the left and both central incisors of SK8 being affected respectively. Evidence for leprosy elsewhere in the skeleton was generally limited for these individuals, with 80% of individuals displaying this lesion being *consistent* or *not consistent* with leprosy as per Lepro-C (only Skeleton 28 from Winchester was *highly consistent*). This suggests that this root malformation is not related to leprosy and is a non-metric trait first and foremost, a view further supported in that this lesion has yet to be identified and linked to leprosy clinically (Roberts, 1986). The root constriction is comparable to that seen in previous research (Roffey and Tucker, 2012; Matos and Santos, 2013), but the evidence here suggests it is not a useful indicator of leprosy.

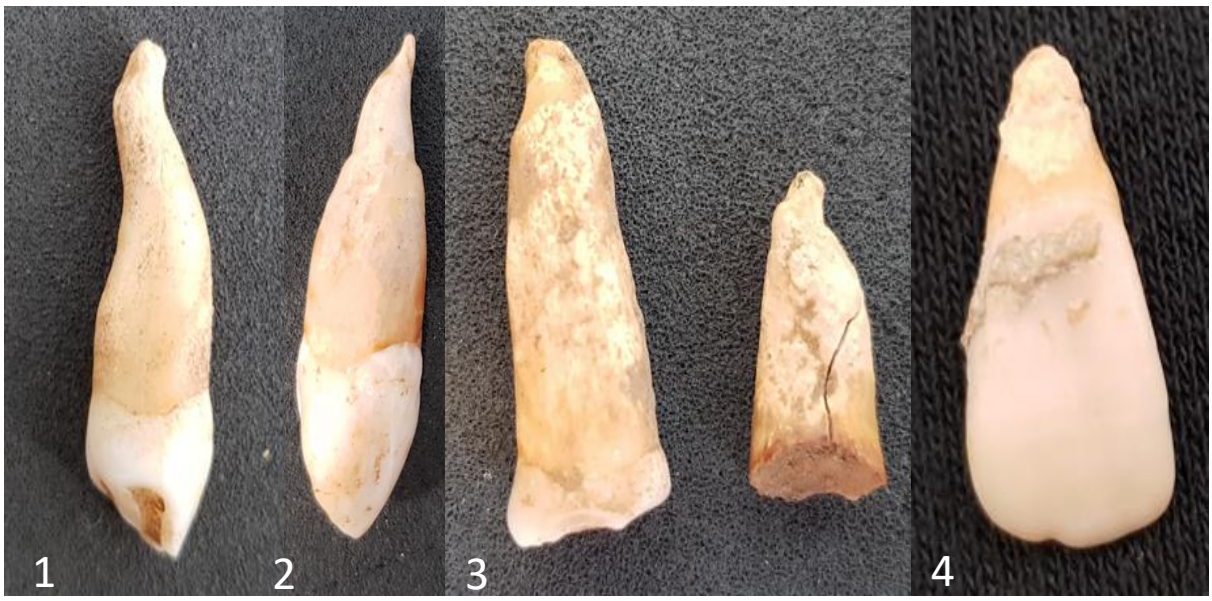


Fig. 7.1: Root malformation of maxillary incisors (1. Chichester 32, 2. C341, 3. C367, 4 (Access to collection to take these images kindly granted by the BARC). Winchester SK28, 5. SK8 (image 5 from Roffey and Tucker, 2012: 175).

7.4.3 Lesions of the Upper Limb

The majority of upper extremity lesions did not show a strong relationship to any adult age group in the phi or binomial logistic regression analysis, and the numbers of lesions in these regions were relatively low. The strongest positive phi relationship was between absorption of the hand phalanges and metacarpals and the 26-35 year age group, where 80% of cases were bilateral. Given that this is one of the most characteristic upper extremity lesions in the osteological presentation of leprosy (Anderson et al., 1992), it is interesting that it is most positively associated with the same year age group where some RMS lesions show the strongest positive associations. The low prevalence of upper limb lesions is notable as there is good preservation at both sites. Neuropathy in the upper limb is common in a modern clinical setting (Pedraza Hueso et al., 2014), and might be expected at Chichester and Winchester given the descriptions of leprosy in contemporaneous

medieval Latin texts, and the relative genetic stability of *M. leprae* since antiquity (Britton and Lockwood, 2004). The results here suggest that neuropathy in the upper limb does not often progress to osteological lesions. Mononeuropathy (where just one nerve/side is affected) is more likely in the upper limb (Nascimento, 2013) and indicative of tuberculoid/borderline tuberculoid leprosy. However, the bilateral nature of the hand lesions and their association with RMS in the 26-35 year age group indicated they were suffering from the more common *mononeuritis multiplex* (Jaiswal et al., 2018), where multiple peripheral nerves are affected, suggestive of lepromatous leprosy.

Unilateral and isolated lesions to the upper limbs occurred in 60% of individuals aged 35+ years suggesting that borderline/tuberculoid leprosy may be more prevalent in older age groups, who were perhaps more immune-resistant to leprosy (Brandao et al., 2018; Liu et al., 2018; Arunraghav and Herakal, 2021).

7.4.4 Lesions of the Lower Limb

In the lower limb, individuals aged 26-35 years were again the most affected overall. Individuals of this age were most strongly associated with periosteal new bone formation on the tibiae and fibulae, which in turn were strongly associated with each other (phi = 0.780). This was reflected also in the binomial logistic regression testing, as individuals of this age were significantly likely to display these lesions (Wald = 17.963, p = <.001 and Wald = 22.178, p = <.001 respectively). This is not particularly surprising, given the close proximity of these bones to each other and the nature of the inflammation of the adjacent soft-tissues in leprosy and ossification of the interosseous membrane that may also occur (Lewis et al., 1995), as well as new bone formation being stimulated by any disturbance of the periosteum (Weston, 2008). The occurrence of PNBF in an age group also suffering more from rhinomaxillary lesions adds weight to the link between PNBF and leprosy in these regions. This is also supported by the strong positive relationship of PNBF on the tibiae and fibulae with RMS indicating that these lesions consistently appear together. There were also strong positive relationships between absorptive and proliferative lesions, which is encouraging as this pattern of lesion type is an essential facet for assessing leprosy using Lepro-C. Periosteal new bone formation is a non-specific lesion, however, so these links must be approached with caution. This is the strength and importance of Lepro-C, as it takes into account the distribution of lesions across the skeleton. So while the trends identified are valuable, and may help in differential diagnosis where evidence for leprosy is lower (i.e. not *diagnostic*), Lepro-C is constructed in such a way that diagnosis of leprosy on the presence of PNBF alone would never occur.

7.4.5 Bilateral vs Unilateral Presentation of Lesions

Whether or not postcranial lesions manifest unilaterally or bilaterally allows for an assessment of the likelihood of tuberculoid, borderline or lepromatous leprosy manifesting in the assemblage. For example, 66.7% and 84.8% of males at Chichester and Winchester respectively displaying periosteal new bone formation did so bilaterally, most of whom were aged 26-35 years. This bilateral presentation further supports the statistical observations of the more severe evidence of lepromatous leprosy occurring mostly in the 26-35 year age group, and therefore these individuals displaying these lesions in this age group are more likely to be affected by multi-nerve involvement. This is not always the case however, for example Chichester 19 displayed all 5 rhinomaxillary syndrome lesions, but only displayed proliferative postcranial lesions on the left lower limbs, and no absorptive postcranial lesions at all. This suggests Chichester 19 was suffering from lepromatous leprosy, but without evidence of the widespread postcranial multi-nerve involvement you might expect. Conversely, Chichester 115 displayed no rhinomaxillary syndrome lesions, and absorptive and proliferative postcranial lesions were displayed unilaterally in some places (Fig. 7.2)(concentric remodelling right MT3 & 4, lesion proximal left ulna), and bilaterally in others (PNBF distal tibiae and fibulae). While Chichester 115 was *consistent* with leprosy, as no rhinomaxillary lesions were present to categorise any higher, the mix of bilateral/unilateral postcranial lesions, combined with the age-at-death of 26-35 years, suggests a complex mix of mono/multi nerve involvement. Therefore, a borderline form of leprosy, perhaps verging closer to the tuberculoid form of the disease as there is no RMS, could be considered during differential diagnosis, as the lesions present and age group of the individual support the statistical observations of where leprosy is most likely to occur. This accentuates the need to record the bilateral/unilateral presentation of lesions and consider them when applying Lepro-C and determining what form of leprosy an individual may have been affected by. It also shows how important Lepro-C is as a method as it allows for this to be consistently recorded to gauge whether borderline forms of leprosy may be present.

Fig. 7.2: Concentric remodelling seen in Chichester 115. Access to collection to take this photo kindly granted by the BARC.

7.4.6 Intraobserver Error Testing

An important part of this research was to test the replicability of the Lepro-C method by recording a subset of 20 individuals at Winchester twice, to see if lesions were being consistently identified, which is essential for Lepro-C to function. The following discusses this, to see whether the intraobserver error testing indicates that the method was replicable.

7.4.6.1 Rhinomaxillary Lesions

For RMS lesions, there was agreement on the presence and absence of lesions for both recordings of the 20 individuals at Winchester. There was very strong agreement for all RMS lesions apart from remodelling of the nasal aperture, in which the agreement was not as strong, but there was still showed good agreement overall. Remodelling of the nasal aperture, as demonstrated in section 7.5, was morphologically variable. This perhaps highlights a weakness of the binary present/absent criteria for recording remodelling of the nasal aperture as tested in this research, and future research should delineate the specific morphologies of remodelling of the margins of the nasal aperture into separate present/absent sub-criteria as part of Lepro-C. This ought to improve the agreement between both observers for this lesion in future versions of Lepro-C by proactively accounting for the morphological variability of remodelling of the nasal aperture. However, there was still agreement between both recordings of remodelling of the nasal aperture overall, just not as strong as for the other RMS lesions, so it is important not to overstate the difference between the two recordings. Therefore, the agreement between both recordings shown in the

intraoberserver error testing for rhinomaxillary lesions shows that the descriptions and recording of lesions were consistent overall, and that the Lepro-C method is replicable.

7.4.6.2 Postcranial lesions

For postcranial lesions, most had a very strong agreement, suggesting that the assessment of lesions overall was highly consistent, and the method is replicable overall. There were two lesions where there was a slight disagreement in the recordings, PNBF around nutrient foramen (kappa = -.071), and osteitis (kappa = -.154). This suggests that these two lesions as described and assessed in the method are too broad and should be delineated into specific nutrient foramen and regions for osteitis across the skeleton (with appropriate descriptions for lesions in those regions) in future versions of Lepro-C to improve the targeting and subsequent identification of these lesions. Additionally, the agreement between both recordings for acroosteolysis, while showing agreement, was not as strong as the other postcranial lesions. This also suggests that the identification of this lesion could benefit from more specific criteria, particularly for marginal cases, delineated into hands and feet and the particular phalanges affected, as in the present study 'acroosteolysis' was a generic category that encapsulated absorption that may have affected all distal phalanges.

7.4.7 Summary

The above patterns observed for the age at death of individuals in this research, showing that there was selective mortality for individuals aged 26-35 years displaying the most extensive evidence of leprosy, highlights the importance of this research, as while previous research has showed that 'younger adults' tend to be affected by leprosy in a more general way (see Lee and Magilton, 2008: 266) we now have this data, and patterns thereof, on a lesion-by-lesion basis for the age and sex. This age-at-death patterns identified for specific leprosy lesions allow for a more nuanced discussion of the likelihood of leprosy during differential diagnosis, particularly when applying Lepro-C. These observations directly address the first and second aims of the thesis, which was to develop Lepro-C as a method, and to explore the nuance and variability of leprosy lesions in skeletal remains.

A future plan is to conduct interobserver error testing to gain further insight into the replicability of Lepro-C, and any improvements that may be made subsequently. The intraobserver rates however do indicate that the method is replicable overall, particularly for the rhinomaxillary syndrome lesions that it hinges on, as well as newly identified lesions, such as those to the proximal ulna, and most postcranial lesions. However, as noted above there is some work to be done on incorporating the variable morphology of remodelling of the nasal aperture into the Lepro-C lesion descriptions and recording forms in future to improve observer error rates, although there was still good agreement between the two recordings for this lesion overall, just not as strong as the other

rhinomaxillary lesions. There is also work to be done for the postcranial lesions with less strong/slight disagreement agreement noted above to improve replicability for those lesions by developing more specific and targeted descriptions and criteria, as they were evidently too broad and generic in this research. This also perhaps highlights a weakness of the binary presence/absence approach adopted, and the subjectivity that ensues in marginal cases. A future approach might be to introduce grading criteria for lesions rather than the binary present/absent criteria as tested in this research, to allow more scope to account for severity of lesions. However, grading criteria for leprosy lesions have also been criticised for being subjective (Andersen and Manchester, 1992; Roberts, 2020: 140) leading to inconsistent recording of pathology, with recording as present/absent being suggested a better approach (Roberts, 2020: 140). Grading by severity also implies the duration of a lesion, however severity does not necessarily reflect duration (Subramaniam et al., 1983; Andersen and Manchester, 1992; Roberts, 2020: 140), so grading criteria are arguably inherently misleading and overly subjective. Therefore, introducing grading criteria to Lepro-C may complicate matters further, rather than improve them, and also make it more difficult to account for interobserver error due to the increased complexity and subjectivity that grading criteria introduce.

7.5 Morphological Variations

The following considers the morphological variation of several lesions, as this was a key aspect of leprosy lesions identified in this research. This is also a direct concern of the second aim of this research, which was to assess the nuance and variability of leprosy lesions in skeletal remains, so it is important to discuss important morphological variations of lesions.

7.5.1 Absorptive Rhinomaxillary Lesions

While all five RMS lesions were strongly related, there was variability in the morphological appearance of these lesions. This is particularly true for the nasal aperture where the descriptive term ‘rounding’ belies the variability of lesions to this region (Fig. 7.3). Lesions to the nasal aperture in individuals also affected by other leprosy lesions often show no rounding of the margins at all, quite the opposite in fact. The remodelling can expose the nutrient canals, leaving two sharp and distinct ridges that run in parallel medio-laterally from either side of the anterior nasal spine, or the remodelling takes the form of pitting along the margins adjacent to the anterior nasal spine. Looking for only ‘rounding’ (as opposed to remodelling) does not give full attention to the complexity and variability of these leprosy lesions. Also noted was porosity and cortical activity in the region of nasal

aperture and adjacent margins, which when viewed anteriorly resemble a bull with horns (see Fig. 7.4). This is the most common morphological presentation of absorption of the anterior nasal spine and adjacent margins of the nasal aperture in individuals *diagnostic* with leprosy from Chichester and Winchester. It was displayed by two of the four *diagnostic individuals* and it is suggested that this lesion combination be defined as 'bull-shaped remodelling' hereafter (Fig. 7.4). Remodelling of the nasal aperture and the nasal spine showed a strong positive relationship when tested using phi, suggesting that these changes are linked. Hence, these lesions occurring together is a strong indicator of leprosy, even in non-diagnostic cases (should there not be enough lesions elsewhere to be diagnostic). This is strengthened in that 50% of the diagnostic individuals displayed 'bull-shaped remodelling', suggesting this morphological combination is a strong indicator of leprosy. Absorption of the anterior maxillary alveolar process was also morphologically variable (see section 7.5.4).

The morphological variation of absorptive rhinomaxillary syndrome lesions could be the result of simultaneous processes of different pathogenesis. Andersen and Manchester (1992: 123-124) suggest that there may be more than just local inflammatory processes at play for absorption of the anterior nasal spine and remodelling of the margins of nasal aperture, but do not speculate what they may be for these lesions. The evidence here shows that inflammatory pitting and absorptive processes can occur in complex variations for rhinomaxillary syndrome lesions. This suggests that there are also neuropathic factors at play that affect the balance of osteoclasts and osteoblasts in these regions leading to absorption, in addition to localised inflammatory processes that can lead to concurrent inflammatory pitting. Morphological variation on this basis is also further supported in the clinical literature, where cranial nerve involvement in leprosy varies between individuals (Gopinath et al, 2004; Kumar et al., 2006; Dave and Bedi, 2013; Talhari et al., 2015; Sharma et al., 2023). Andersen and Manchester (1992: 123) tentatively suggest that a neuropathic process affects the anterior maxillary alveolus in leprosy similar to that seen in diaphyseal remodelling. However, the variability of all the absorptive rhinomaxillary lesions in this present research suggests that neuropathic processes similar to that seen for diaphyseal remodelling occurs in conjunction with localised inflammation for all absorptive rhinomaxillary lesions to varying degrees between individuals. This demonstrates the importance of this research, as assessing the nuance and variability of leprosy lesions to this level of detail as per the second aim of the research has revealed this.

Fig. 7.3: Variability in the morphology of remodelling of the margins of the nasal aperture. Clockwise from top left; pitting extending medio-laterally from either side of the ANS, with pores ~1-2mm in diameter; remodelling exposing nutrient canals; pitting of larger diameter than along margins, perhaps where primary granulomata have developed; rounding of margins capped by new cortical bone, with sporadic pitting. Access to collection to take top two images kindly granted by the BARC.

Fig. 7.4: Demonstration of ‘bull-shaped remodelling’ as part of the rhinomaxillary syndrome. Top: actual image, middle: overlay of bullhorn and skull shape on individual SK111 (left) and C50 (right), bottom: normal morphology for comparison (C32). Access to collection to take pictures of C32 and C50 kindly granted by the BARC.

7.5.2 Anterior Nasal Spine

The anterior nasal spine, as a projecting area of bone, is often damaged post-mortem, and it is important to establish some guidelines for separating pathology and taphonomy for this area, particularly as it can be misinterpreted (see Chapter 6). For example, absorption of the anterior nasal spine should be noted as a lesion if there is a gentle and continuous broad curve when viewed laterally. Post-mortem damage is suggested if the surviving bone surfaces in the same view appear sharp and straight with non-symmetrical breaks on either side of the intermaxillary process. Additionally, to be a lesion the affected area should show evidence of remodelling, which if not smooth, should show some cortical activity, such as pitting, that is the same colour as the unaffected bone, not an abrupt transition from the adjacent unaffected cortical bone to exposed trabeculae with lighter coloured bone at the margins of the affected area. Absorption of the anterior nasal spine also tends to be symmetrical (Fig. 7.5 and 7.6).

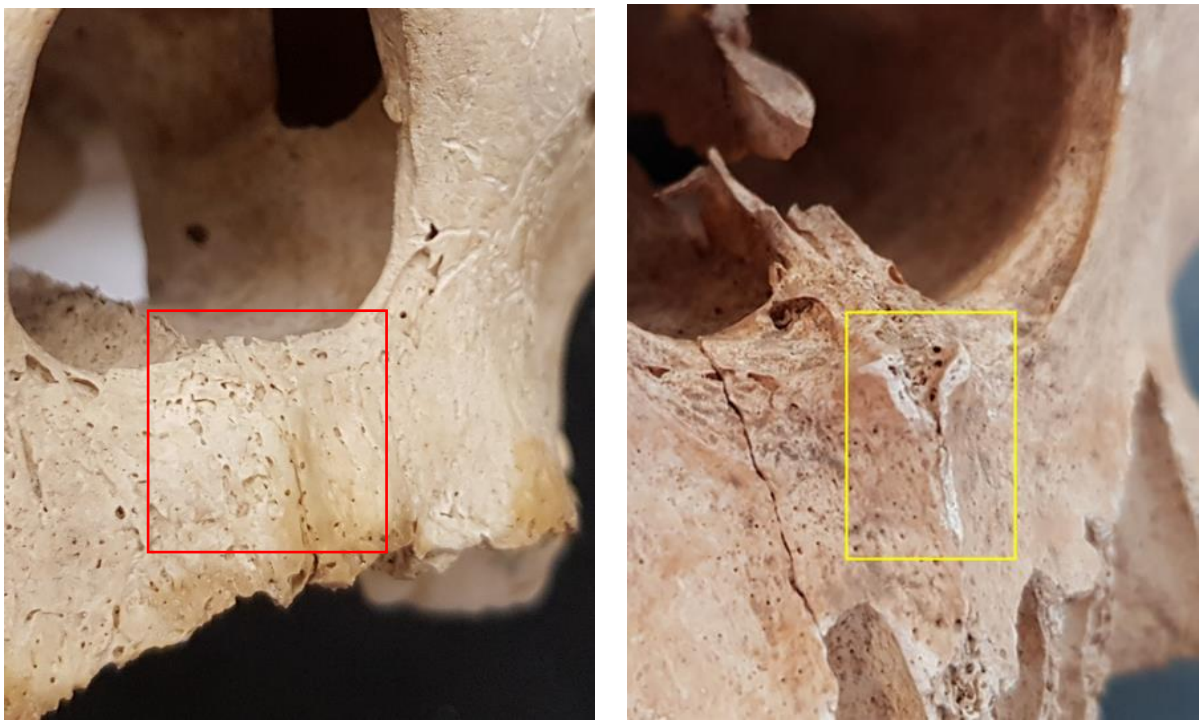


Fig. 7.5: A comparison of pathology and post-mortem damage to the anterior nasal spine. Left: Pathological absorption of the anterior nasal spine in Winchester SK28 (red box) Right: post-mortem damage in Chichester 337 (yellow box). Access to collection to take picture of C337 kindly granted by the BARC.

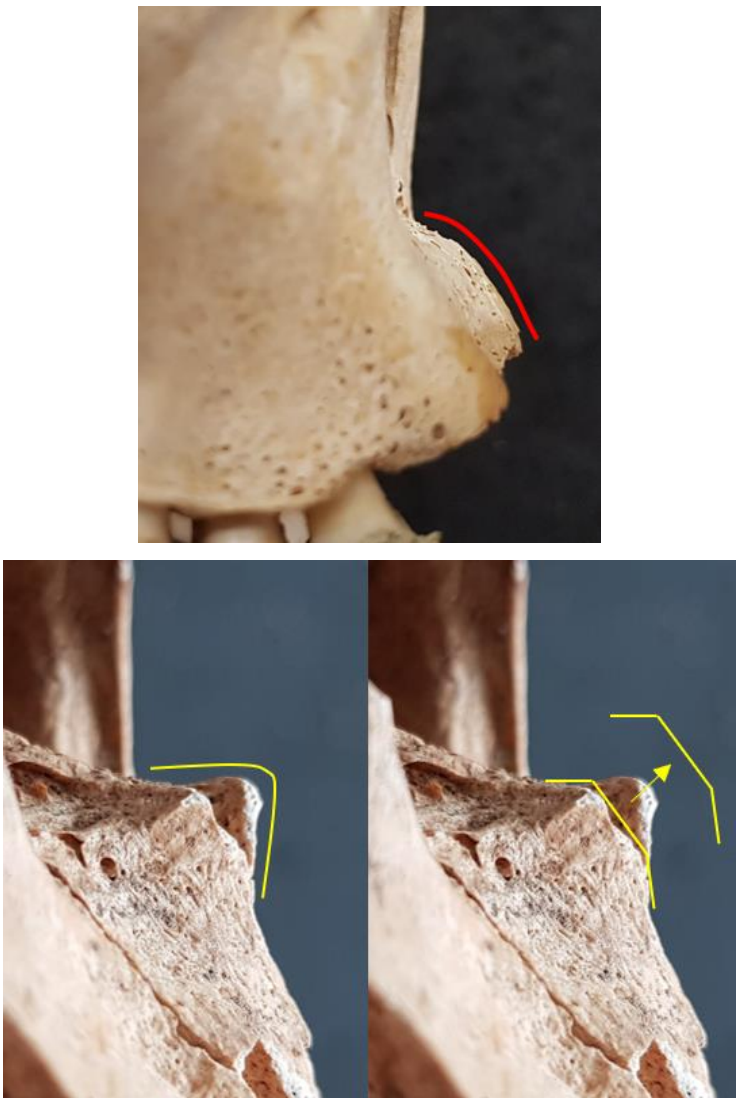


Fig. 7.6: Lateral view showing differences between morphology due to pathology, and due post-mortem damage of anterior nasal spine; top: symmetrical absorption (red line shows gentle continuous curve) in Winchester SK28 compared to, bottom: asymmetrical breaks due to post-mortem damage in Chichester C337 (yellow lines indicate shape, line transposed in right image for clarity). Access to collection to take photos of C337 kindly granted by the BARC.

7.5.3 Periosteal New Bone Formation on the Tibiae and Fibulae

7.5.3.1 Distal Tibia

In order to assess whether there was a particular form of PNBF that could be termed 'leprous periostitis' on the tibia and fibula, the strength of the relationship between different types of new bone on these bones (Fig. 7.7) was compared with RMS. In the tibia, nodular new bone formation had no relationship with RMS (phi = 0.04), while longitudinally striated new bone and porous disorganised new bone formation showed a strong relationship to each other(phi = 0.273), and with RMS (phi = 0.44 and 0.40 respectively), suggesting a systematic co-occurrence. While these results

may suggest these new bone formation types may be indicative of leprosy when found with some RMS lesions in *consistent* and *highly consistent* cases, it is important to note that new bone formation is a non-specific response (Weston, 2008). We do not have the data on these precise forms of new bone formation on the tibia and fibula and how they occur in other diseases. Therefore, any inferred link here between PNBF on the tibia and leprosy is very tentative at this point.

7.5.3.2 Fibula

All three forms of periosteal new bone formation displayed a strong positive relationship with cranial lesions; nodular (phi = 0.317), longitudinally striated (phi = 0.328), porous and disorganised (phi = 0.39). Nodular and porous and disorganised periosteal new bone formation appeared together frequently, as phi revealed a strong positive relationship between these two morphologies occurring together in single individuals (phi = 0.58). However, as with tibia lesions above, there is no consistent evidence linking PNBF of any one morphology to leprosy, which probably reflects the non-specific aetiology of the lesion.

7.5.3.3 Co-occurrence of Tibia and Fibula Lesions

The higher likelihood of finding nodular PNBF, whether in isolation or in combination with another morphology of PNBF, on the fibula rather than the tibia, suggests that perhaps the interosseous membranes are more greatly affected adjacent to the fibula, and that the nodular PNBF more commonly observed on the lateral tibia and medial fibula (defined as relatively fine nodules 1-2mm in diameter, and projecting a similar length from the bone surface, often on the interosseous margins) may be indicative of the early stages of ossification of the interosseous membrane, and further indicate that ossification of the interosseous membrane more often begins and progresses from the fibula side rather than the tibia.

While periosteal new bone formation may be non-specific, to discount the further study of it purely on that basis belies the morphological variation and complexity of periosteal new bone formation (Weston, 2008; 2011), and the potential uses of these varying morphologies for differential diagnosis and exploring possible progression of disease, particularly in the case of leprosy as explored above. Therefore, while this hints at the nuance and variability of these lesions in relation to leprosy, more research is required generally on the variable morphology of PNBF and whether/how it relates to specific diseases.

Fig. 7.7: Examples of new bone formation on distal tibia. Left – mix of longitudinal striations and porous and disorganised healed bone formation. Right – nodular bone formation. These morphologies can also be present on fibulae. Access to collection to take these pictures kindly granted by the BARC.

7.5.3.4 Horizontal Tibial striations

Sixteen individuals displaying periosteal new bone formation on the distal tibia also displayed some form of horizontal tibial striations, in all cases on the lateral aspect of the of the tibia (Fig. 7.8). While the lesions were morphologically variable, horizontal tibial striations showed no strong relationships to age via phi analysis, but a strong positive relationship to the *diagnostic* Lepro-C category (they were present in 2/4 (50%) of the diagnostic individuals), suggesting that there is no consistent link of these horizontal striations to leprosy. Further research is required on horizontal striations in non-leprosarium assemblages to gauge their occurrence generally, while again hinting at the nuance and variability of these lesions in relation to leprosy.

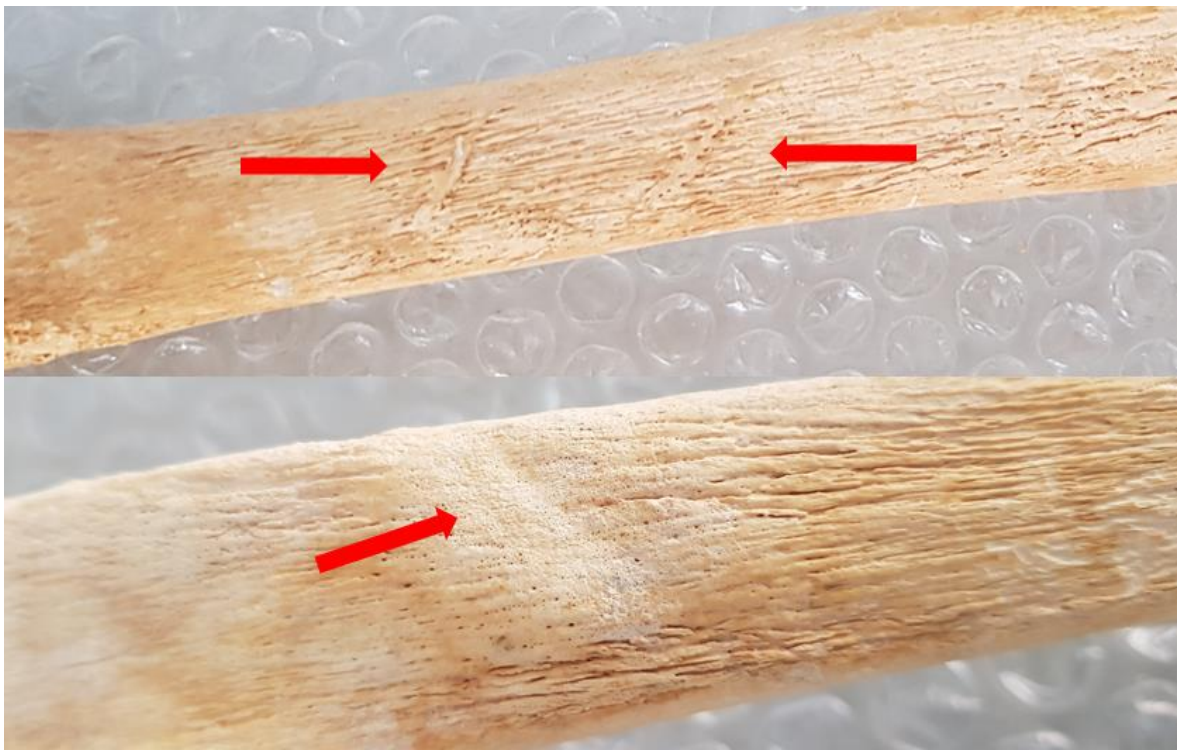


Fig. 7.8: Horizontal tibial striations. Top: horizontal PNBF on distal left medial tibia (Winchester 48, male, 26-35 years). Bottom: horizontal depression right medial midshaft of tibia (Winchester 107, male, 26-35 years).

7.5.4 Diagnostic Case Studies Demonstrating Morphological Variability

This section details the *diagnostic* case studies, to actively demonstrate how Lepro-C was implemented and used to diagnose leprosy in the study, as per the first aim of the research. They are also presented here to demonstrate the nuance and variability of leprosy lesions that can occur, as per the second aim of the research. This is because the absorptive rhinomaxillary syndrome lesions displayed by each individual showed morphological variation, and the postcranial lesions displayed also showed variability in the precise bones affected. This demonstrates the importance of the method as it shows the variability of lesions, both in morphology and distribution, that can be present in even *diagnostic* cases. It is particularly important to demonstrate the morphological variability for rhinomaxillary syndrome lesions, as they are key for diagnosing lepromatous leprosy in skeletal remains and could easy be missed if this variability is not accounted for.

Four individuals were determined to have diagnostic features of leprosy when assessed using the Lepro-C criteria: these individuals were designated Winchester 19, Winchester 111, Chichester 50 and Chichester 88. The variation in expression of the lesions and distributions of lesions are discussed below. However, despite these individuals all falling within the 'diagnostic' category, the

appearance of their lesions differed, cranially and postcranially. The following details the lesions displayed by these individuals.

7.5.4.1 Winchester 19

Winchester 19 (26-35 years old, male) presented with the most advanced RMS lesions, and is a 'classic' case of leprosy (Fig. 7.9 and 7.10). The anterior nasal spine and adjacent margins of the nasal aperture have been completely obliterated, with porous reactive bone on the remaining surfaces. The surface porosity on the remaining bone is indicative of a process that was still active at death, despite the lesions being advanced, demonstrating the ongoing nature of full lepromatous leprosy. The inferior margins of the nasal aperture were completely obliterated (with the remaining inferomedial third of the margins displaying porosity and cortical activity). Despite the porosity and cortical activity, the surviving margins remain sharp and unrounded. The margins superior to this point are unaffected by any pathology. The anterior maxillary alveolus was totally obliterated, with the lunate shape stopping abruptly at the first premolars on either side. This maxillary absorption is extensive, and exacerbated by the antemortem loss of the premolars, evidenced by the absorbed crypts. While absorption of the anterior maxillary alveolus in leprosy is most often limited to the maxillary incisors, in advanced cases of rhinomaxillary syndrome it can extend further to the alveolar bone of the adjacent teeth (Andersen and Manchester, 1992: 123). This is supported clinically also, as the maxillary branch of the trigeminal nerve is often affected in clinical leprosy (Gopinath et al, 2004; Kumar et al., 2006; Dave and Bedi, 2013; Sharma et al., 2023), a branch of which is the anterior superior alveolar nerve that innervates the alveolar bone around the canines and premolars. The oral and nasal surfaces of the palate were completely obliterated, with inflammatory pitting on the surviving margins, indicative of the chronic and ongoing nature of full lepromatous leprosy and secondary complications that follow.

For postcranial lesions, Winchester 19 displayed a combination of longitudinally striated and porous and disorganised PNBF, and affected all aspects of the tibiae and fibulae. Winchester 19 displayed the most severe tarsal disintegration (Fig. 7.10), where the right foot was extensively affected, including full ankylosis and deformation of the right navicular, cuneiforms, and proximal remnants of the second and third metatarsals. The calcaneus was missing, the talus unaffected, however there was a large dorsal exostosis on the cuboid. The remaining bones were fragmented pre-mortem due to osteoclastic changes. These changes were enough to include this individual in the diagnostic group for Lepro-C, however he also displayed concentric remodelling of the intermediate phalanges on both hands (1st and 4th on left hand, 3rd and 4th right hand), acroosteolysis on all distal hand phalanges, and interarticular lytic lesions on the left third proximal interphalangeal joint, with the respective distal and proximal thirds of each bone displaying extensive lytic lesions with cortical

deformation and reactive bone formation. Winchester 19 also had proliferative lesions including newly described lesions on the proximal ulna, and active periosteal new bone formation on all aspects of the right 5th metacarpal, and lateral/dorsal aspect of the right 4th metacarpal.

Fig. 7.9: Rhinomaxillary syndrome displayed by Winchester 19. Left: frontal view, Right: inferior view of palate perforation.

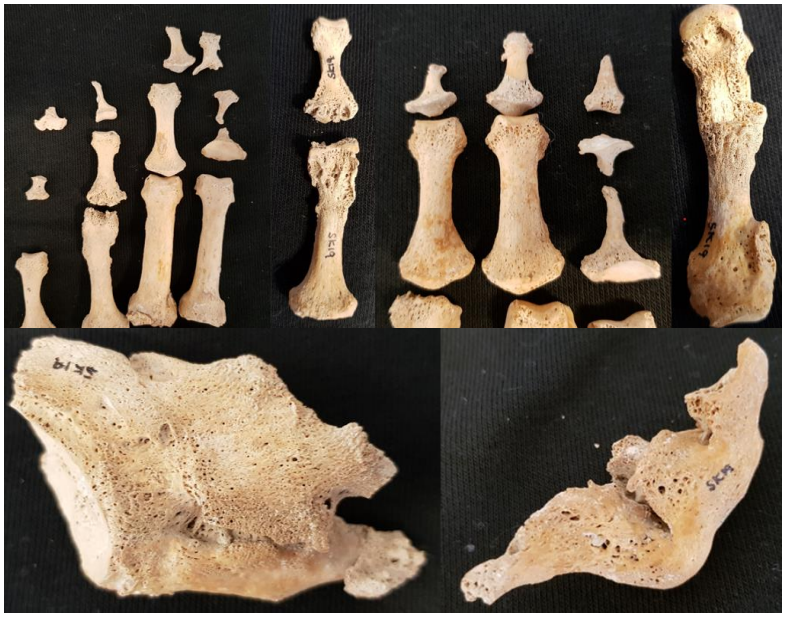


Fig. 7.10: Some postcranial lesions for Individuals Winchester SK19. Clockwise from top left: concentric remodelling and acroosteolysis of left hand phalanges; interarticular lytic lesions on the left third proximal interphalangeal joint; concentric remodelling and acroosteolysis of right hand phalanges; active periosteal new bone formation on all aspects of the MT5; fragment of ankylosed

and disintegrated foot bones; ankylosis and deformation of the right navicular, cuneiforms, and proximal remnants of the second and third metatarsals.

7.5.4.2 Winchester 111

Winchester 111 (26-35 years old, male) displayed absorption of the anterior nasal spine (Fig. 7.11), but the underlying bone remained. The remaining bone was porous, with the porosity extending laterally to the adjacent margins of the nasal aperture and inferiorly down the intermaxillary suture. This is the 'bull-shaped' remodelling introduced in 7.7.1. This is the most common morphological presentation of absorption of the anterior nasal spine and adjacent margins of the nasal aperture in individuals with leprosy from Chichester and Winchester. The margins of the nasal aperture for Winchester 111 displayed pitting along the margins of the lower nasal aperture surface, extending from the anterior nasal spine on both sides, exposing nutrient canals c. 5mm in length where the outer cortical bone has been absorbed. The absorption of the anterior maxillary alveolus displayed by Winchester 111 was lunate in shape, with the absorption is at its greatest at the intermaxillary suture and stopping abruptly at the first premolars. The margins of the alveolar bone are characterised by smooth-edged pits around 1-2mm, indicative of a chronic absorptive process. The posterior sections of the oral palate were obliterated, with the surviving margins capped by new cortical bone with inflammatory pitting of the adjacent surfaces of the palate, most severe at the midline.

Winchester 111 also had absorptive and proliferative postcranial lesions that satisfied the Lepro-C criteria with lytic lesions that obliterated the articular surface on the distal first metatarsal on both sides, acroosteolysis of four distal phalanges on the right foot, and periosteal new bone formation on the distal tibiae and fibulae (Fig. 7.12). In addition, there were dorsal tarsal exostoses on both cuboids, proximal osteophyte formation on the medial aspect inferior to the radial notch on the ulna, and plaques of new bone on the medial aspects of both distal fibulae consistent with ossification of the interosseous membrane in addition to the periosteal new bone formation on the cortical surface.

Fig. 7.11: Rhinomaxillary syndrome in Winchester SK111. Clockwise from top left, frontal view of rhinomaxillary syndrome with bull-shaped remodelling; lateral view of absorption of anterior maxillary alveolus; palate perforation and oral pitting; palate perforation and nasal pitting.

Fig. 7.12: Examples of postcranial lesions displayed by SK111, left to right: lytic destruction of articular surface of right first metatarsal; longitudinally striated periosteal new bone formation on anterior surface of distal right tibia; periosteal new bone formation on medial left fibulae, with plaques that might be ossification of interosseous membrane (red arrow); acroosteolysis on 2nd , 3rd and 5th distal phalanges of right foot.

7.5.4.3 Chichester 88

Chichester 88 (26-35 years old, male) displayed full absorption of the anterior nasal spine and diffuse surface porosity extending laterally along the adjacent margins of the nasal aperture, inferiorly down the intermaxillary suture, and posteriorly across the nasal palatine surface. Chichester 88 has been glued together along the palatine suture, obscuring the margins (Fig. 7.13), so it is difficult to assess whether there was any pathological perforation along the suture on the nasal and oral surfaces in the glued regions, however the bone surfaces and margins unaffected by glue show extensive pathology. For the margins of the nasal aperture, Chichester 88 displays morphologically similar porosity to Winchester 19, but not as advanced as the underlying cortical bone is not fully obliterated. The alveolar absorption displayed is not a lunate shape, however the margins of the incisors display porosity and there is a large lytic lesion on the right anterior surface with disorganised margins. This lesion may represent the early stages of full obliteration as seen in Winchester 19. The oral and nasal pitting was extensive, with inflammatory pits radiating out form the midline, perforation and loss of the posterior regions of the palate, and larger pits possibly indicative of primary granuloma.

Chichester 88 also had absorptive and proliferative postcranial lesions (Fig. 7.14), displaying palmar grooving on the phalanges of the left second and fourth metacarpal, ankylosis of the distal and intermediate phalanges of second left metatarsal, acroosteolysis of foot phalanges, concentric remodelling of right 5th metatarsal, porous new bone formation to the left proximal ulna, along with active new bone formation on all aspects of the midshaft, and the anterior aspect of the left radius distally from the midshaft. There was also some lamellar bone on the lateral aspect of the distal

right ulna and medial right radius. The PNBF on the distal tibiae and fibulae was characterised by large plaques of active and healed new bone formation on all aspect to the midshaft, with a mix of longitudinally striated and porous and disorganised morphology, suggesting a chronic and repeated process of bone deposition and healing. There was also a large lytic lesion that obliterated the proximal articular surface of the proximal phalanx of the right fifth metatarsal.

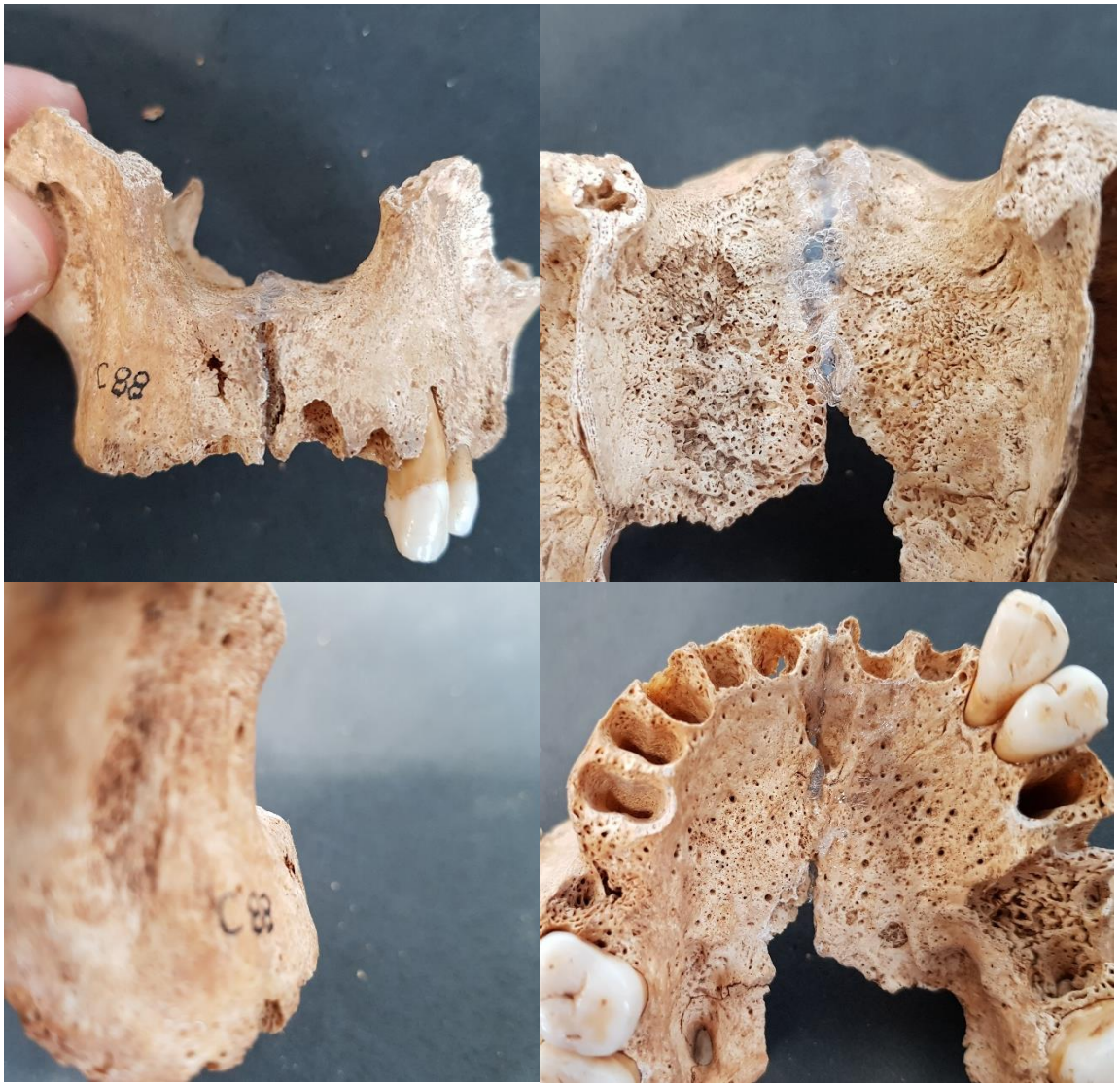


Fig. 7.13: Rhinomaxillary syndrome in Chichester 88. Clockwise from top-left; frontal view of rhinomaxillary syndrome; nasal pitting; oral pitting; lateral view of absorption of anterior nasal spine. Access to collection to take these photos kindly granted by the BARC.

Fig. 7.14: Example of postcranial lesions displayed by Chichester 88. Left to right: Large plaques of periosteal new bone formation on distal right tibia; large lytic lesion on proximal phalanx of the right fifth metatarsal; concentric remodelling of right 5 metatarsal (red arrow). Access to collection to take these photos kindly granted by the BARC.

7.5.4.4 Chichester 50

Chichester 50 (36-45 years old, male) also displayed 'bull-shaped remodelling' of the nasal spine and margins of the inferior aperture. Chichester 50 displayed pitting along the margins of the lower nasal aperture surface, extending from the anterior nasal spine on both sides, exposing nutrient canals c. 5mm in length where the outer cortical bone has been absorbed, similar to Winchester 111 (Fig. 7.15). The absorption of the maxillary alveolus for individual Chichester 50 is perhaps the least clear case of the four diagnostic individuals (Fig. 7.16), as the alveolar margins and dental crypts are affected by post-mortem damage, particularly on the right side, and the lunar shape of the lesion is not as distinct. However, there are indicators of absorption of the anterior maxillary alveolus, most notably on the alveolar margins adjacent to the intermaxillary suture, which displays pits approx. 1-2mm in diameter across the disorganised and un-smooth cortical surface, indicative of a chronic absorptive process. The surviving alveolar margins on the left side display the same porous and disorganised cortical surface as near the intermaxillary suture, whereas the right side was broken postmortem. The absorption is also at its greatest at the midline, and is least advanced by the canine, and stops abruptly at the premolars. This demonstrates the variability of lesions that should be expected in leprosy, and how subtle some of the lesions can be. Interestingly, the anterior cortical surface of the alveolar bone over the left maxillary lateral incisor was porous and thinned, while the other crypts in this region are clearly affected by post-mortem damage. Perhaps they were similarly affected by porosity and were subsequently broken post-mortem. Hence, exposed crypts for the anterior maxillary teeth post-mortem may provide further evidence for absorption of the anterior maxillary alveolus in life (where other evidence for leprosy exists). Optimising the potential

synergies between pathology and patterns of taphonomy in skeletal remains would be an interesting avenue for future research. Chichester 50 displayed extensive oral and nasal pitting approx. 1-2 mm across, most severe on at the midline, but extending across the oral and nasal surfaces, with some perforation and loss of the posterior sections of the palate. There are also some larger pits ~3mm which may be primary granulomata.

Fig. 7.15: Rhinomaxillary syndrome (RMS) in Chichester 50. Clockwise from top-left; frontal view of RMS with bull-shaped remodelling; lateral view of absorption of anterior nasal spine; oral pitting; nasal pitting. Access to collection to take these photos kindly granted by the BARC.

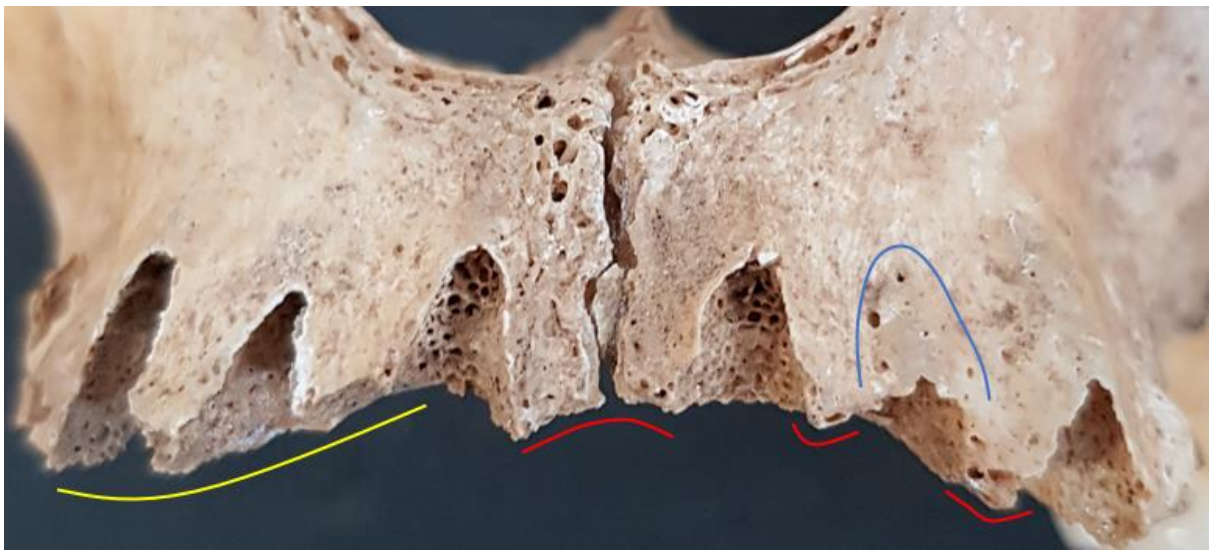


Fig. 7.16: Anterior alveolus of individuals Chichester 50, showing post-mortem damage and absorption. Yellow line denotes where alveolar margin is broken post-mortem. Red lines show where absorption has occurred, with porosity present. Blue line shows outline of porous and delicate bone overlaying left lateral incisor. Access to collection to take this photo kindly granted by the BARC.

In addition to RMS, individual Chichester 50 displayed periosteal new bone formation on the distal tibiae and fibulae, including plaques of lamellar bone that could be ossification of the interosseous membrane, active new bone on the dorsal aspects of the left second and third metacarpal, woven bone formation on the proximal left ulna, interarticular lytic arthropathy of the proximal interphalangeal joint of the left third metacarpal, absorption of the proximal and distal ends of distal phalanx of third metacarpal, and distal end of proximal phalanx of left second metatarsal. There was also a cloaca on the distal dorsal aspect of the right third metacarpal, indicative of osteomyelitis (Fig. 7.17).

Fig. 7.17: Example of postcranial lesions displayed by C50, left to right; plaques of active periosteal new bone formation on the dorsal aspects of the left second and third metacarpal; interarticular lytic arthropathy of the proximal interphalangeal joint of the left third metacarpal; absorption of distal end of proximal phalanx of left second metatarsal. Access to collection to take these photos kindly granted by the BARC.

7.5.4.5 Summary

The four *diagnostic* individuals demonstrate the variability of rhinomaxillary syndrome lesions, with the greatest variability seen in the absorptive RMS lesions. This variability could be a demonstration of the lesions at various stages of severity, although severity should not be linked with how long an individual may have been affected by leprosy (Roberts, 2020). It could perhaps also be indicative of an underlying variability in the precise patterns of neuropathy of the facial and or trigeminal nerves (and branches thereof) that then influences the variable morphology of the absorptive lesions that follow, as clinical research shows that facial and trigeminal nerve invasion by *M. leprae* varies between individuals (see Kumar, 2006). This is probably also in conjunction with localised inflammation (Andersen and Manchester, 1992). The morphological nature of oral/nasal pitting is arguably the most consistent for the 5 rhinomaxillary syndrome lesions used to assess leprosy in this research, with each of the four diagnostic individuals displaying the same morphological characteristics for this lesion, with pits radiating from the midline, just at various stages of severity (Fig. 7.18).

Fig. 7.18: Oral pitting/perforation in individuals (clockwise from top left to right); SK19; SK111, C88 and C50. The lesions are similar but at varying stages of severity. Access to collection to take these photos kindly granted by the BARC.

All four diagnostic individuals displayed periosteal new bone formation on the distal tibiae and fibulae. In all cases this was a combination of longitudinally striated and porous and disorganised, and affected all aspects of the tibiae and fibulae. The postcranial lesions for diagnostic individuals affected similar locations and shared similar morphology. Lytic lesions on the articular surfaces of the phalanges on either the hands or the feet for the diagnostic individuals tended to be extensive, and often obliterating the articular surface and extending often a third of the way up the midshaft, characterised by diffuse lytic pores with marginal reactive new bone formation. Despite this similarity, the individual hand and foot bones affected varied. The postcranial lesions for diagnostic individuals affected similar locations and shared similar morphology.

7.6 New and Underexplored Leprosy Lesions

7.6.1 Lesions to the Medial Epicondyle of Humerus

The possible appearance of skeletal lesions on the medial epicondyle as the result of ulnar nerve hypertrophy seen in leprosy was explored (Donaghy, 2003; Payne et al., 2015; Fonseca et al., 2018). The lesion was characterised by slight osteophyte formation on the medial epicondyle of humerus (Fig. 7.19). Only four individuals had lesions in the related area, two males from each site, and three were aged 46+. The lesion appeared in individuals in the *not consistent* or *consistent* categories, and in age groups where leprosy lesions were not common, meaning its association with leprosy was not strong in this study. The three relatively complete individuals (over 50% complete) where this lesion appeared all displayed degenerative joint disease in the elbows, and included one individual with diffuse idiopathic skeletal hyperostosis (DISH). So this may be an age related change in these individuals and suggests an incidental occurrence, not a direct relationship.

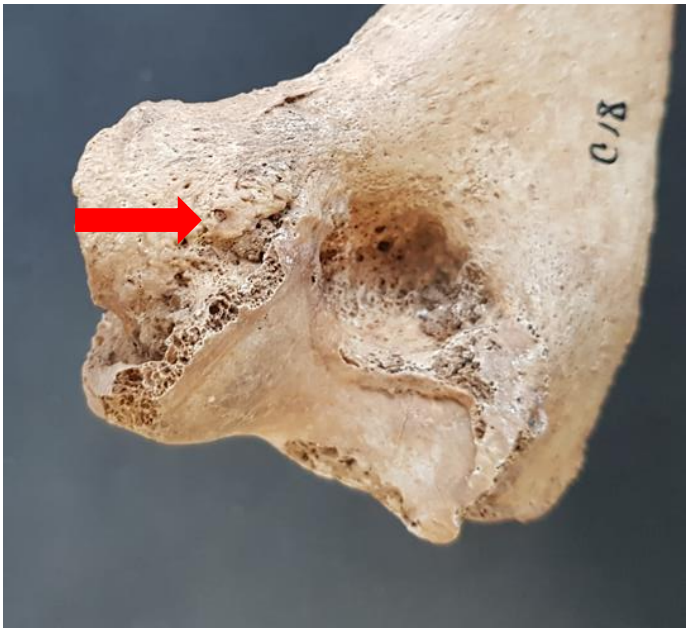


Fig. 7.19: New bone formation on medial epicondyle of right humerus (C18). Access to collection to take these photos kindly granted by the BARC.

7.6.2 Lesions to the Proximal Ulna

Lesions to the proximal ulna were characterised by porous active periosteal new bone formation, principally on the anterior and posterior surfaces (Fig. 7.20 and 7.21). They were recorded in all four individuals determined to be *diagnostic* of leprosy, as well as five *highly consistent* individuals. However, the lesion was also present in one *not consistent* individual. The lesion showed the

strongest positive association with individuals aged 26-35 years, and strongest negative association with individuals aged 46+ years, matching the pattern broadly seen with rhinomaxillary lesions. None of these associations were significant, however. The binomial logistic regression test indicated also that there was not a significant relationship between this lesion and the age of an individual. This lesion needs more research to establish it as an indicator of leprosy in the skeleton, as ulnar nerve hypertrophy is one of the most prevalent clinical presentations of leprosy at any stage of the disease, and in any form of leprosy on the spectrum that may develop (Donaghy, 2003; Vital et al., 2013). However, this lesion may also be related to trauma (Shin and Ring, 2007) or osteoarthritis, so further research on non-leprosarium cemeteries would help to clarify the links of this lesions to leprosy.

Fig. 7.20: Lesion on the left anterior proximal ulna (SK82 – positions reversed), right – close up of lesion.

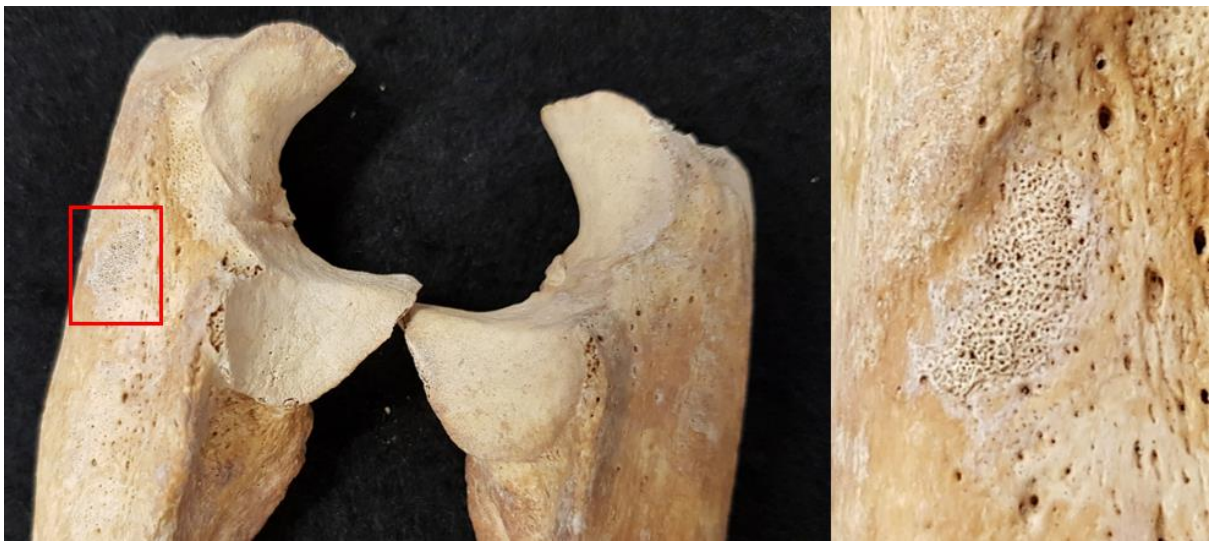


Fig. 7.21: Lesion on right posterior proximal ulna (SK49 – positions reversed). Right - close up of lesion demarcated in red square.

7.6.3 Nutrient Foramen

7.6.3.1 Enlargement

Enlargement of the nutrient foramen (Fig. 7.22) was not present in any *diagnostic* individual and appeared principally in individuals in the *consistent* category (68.8%). This suggests that enlargement of nutrient foramen is not a reliable indicator of leprosy and may represent normal variation. More research is needed in non-leprosy individuals to assess how often this lesion occurs.

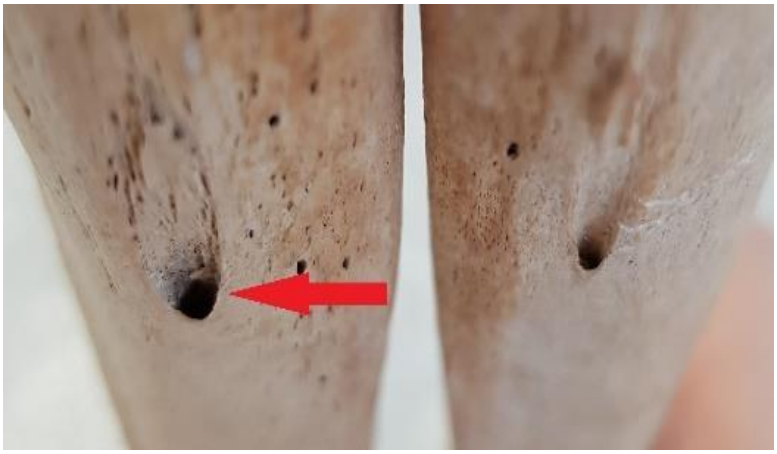


Fig. 7.22: Enlargement of nutrient foramen on left posterior proximal tibia (SK18).

7.6.3.2 Periosteal New Bone Formation

Periosteal new bone formation (PNBF) around nutrient foramen (Fig. 7.23) was present in 32 individuals (12.74%) considered to have lesions *consistent* or *highly consistent* with leprosy.

However, as with enlargement, this lesion was not present in any *diagnostic* individual, suggesting it may not be a particularly strong indicator of leprosy. This lesion was present principally on the proximal posterior nutrient foramen of the tibiae (and unilaterally), although seven individuals displayed PNBF on the posterior fibula nutrient foramen also. This lesion showed no strong phi coefficient relationship with any of the adult age groups, or any significant relationships in the binomial logistic regression, and it is not regarded as a powerful diagnostic indicator in isolation.

Fig. 7.23: Left: PNBF around nutrient foramina of left posterior proximal tibia (SK18). Right: right posterior proximal tibia (C70). Access to take photo of C70 kindly granted by BARC.

7.7 Adjusting Lepro-C for Future Research

One of the main aims of this research was to develop a new method to diagnose leprosy in skeletal remains, called Lepro-C. The following discusses the version of Lepro-C tested in this research, and how the *diagnostic* category was too stringent, and presents an updated version for use going forward. This is done in reference to *highly consistent* individuals that displayed full rhinomaxillary syndrome.

There were 6 individuals in the dataset that displayed the 5 RMS lesions specified in the leprosy criteria, however did not satisfy the postcranial lesion criteria to be considered *diagnostic* of leprosy as per Lepro-C tested in this research, so were recorded as *highly consistent* (Table 7.1). Rhinomaxillary syndrome lesions, when viewed in isolation, all have separate differential diagnoses, as detailed in Chapter 3, but there are some combinations of RMS lesions that might occur in other diseases, particularly syphilis (Cook, 2002), so the criteria were initially formulated to also include postcranial lesions in the *diagnostic* category to protect against this. It was not expected, however,

that individuals might display all 5 RMS lesions and not also display the requisite postcranial lesions, as was the case for these 6 individuals. On reflection, the concerns of Cook (2002), who questioned the specificity of the rhinomaxillary syndrome in the diagnosis of leprosy, seem to be overstated, as these 6 individuals display all 5 RMS lesions and are of the morphology of that expected for leprosy, which differs from that of other differential diagnoses, and it is unlikely that all 5 RMS lesions would appear and not be leprosy. This is particularly the case as the medieval Latin texts translated in this research show a solid grasp of the signs and symptoms of leprosy by physicians in late Medieval England, as while Cook (2002: 83) notes that 'nasal lesions of leprosy are easily mistaken for syphilis', it does not follow that the medical presentation and assessment of it in the late medieval period had a similar issue, and the skeletal and historical evidence here suggests that mistaking syphilis for leprosy was not routinely an issue in leprosaria in late Medieval England. Therefore, the Lepro-C criteria will also be revised for future research to remove the requirement for postcranial lesions to be present in addition to RMS for an individual to be considered *diagnostic* of leprosy, as this category was evidently too stringent (see Table 7.2 below for revised criteria).

7.7.1 Individuals with Full RMS but Without Postcranial Lesions, or Only Proliferative Postcranial Lesions

It is important to discuss an individual displaying full RMS but without the postcranial lesions required to diagnose leprosy as per the Lepro-C criteria tested in this research, to demonstrate why the Lepro-C diagnostic criteria will be revised for use in future research to no longer require postcranial lesions in the *diagnostic* category. Chichester 360 clearly displays the full 5 RMS lesions (Fig. 7.24). For example, the oral/nasal pitting present for C360 is a markedly destructive lytic foci centred on the midline of the palate (with full perforation), with smaller lytic foci on the left oral surface, with marked sclerosis of the remaining surfaces of the oral palate immediately adjacent to the lytic foci. This lytic destruction with surrounding sclerosis could arguably more representative of that seen in tertiary syphilis when the lesion is viewed in isolation (Ortner, 2003, Rubini and Zaio, 2009), as opposed to leprosy where the oral pitting, while potentially as destructive, often has a more delicate morphological quality to the margins of the lesions and surviving surrounding bones. This must be balanced however in the fact that all 5 RMS lesions are present. For example, with the other lesions displayed by C360, the anterior nasal spine is totally absorbed, and while this may occur in syphilis, it is unlikely (Rogers and Waldron, 1989; Waldron, 2008). The absorption observed is not smooth and rounded, as in some cases of absorption of the anterior nasal spine in leprosy, however the margins of the nasal aperture are affected symmetrically, which you would expect more in advanced lepromatous leprosy than the irregular destructive lesions characteristic of syphilis (Hackett, 1975; Ortner, 2003). The absorption of the anterior maxillary alveolar margin is

not strictly lunar shaped, however it is limited to the incisors and stops abruptly at the canines (lost post-mortem), which is more indicative of leprosy than syphilis (Andersen and Manchester, 1992). All of this is to say that the 5 rhinomaxillary lesions when viewed in isolation are potentially indicative of more than 1 disease, however when viewed together are *diagnostic* of leprosy, even in the absence of postcranial pathology.

Fig. 7.24: Rhinomaxillary syndrome in C360. Individual displays all rhinomaxillary syndrome lesions but not requisite postcranial lesions to be *diagnostic* with leprosy as per Lepro-C as initially tested. Access to collection to take these photos kindly granted by the BARC.

Table 7.1: Summary of postcranial pathology of 6 *highly consistent* individuals displaying all 5 rhinomaxillary lesions.

Individual	**Postcranial pathology**
C19 (26-35, Male)	Longitudinally striated and porous periosteal new bone formation (PNBF) on medial distal tibiae and medial aspect of left fibula. Dorsal tarsal exostosis on left lateral cuneiform
C338 (17-25, Indeterminate Sex)	No postcranial lesions related to leprosy
C345 (26-35, Female)	Longitudinally striated PNBF on lateral distal left tibia and medial distal right tibia
C350 (36-45, Male)	Longitudinally striated PNBF on all aspects of distal tibiae and fibulae
C360 (17-25, Female)	No postcranial lesions related to leprosy
SK28 (12-14, Female)	PNBF around posterior nutrient foramen on both tibiae

For all of these individuals, it is also noteworthy that where postcranial lesions are present there are no absorptive postcranial lesions present, just inflammatory/proliferative postcranial lesions, mostly on the distal tibiae and fibulae (Fig. 7.25). Perhaps from this we can infer that absorptive postcranial lesions are the last to develop in individuals where full RMS develops. This perhaps matches the progression of the disease suggested by Lewis et al. (1995), where infection progresses up the muscle planes of the lower legs, with the inflammation of the soft tissues adjacent to the tibiae and fibulae stimulating osteoblastic activity by disturbing the periosteum. However, in the observations here it is not obvious that this is due to secondary pyogenic infection as Lewis et al. (1995) suggest, as these individuals do not display extensive inflammatory lesions (or any absorptive lesions) to the feet, which might be expected where ulcerated and infected feet are the primary entry site by secondary infection. The hematogenous spread of M. Leprae bacteria (Talhari et al., 2015) can result in skip lesions along the tibial nerves (Richard et al., 2001), which may then also become enlarged (Khambati et al., 2009). The fibular nerve can be affected also (Ding and Legua, 2019). So, it is feasible that *M. leprae* infection and inflammation of the adjacent soft tissues (that may then lead to ulceration and secondary infection) could affect soft tissues adjacent to the tibia and fibula and not the plantar aspects of the feet in an infected individual, as opposed to plantar ulceration being an essential precursor to any tibiofibular lesions as suggested by Andersen et al., (1994). Indeed, the observations here suggest that proliferative/inflammatory lesions on the tibiae and fibulae preferentially develop over lesions to the feet in individuals displaying all 5 signs of rhinomaxillary syndrome. The clinical literature perhaps supports this also, in that the absorptive lesions of the hands and feet arise in leprosy from the chronic neuropathy of peripheral nerves that can lead to the defective signalling of osteoblasts and osteoclasts that drives the absorption of the metacarpals/metatarsals/phalanges (Marks, Jr., 1979; Andersen et al., 1994). In other words, the absorptive lesions are the sequelae of chronic neuropathy, as opposed to the localised and relatively acute inflammatory processes in leprosy infection (Nery et al., 2013; Kahawita and Lockwood, 2008; Walker and Lockwood, 2008; Leon et al., 2016) that can affect soft tissues adjacent to the tibiae and fibulae, which in turn can lead to periosteal new bone formation due to disturbing the periosteum (Weston, 2008). This suggests that periosteal new bone formation could develop relatively quickly and extensively before absorptive lesions appear, although leprosy reactions can also increase the speed at which neuropathy develops (Sarno and Pessolani, 2001). Indeed, the mix of porous and disorganised and longitudinally striated PNBF that was common on the tibiae and fibulae suggests that the lesions are the result of repeated and relatively acute periods of inflammation. It is possible that issues with proprioception resulting from leprous neuropathy may also predispose the tibia and fibulae to trauma, which could also lead to periosteal new bone formation in these sites (Lewis et al. 1995).

This leads us to question why the absorptive lesions of the nasal aperture, nasal spine, and anterior maxillary alveolus for RMS are present in these individuals, while postcranial absorptive lesions are not. However this is perhaps best explained in that leprosy is thought to spread primarily via droplet infection (Lastoria and Abreu, 2014), meaning that *M.leprae/lepromatosis* bacilla would be present in the nasal/oral regions from the very onset of infection, meaning that these lesions by definition have more time to develop than postcranial absorptive lesions in those with the low-immunity that predisposes them to lepromatous leprosy (the form where RMS occurs). This is particularly the case for bacteria like *M.leprae/lepromatosis* which spread and multiply slowly (Lockwood, 2004). Therefore, by the time the bacteria reach the lower legs it may have already been present in the nasal/oral regions for several years.

Again, all but 1 (83.3%) were aged 26-35 or younger, with the youngest aged 12-14. This further supports the pattern observed that those displaying the most extensive leprosy lesions were more likely to die relatively young. This revision to Lepro-C below, and discussion of the patterns of lesions in these *highly consistent* individuals, directly demonstrates the importance of this work, as further improvements have been made to Lepro-C going forward, and the nuance and variability of leprosy lesions has been shown, as per aims 1 and 2 of this research respectively.

Fig. 7.25: Examples of postcranial lesion for individuals with full RMS displaying just proliferative postcranial lesions - lamellar bone on distal medial left tibia of Chichester 19. This was the typical lesion present for these individuals. Access to collection to take this photo kindly granted by the BARC.

Table 7.2: Revised Lepro-C Criteria.

Diagnostic	Full RMS (all 5 aspects affected).
Highly consistent	Presence of at least one absorptive *and* two inflammatory RMS lesions, or *vice versa*, up to four RMS lesions OR At least one absorptive *and* at least one inflammatory RMS lesion (e.g. absorption of anterior nasal spine and inflammatory pitting of oral surface of palatine process) *in addition* to the presence of at least one bilateral absorptive *and* at least one bilateral proliferative/inflammatory postcranial lesion associated with leprosy. OR **If at least 2 RMS lesions present, but RMS prerequisites above not met,** presence of at least two bilateral absorptive postcranial lesions *and* at least one bilateral proliferative/inflammatory postcranial lesion associated with leprosy, or *vice versa* (e.g. evidence of absorption of hand *and* foot phalanges in conjunction with bilateral tibial PNBF) **A combination of unilateral and bilateral lesions (where applicable) in these combinations is highly consistent with a borderline form of lepromatous leprosy**. **Unilateral lesions only may indicate tuberculoid leprosy.**
Consistent	One absorptive *and* one inflammatory RMS lesion, with one bilateral absorptive or one bilateral proliferative/inflammatory postcranial lesion associated with leprosy, or two or more postcranial lesion indicative of the same underlying process (e.g two absorptive lesions) OR At least two RMS lesions indicative of same underlying process (e.g. two absorptive lesions and no inflammatory lesions, and *vice versa*). May be present with up to one inflammatory and/or one absorptive postcranial leprosy lesion, or two or more postcranial lesions indicative of the same process. OR **If RMS prerequisites above not met, or no RMS lesions at all**, presence of at least one postcranial bilateral absorptive lesion associated with leprosy (e.g. concentric remodelling) *and* at least one bilateral postcranial proliferative/inflammatory lesion associated with leprosy, (e.g. bilateral new bone formation on the tibia and fibula) or *vice versa* OR presence of at least two postcranial lesions indicative of the same underlying process (e.g. two absorptive lesions and no inflammatory lesions, and *vice versa)*. **A combination of unilateral and bilateral lesions (where applicable) in these combinations is consistent with a borderline form of lepromatous leprosy, unilateral lesions only (where applicable) is consistent with tuberculoid leprosy**.
Not consistent	A single lesion proliferative or erosive lesion in the maxilla, or single lesion in postcranial area (i.e. foot/hand) often linked to leprosy

7.8 Non-adult Individuals, Leprosy and Lepro-C

Most of the non-adult individuals under 10 years of age in the dataset did not display any macroscopic leprosy lesions (90.5%). The macroscopic evidence of leprosy in non-adults aged 12-16 years was stronger, however, as there were 6 individuals at Winchester aged 12-16 years displaying a *highly consistent* combination of lesions with leprosy. This suggests that the current Lepro-C criteria are suitable for individuals of aged 12-16, but not younger than 10 years old. A version of Lepro-C for use in individuals <10 years old should be developed in future research, perhaps with an emphasis on radiographic indicators of leprosy, which may be more visible in young non-adults, particularly carpals and metacarpals (Lewis, 2017).

It is important to briefly discuss a *highly consistent* individual of this age to demonstrate the morphology of leprosy lesions in this age group. Skeleton 56 at Winchester (14-16 years of age, female) displayed oral and nasal pitting, as well as absorption of the anterior maxillary alveolus. (Fig. 7.26). Postcranially she displayed acroosteolysis of the distal foot phalanges, ankylosis of the distal and intermediate phalanges of the left fifth metatarsal, and active periosteal new bone formation on the right tibiae and fibulae. These lesions are morphologically similar to the lesions we see in adults, both the rhinomaxillary syndrome lesions and postcranial lesions. The extent of lesions suggests that leprosy lesions may develop relatively quickly in those that catch the disease very young. This is supported in modern day clinical literature – Viera et al. (2018) demonstrate that incidence of WHO grade 2 deformity in Brazil, that is; severe visual impairment of the eyes and visible deformities to the hands and feet (Brandsma and Brakel, 2003), was high in non-adults aged 10-14 displaying leprosy, particularly boys. Winchester 28 (12-14, female) would also be *diagnostic* of leprosy as per the revised Lepro-C criteria (Fig. 7.27). Therefore, specific Lepro-C criteria should be developed and tested in future research for individuals younger than 10 years old. It is not enough to simply delineate criteria between adults and non-adults, as the strong macroscopic evidence for leprosy in individuals aged 12-16 in this research shows the picture is more nuanced than that. This further demonstrates the nuance and variability of leprosy in skeletal remains, and highlights the importance of this research.

The suitability of using the macroscopic lesions that form Lepro-C for assessing leprosy in individuals aged 12 and older is supported by recent literature. Filipek et al. (2022) conducted an isotope study on 19 'adolescent' individuals aged 8.5 to 25 years old from St Mary Magdalen, Winchester, with these individuals chosen due to displaying 'previously recorded evidence of leprosy' (Filipek et al., 2022: 144). The 18 individuals older than 12 years old in that study are *consistent* or *highly consistent* with leprosy, as assessed in this present thesis. This displays the use of Lepro-C for individuals of this age and how it can be applied to assess the likelihood of leprosy consistently in

skeletal remains generally, as without the application of Lepro-C it is unclear how much evidence of leprosy each individual displayed when reading Filipek (2022), to the detriment of the discussion that follows. The additional level of detail that Lepro-C provides gives the appropriate macroscopic context to the isotopes/aDNA values. Filipek et al. (2022) neatly encapsulate this issue as the paper does not disclose the precise macroscopic evidence for each individual, which detracts from the isotope evidence presented later as any patterns between the Lepro-C categories of an individual (i.e. how much macroscopic evidence of leprosy they displayed), and the isotope levels they display, could be significant. This level of resolution and due attention to the macroscopic evidence is exactly what Lepro-C aims to address, as macroscopic assessment is on the frontline of bioarchaeological investigation so needs to be treated with due rigour and attention at all stages of the investigation. Not only does Lepro-C clearly convey the extent of leprosy lesions displayed by an individual, it also then becomes a useful shorthand when reporting the extent of leprosy lesions expressed by an individual in a research paper to appropriately inform discussions. This demonstrates the importance of this research, and directly relates to aims 1 and 2.

Fig. 7.26: Oral pitting in Winchester 56 (14-16; female).

Fig. 7.27: Rhinomaxillary syndrome lesions in Winchester 28 (12-14 years; female).

Chapter 8: Conclusions, Limitations and Recommendations for Future Research

8.1 Conclusions

The aims of the research were:

1. Develop a new method to diagnose leprosy in skeletal remains, called Lepro-C, to increase diagnostic rigour in palaeopathology, based on the Modified Istanbul Protocol.

2. Assess the nuance and variability in the expression of leprosy in skeletal remains with reference to recent clinical research, including identifying previously unexplored lesions in archaeological assemblages.

3. Reassess diagnostic capabilities of medieval physicians by engaging with medieval medical texts.

So, the main conclusions from this research based on these aims were:

- Lepro-C shows promise as a rigorous and replicable approach to assessing leprosy in skeletal remains.
- Rhinomaxillary syndrome lesions are morphologically variable. New descriptions and terminology have been highlighted for lesions to the anterior nasal spine and margins of the nasal aperture, highlighting how to identify the former and account for the variability of the latter. A collective description for these two lesions appearing with a specific morphological pattern of inflammatory pitting has been defined as 'bull-shaped remodelling'.
- Adults aged 26-35 were most likely to die displaying the most serious evidence of leprosy, demonstrating that there was selective mortality for those with rhinomaxillary syndrome.
- Females tended to display evidence of rhinomaxillary syndrome younger than males.
- Previously unexplored lesions such as lesions to the proximal ulna show encouraging links to *diagnostic* individuals, so may be useful indicators of leprosy in skeletal remains. They need to be tested on non-leprosarium assemblages but have exciting potential.
- Medieval physicians had a solid grasp on the variable manifestation of leprosy in affected individuals, demonstrating that 'medieval' and 'modern' leprosy are directly comparable.
- There needs to be a minimum standard for the description and illustration of leprosy in publications.

This study has demonstrated that a rigorous and replicable framework for assessing leprosy can be adopted, despite the inherent morphological variability of leprosy as a disease. By using the aetiology of the lesions as a base for building the criteria it has been proved possible to accommodate the range of lesions that may occur in leprosy, while also keeping the criteria simple and replicable. This can address the lack of consistency of the lesions (and combinations thereof) adopted previously to assess leprosy in skeletal remains and can lead to a body of directly comparable research data going forward.

This research has also established an updated morphological description for absorption of the anterior nasal spine. To be considered pathological the lesion must be a broad and continuous curve when viewed laterally. This research also establishes that 'rounding' of the margins of the nasal aperture should be re-termed 'remodelling of the margins of the nasal aperture', as this more appropriately captures the morphological variability of this lesion. A new collective description for absorption of the anterior nasal spine and remodelling of the nasal aperture when both are present in a specific morphological combination characterised by inflammatory pitting has been termed 'bull-shaped remodelling', as the shape of the affected areas resemble a bull with horns. These criteria and the descriptions should be the base starting point going forward when assessing lesions to the anterior nasal spine and inferior margins of the nasal aperture and their variability. These two lesions also showed strong statistical links to each other, so may be highly indicative of leprosy when found in combination, even in non-diagnostic cases, so this should be accounted for during differential diagnosis.

This study indicates that the most distinctive evidence of leprosy systematically occurs in individuals aged 26-35 years at Chichester and Winchester. Previous studies have noted this broad pattern of young/middle adults being affected by leprosy more often than other age groups, but this study has revealed the patterns for specific lesions and age groups. Rhinomaxillary syndrome lesions showed a strong positive association with the 26–35-year age group, and strong negative associations with the 46+ age groups, indicating that those suffering from leprosy that affected the rhinomaxillary region from an earlier age are more frail and were likely to die before 35 years, so there was selective mortality in those displaying rhinomaxillary syndrome. This is supported further in that the only significant relationships between RMS lesions and age in the binomial logistic regression models occurred in individuals aged 26-35. Females also demonstrated a tendency to display RMS younger than males, perhaps suggesting that menarche and/or pregnancy in these individuals may have predisposed them to lepromatous leprosy due to the ensuing immunological changes (Lewis, 2022).

This study has also shown that lesions that were previously not considered in the assessment of leprosy in skeletal remains may be of use going forward. This is particularly the case for lesions to

the proximal ulna. The ulnar nerve where it passes the elbow is the region most often affected by nerve hypertrophy in clinical cases of leprosy (Donaghy, 2003), so it is encouraging that lesions have been found on the proximal ulna indicating an inflammatory response in response to the disturbance of the periosteum. The possible link of this lesion to leprosy in skeletal remains is supported by the statistical patterns reflecting those seen for the rhinomaxillary syndrome lesions (tending to occur in individuals aged 26-25 years, and not in individuals aged 46+ years), and the lesion was also present in *diagnostic* individuals. Lesions to the proximal ulna also showed a strong positive association with the *diagnostic* category, and the five rhinomaxillary syndrome lesions, although it did not show a significant relationship to age sex and site in binomial logistic regression models. So, while it shows promise as useful indicator of leprosy in skeletal remains, more research is required.

This study has also demonstrated that medieval physicians had a solid grasp on the manifestations of leprosy. They described symptoms comparable to those seen in modern clinical tuberculoid and lepromatous leprosy, despite the incongruent galenic medical framework subsequently used to treat the disease. This is significant as it has previously been suggested that medieval physicians were unable to diagnose leprosy properly (Brody, 1976; Covey, 2001). This new evidence suggests that individuals displaying no skeletal lesions may have been suffering from a form of leprosy that did not manifest skeletally, rather than them having another disease. This is not to say that individuals not suffering from leprosy, but from another condition presenting similarly to leprosy, were never admitted to leprosaria, or that individuals suffered solely from leprosy, but the evidence suggests leprosy would have been successfully diagnosed often, and that 'medieval' and 'modern' leprosy are directly comparable. This shows the value of actively implementing a multidisciplinary approach in research design, and how directly engaging with historical documentary evidence can be beneficial for bioarchaeological studies as it forces us to reframe discussions about lesion patterns observed.

Finally, as highlighted in Chapter 6, there needs to be a minimum standard for describing and illustrating leprosy in publications. This research has shown that vague descriptions and inappropriate photograph angles can be unhelpful and misleading, particularly given the variability of lesions demonstrated in this research. Therefore, where possible, images of lesions, especially the rhinomaxillary syndrome, should be provided from several angles, as single images can be misleading, and generic descriptors of lesions should be avoided when initially describing the lesions displayed by an individual. Descriptions must be appropriately detailed so the full morphological variability of lesions can be accounted for, and so it is firmly established what the precise morphology of the lesions were.

8.2 Limitations and Recommendations for Future Research

8.2.1 Limitations of this Research

While Lepro-C proposes a way forward and is a foundation to build upon, there are revisions to be made for future research.

The *diagnostic* category of Lepro-C was too stringent in the iteration tested on the assemblages. It required absorptive and inflammatory/proliferative postcranial lesions to be present also, to address concerns that RMS lesions may have differential diagnoses (Cook, 2002). It was not expected however that individuals could have extensive RMS and not have postcranial lesions, as proved to the be case in six individuals. The initial concerns of differential diagnoses for individual RMS lesions were overstated, as it is highly unlikely that all five will occur and not be leprosy. Therefore, the future use of the criteria should use the revised version proposed in Chapter 7 where the diagnostic category does not ask for postcranial lesions to be present. It is important to note that even with these changes there still would have been only 10 *diagnostic* cases of leprosy across the dataset. This shows that certain diagnosis of leprosy based on macroscopic lesions in skeletal remains is rare, even in a population where evidence of leprosy overall is high. This highlights the limitations of diagnostic macroscopic leprosy lesion expression in skeletal remains, as *diagnostic* combinations are not frequent, and means that less advanced cases of leprosy cannot be diagnosed with certainty if full rhinomaxillary syndrome is absent. However, this also shows the importance of Lepro-C as a method as it allows the certainty of leprosy in skeletal remains to be consistently gauged and for further investigation and discussion to be framed accordingly. As while a *diagnostic* combination of RMS might not be present, the combination of lesions that are present, along with the context of the individual, can still lead to leprosy being the most reasonable differential diagnosis for individuals displaying lesions *consistent* and *highly consistent* with leprosy. The statistical relationships shown between leprosy lesions, particularly RMS, in this research can also be used to guide discussion and differential diagnosis for individuals displaying lesions *consistent* and *highly consistent* with leprosy. The overall combination of lesions displayed by an individual remains of paramount importance, however, and must be assessed case-by-case.

This research suggests that Lepro-C in its current form is not suitable for assessing leprosy in non-adult individuals <10 years old, as the macroscopic lesions that the method currently depends upon are not present in these individuals. This is perhaps not surprising, as radiological indicators of leprosy should be more apparent in non-adult individuals <10 years old than morphological signs (Lewis, 2017), however it is good to have some firm evidence of this.

8.2.2 Recommendations for Future Research

Future research should apply the Lepro-C criteria to individuals from lay cemeteries. The benefits of this will be two-fold, as it will allow rigorous and replicable insight into the prevalence of leprosy outside the leprosarium context. This will be particularly interesting if lesions are found in the appropriate combinations to be categorised *highly consistent* or *diagnostic*. It will also allow further investigation into the specificity of leprosy lesions and whether any lesions tend to occur in isolation outside a leprosarium context. These data can then be compared to the data from leprosarium cemeteries, to inform discussion about the wider prevalence of leprosy in late-medieval England.

The Lepro-C method devised in this research is also important as it will allow future studies to provide the appropriate macroscopic context (and of the appropriate resolution) on a consistent basis to further inform discussions into aDNA and biochemical markers and how they relate to individuals displaying variable evidence of leprosy. Furthering our understanding of how leprosy affects the skeleton, and consistently categorising it accordingly, will allow us to shed light on the lived experience of individuals, and the interplay between aDNA and skeletal pathology. As it stands, aDNA is principally useful in gauging the historical epidemiological distribution of the *M. leprae* pathogen, and by inference the geographical movement of individuals due to strain variation and origins thereof (Britton an Lockwood, 2004), whereas macroscopic skeletal pathology is principally useful in assessing leprosy, the disease that can develop from *M. leprae* infection, and how that may have affected individuals, particularly in reference to their social context. Future research may be able to optimise the potential synergies of skeletal pathology and aDNA. This emphasises the use of Lepro-C as part of the toolkit to assess leprosy in skeletal remains in conjunction with other methods, such as aDNA, for palaeopathology to create well-rounded contributions as a field.

Lepro-C may also be expanded in future to include an option whereby an individual can be *highly consistent* with leprosy if the rhinomaxillary region is missing but there is extensive postcranial evidence, for example if two absorptive and two inflammatory/proliferative postcranial lesions are present. This is because the method is currently highly dependent on the preservation of the maxilla and nasal regions, but certain postcranial lesions are characteristic of leprosy, albeit not diagnostic. Absorption of the alveolar margin at the third molar, which can occur in advanced cases of RMS (Deps et al., 2020), should also be explored in future research. The method is also dependent on individuals being relatively complete to reach the higher categories, and with a full preserved maxilla and nasal region to be *diagnostic*. Therefore, it might be valuable for future versions of Lepro-C to exclude individuals of limited completeness, however individuals of limited completeness may still display some informative pathology, so this would have to be implemented carefully and not be at the expense of useful data.

Future research should also adapt the Lepro-C method into a criteria for individuals aged < 10 years, based primarily on radiographic indicators of disease. This will be important as it will allow us to consistently assess the nature of leprosy in these very young individuals, as while it could be the case that leprosy is very uncommon in these individuals, as hinted by the lack of macroscopic lesions, this may be an illusion that could be negated by incorporating radiological signs of leprosy into Lepro-C for use in individuals aged 10 years or younger. Fully diagnosing leprosy in these individuals would remain difficult, as the full signs of rhinomaxillary syndrome remain essential, and have not occurred in the macroscopic assessment of these individuals here (it also takes time to get these lesions), but nonetheless there is more work to be done on the nature of leprosy lesions in individuals this age to build upon this research.

On the History side, future research should also expand the translation of medieval Latin texts to gain further insight into how leprosy was treated and managed in the medieval period. This is because these are neglected resources in historical research but are key sources of information for how disease was assessed in the past and can feed into bioarchaeological discussions of disease in the past.

Finally, the methodological issues tackled here for leprosy are indicative of a wider issue of rigour in the assessment of disease in palaeopathology, so future research should also consider developing equivalents of Lepro-C for other diseases so that the macroscopic assessment of skeletal remains can provide a firm and replicable foundation for bioarchaeological investigations in the future.

References

Agrawal, R., Singh, V., Sharma, A. and Mangale, N. (2020) 'Leprosy-Induced Hip Arthritis: A Rare Case Report', *Journal of Orthopaedic Case Reports,* 10(3), pp. 71.

Ahn, C. S. and Maitz, P. K. (2010) 'Volkmann's contracture in high-voltage electrical injury', *European Journal of Plastic Surgery,* 33, pp. 323-329.

Ahn, S., Park, H. J., Kim, J. P. and Park, T. H. (2016) 'Temporalis muscle transfer for the treatment of lagophthalmos in patients with leprosy: refinement in surgical techniques to prevent postoperative ptosis', *Journal of Craniofacial Surgery,* 27(1), pp. 94-96.

Alam, F. and Emadi, S. A. (2014) 'Case of arthritis secondary to leprosy', *Springerplus,* 3(1), pp. 1-5.

AlQahtani, S. J., Hector, M. P. and Liversidge, H. M. (2010) 'Brief communication: The London atlas of human tooth development and eruption', *American Journal of Physical Anthropology,* 142(3), pp. 481-490.

Aldama Olmedo, O. M., Escobar, M., Martínez, M. J., Aldama, M., Montoya Bueno, C., Celias, L. F., Hernandez-Castro, R., Arenas-Guzmán, R. and Pereira Brunelli, J. (2020) 'Necrotizing erythema nodosumin lepromatous leprosy associated with mixed infection by Mycobacterium lepromatosis and Mycobacterium leprae', *Revista del Nacional (Itauguá),* 12(2), pp. 107-115.

Andersen, J. (1969) *Studies in the Mediaeval Diagnosis of Leprosy in Denmark.* Bogtrykkeri, Norway: Costers.

Andersen, J. G. and Manchester, K. (1987) 'Grooving of the proximal phalanx in leprosy: a palaeopathological and radiological study', *Journal of Archaeological Science,* 14(1), pp. 77-82.

Andersen, J. G. and Manchester, K. (1988) 'Dorsal tarsal exostoses in leprosy: a palaeopathological and radiological study', *Journal of Archaeological Science,* 15(1), pp. 51-56.

Andersen, J. G. and Manchester, K. (1992) 'The rhinomaxillary syndrome in leprosy: a clinical, radiological and palaeopathological study', *International Journal of Osteoarchaeology,* 2(2), pp. 121-129.

Andersen, J. G., Manchester, K. and Ali, R. S. (1992) 'Diaphyseal remodelling in leprosy: a radiological and palaeopathological study', *International Journal of Osteoarchaeology,* 2(3), pp. 211-219.

Andersen, J. G., Manchester, K. and Roberts, C. (1994) 'Septic bone changes in leprosy: a clinical, radiological and palaeopathological review', *International Journal of Osteoarchaeology,* 4(1), pp. 21-30.

Andres, M., Agullo, A., Negrete, R., Batlle, E. and Martinez, A. (2011) 'Lepromatous leprosy presenting as an acute polyarthritis in a Colombian immigrant in Spain', *Joint Bone Spine,* 79(2), pp. 203-204.

Ankad, B. S. and Halawar, R. S. (2015) 'Bone involvement in leprosy: early changes', *Radiology of Infectious Diseases,* 1(2), pp. 88-89.

Antunes-Ferreira, N., Matos, V. and Santos, A. (2013) 'Leprosy in individuals unearthed near the Ermida de Santo Andre and Leprosarium of Beja, Portugal', *Anthropological Science,* 121(3), pp. 149-159.

Apajalahti, S., Arte, S. and Pirinen, S. (1999) 'Short root anomaly in families and its association with other dental anomalies', *European Journal of Oral Sciences,* 107(2), pp. 97-101.

Appleby, J., Thomas, R. and Buikstra, J. (2015) 'Increasing confidence in paleopathological diagnosis–Application of the Istanbul terminological framework', *International Journal of Paleopathology,* 8, pp. 19-21.

Araujo, S., Freitas, L. O., Goulart, L. R. and Goulart, I. M. B. (2016) 'Molecular evidence for the aerial route of infection of Mycobacterium leprae and the role of asymptomatic carriers in the persistence of leprosy', *Clinical Infectious Diseases,* 63(11), pp. 1412-1420.

Arkkila, P. E. and Gautier, J.-F. (2003) 'Musculoskeletal disorders in diabetes mellitus: an update', *Best Practice & Research in Clinical Rheumatology,* 17(6), pp. 945-970.

Arunraghav, P. and Herakal, K. (2021) 'Leprosy in elderly and children among new cases–A 3-year retrospective study', *Indian Dermatology Online Journal,* 12(2), pp. 294.

Atkin, S., Welbury, R., Stanfield, E., Beavis, D., Iwais, B. and Dick, W. (1987) 'Clinical and laboratory studies of inflammatory polyarthritis in patients with leprosy in Papua New Guinea', *Annals of the Rheumatic Diseases,* 46(9), pp. 688-690.

Aufderheide, A. and Rodriguez Martin (1998) *The Cambridge Encyclopedia of Human Paleopathology*. Cambridge: Cambridge University Press.

Babu, A., Bhat, M. R. and Jayaraman, J. (2018) 'Childhood leprosy in the postelimination era: A vision achieved or a concern growing at large', *Indian Journal of Paediatric Dermatology,* 19(1), pp. 26-30.

Bairappagari, M. E. J., Thompson, K. J. and Daniel, E. (2017) 'Chapter 3.1: The eye in leprosy', in Scollard, D.M. and Gillis, T.P. (eds.) *International Textbook of Leprosy*. Published Online. www.internationaltextbookofleprosy.org

Balint, Z., Farkas, H., Farkas, N., Minier, T., Kumanovics, G., Horvath, K., Solyom, A., Czirják, L. and Varjú, C. (2014) 'A three-year follow-up study of the development of joint contractures in 131 patients with systemic sclerosis', *Clinical and Experimental Rheumatology,* 32(6 Suppl 86), pp. S68-74.

Barnes, P. F. and Wizel, B. (2000) 'Type 1 cytokines and the pathogenesis of tuberculosis', *American Journal of Respiratory and Critical Care Medicine*, 161(6), pp. 1773-1774.

Bataille, C., Mauprivez, C., Haÿ, E., Baroukh, B., Brun, A., Chaussain, C., Marie, P. J., Saffar, J.-L. and Cherruau, M. (2012) 'Different sympathetic pathways control the metabolism of distinct bone envelopes', *Bone,* 50(5), pp. 1162-1172.

Bathala, L., N. Krishnam, V., Kumar, H. K., Neladimmanahally, V., Nagaraju, U., Kumar, H. M., Telleman, J. A. and Visser, L. H. (2017) 'Extensive sonographic ulnar nerve enlargement above the medial epicondyle is a characteristic sign in Hansen's neuropathy', *PLoS Neglected Tropical Diseases,* 11(7), pp. e0005766.

Batt, M., Kemp, S. and Kerslake, R. (2001) 'Delayed union stress fractures of the anterior tibia: conservative management', *British Journal of Sports Medicine,* 35(1), pp. 74-77.

Bechet, P. E. (1936) 'Psoriasis: A Brief Historical Review', *Archives of Dermatology and Syphilology,* 33(2), pp. 327-334.

Bedić, Ž., Šlaus, M. and Donoghue, H. D. (2019) 'The earliest recorded case of lepromatous leprosy in continental Croatia', *Journal of Archaeological Science: Reports,* 25, pp. 47-55.

Behr, M. A., Edelstein, P. H. and Ramakrishnan, L. (2018) 'Revisiting the timetable of tuberculosis', *British Medical Journal,* 362, pp. 362.

Belcastro, M., Mariotti, V., Facchini, F. and Dutour, O. (2005) 'Leprosy in a skeleton from the 7th century necropolis of Vicenne-Campochiaro (Molise, Italy)', *International Journal of Osteoarchaeology,* 15(6), pp. 431-448.

Bennike, P. (2012) Paleopathology in Denmark: The Pioneers Vilhelm Møller-Christensen and Johannes G. Andersen. In: Buikstra, J. and Roberts, C. (eds.) *The Global History of Paleopathology: Pioneers and Prospects*. Oxford: Oxford University Press, pp. 361-374.

Bergovec, M., Jelicic, J., Oljaca, A. and Bilic, R. (2018) 'Hand function and recurrence after limited fasciectomy for Dupuytren's contracture: Long-term follow-up', *Journal of Orthopaedic Surgery,* 26(1), pp. 2309499018762195.

Beswick, T. (1962) 'The origin and the use of the word 'herpes'', *Medical history,* 6(3), pp. 214-232.

Betsinger, T. K. and Smith, M. O. (2019) 'A singular case of advanced caries sicca in a pre-Columbian skull from East Tennessee', *International Journal of Paleopathology,* 24, pp. 245-251.

Bhat, R. M. and Prakash, C. (2012) 'Leprosy: an overview of pathophysiology', *Interdisciplinary Perspectives on Infectious Diseases*, 2012: 181089.

Biehler-Gomez, L., Castoldi, E., Baldini, E., Cappella, A. and Cattaneo, C. (2019) 'Diabetic bone lesions: a study on 38 known modern skeletons and the implications for forensic scenarios', *International Journal of Legal Medicine,* 133, pp. 1225-1239.

Blau, S. and Yagodin, V. (2005) 'Osteoarchaeological evidence for leprosy from western Central Asia', *American Journal of Physical Anthropology,* 126(2), pp. 150-158.

Bleharski, J. R., Li, H., Meinken, C., Graeber, T. G., Ochoa, M.-T., Yamamura, M., Burdick, A., Sarno, E. N., Wagner, M. and Rollinghoff, M. (2003) 'Use of genetic profiling in leprosy to discriminate clinical forms of the disease', *Science,* 301(5639), pp. 1527-1530.

Blondiaux, J., Naji, S., Bocquet-Appel, J.-P., Colard, T., de Broucker, A. and de Seréville-Niel, C. (2016) 'The Leprosarium of Saint-Thomas d'Aizier: the cementochronological proof of the medieval decline of Hansen disease in Europe?', *International Journal of Paleopathology,* 15, pp. 140-151.

Boel, L. and Ortner, D. J. (2013) 'Skeletal manifestations of skin ulcer in the lower leg', *International Journal of Osteoarchaeology,* 23(3), pp. 303-309.

Bogoch, E. R. and Gross, D. K. (2005) 'Surgery of the hand in patients with systemic sclerosis: outcomes and considerations', *The Journal of Rheumatology,* 32(4), pp. 642-648.

Boldsen, J. L. (2001) 'Epidemiological approach to the paleopathological diagnosis of leprosy', *American Journal of Physical Anthropology,* 115(4), pp. 380-387.

Boldsen, J. L. (2005) 'Leprosy and mortality in the Medieval Danish village of Tirup', *American Journal of Physical Anthropology,* 126(2), pp. 159-168.

Boldsen, J. L. (2009) 'Leprosy in Medieval Denmark—Osteological and epidemiological analyses', *Anthropologischer Anzeiger*, 67(4), pp. 407-425.

Boocock, P., Roberts, C. and Manchester, K. (1995) 'Maxillary sinusitis in medieval Chichester, England', *American Journal of Physical Anthropology,* 98(4), pp. 483-495.

Botou, A., Bangeas, A., Alexiou, I. and Sakkas, L. I. (2017) 'Acro-osteolysis', *Clinical rheumatology,* 36, pp. 9-14.

Brandão, L. S. G., Marques, G. F., Barreto, J. A., Coelho, A. P. C. P. and Serrano, A. P. d. P. (2015) 'Tuberculoid leprosy presenting as a "racket" lesion', *Anais Brasileiros de Dermatologia,* 90, pp. 420-422.

Brandsma, J. W. and Van Brakel, W. H. (2003) 'WHO disability grading: operational definitions', *Leprosy Review,* 74(4), pp. 366-373.

Brass, T. (2004) ''Medieval working practices'? British agriculture and the return of the gangmaster', *Journal of Peasant Studies,* 31(2), pp. 313-340.

Brenner, E. (2015) "Rouen's Other Leper Houses: Institutions, Gender and Status," in *Leprosy and Charity in Medieval Rouen*. NED-New edition [Online]. United Kingdom: Boydell & Brewer. pp. 58-82.

Britton, W. J. and Lockwood, D. N. (2004) 'Leprosy', *Lancet,* 363(9416), pp. 1209-19.

Brody, S. N. (1974) *The Disease of the Soul: Leprosy in Medieval Literature.* New York: Cornell University Press.

Brooks, S. and Suchey, J. M. (1990) 'Skeletal age determination based on the os pubis: a comparison of the Acsádi-Nemeskéri and Suchey-Brooks methods', *Human evolution,* 5, pp. 227-238.

Brostoff, J., Keen, H. and Brostoff, J. (2007) 'A diabetic life before and after the insulin era', *Diabetologia,* 50, pp. 1351-1353.

Brothwell, D. R. (1981) *Digging up bones: the excavation, treatment, and study of human skeletal remains.* New York: Cornell University Press.

Brubaker, M., Meyers, W. and Bourland, J. (1985) 'Leprosy in children one year of age and under', *International Journal of Leprosy and Other Mycobacterial Diseases,* 53(4), pp. 517-523.

Buckley, L. (2008) 'Outcasts, or care in the community?', *Archaeology Ireland,* 22(1), pp. 26-31.

Buikstra, J. E. (1994) 'Standards for data collection from human skeletal remains', *Arkansas Archaeological Survey Research Series,* 44, p. 18.

Canakci, V., Akgül, H. M., Akgül, N. and Canakci, C. F. (2003) 'Prevalence and handedness correlates of traumatic injuries to the permanent incisors in 13–17-year-old adolescents in Erzurum, Turkey', *Dental Traumatology,* 19(5), pp. 248-254.

Capelli, A. 1982. *The elements of abbreviation in medieval Latin paleography*. Translated by Heimann, D. and Kay, R.) Lawrence: University of Kansas Libraries.

Capener, N. (1961) 'John of Gaddesden', *Annals of Surgery,* 154(Suppl 6), pp. 13.

Carlock, S., Fulton, E. H., Rosenbaum, E., Mukasa, L., Gardner, J. M., Shalin, S. C. and Kaley, J. R. (2020) 'Hansen disease (leprosy) and Armadillo exposure in Arkansas: a case series', *The American Journal of Dermatopathology,* 42(10), pp. 769-773.

Chaise, F. and Roger, B. (1985) 'Neurolysis of the common peroneal nerve in leprosy. A report on 22 patients', *The Journal of Bone and Joint Surgery. British volume,* 67(3), pp. 426-429.

Chalom, E. C., Ross, J. and Athreya, B. H. (1997) 'Syndromes and arthritis', *Rheumatic Disease Clinics of North America,* 23(3), pp. 709-727.

Chamarbagwala, R. (2006) 'Economic liberalization and wage inequality in India', *World Development,* 34(12), pp. 1997-2015.

Chauhan, S., Wakhlu, A. and Agarwal, V. (2010) 'Arthritis in leprosy', *Rheumatology,* 49(12), pp. 2237-2242.

Chen, X., Zha, S. and Shui, T.-J. (2021) 'Presenting symptoms of leprosy at diagnosis: Clinical evidence from a cross-sectional, population-based study', *PLoS Neglected Tropical Diseases,* 15(11), pp. e0009913.

Chimenos Küstner, E., Pascual Cruz, M., Piñol Dansis, C., Viñals Iglesias, H., Rodríguez de Rivera Campillo, M. E. and López López, J. (2006) 'Lepromatous leprosy: a review and case report', *Medicina Oral, Patología Oral y Cirugia Bucal,* 11(6)*,* pp. 474-479.

Cholmeley, H. P. (1912) *John of Gaddesden and the Rosa Medicinae.* Oxford: Clarendon Press.

Christensen, T., Martínez-Lavín, M. and Pineda, C. (2013) 'Periostitis and osteolysis in a medieval skeleton from South-West Hungary:(Leprosy, treponematosis, tuberculosis or hypertrophic osteoarthropathy) A diagnostic challenge!', *International Journal of Osteoarchaeology,* 23(1), pp. 69-82.

Cole, G. and Waldron, T. (2011) 'Apple Down 152: a putative case of syphilis from sixth century AD Anglo-Saxon England', *American Journal of Physical Anthropology,* 144(1), pp. 72-79.

Cole, G., Taylor, G., Stewart, G. and Dawson-Hobbis, H. (2022) 'Ancient DNA confirmation of lepromatous leprosy in a skeleton with concurrent osteosarcoma, excavated from the leprosarium of St. Mary Magdalen in Winchester, Hants., UK', *European Journal of Clinical Microbiology & Infectious Diseases,* 41(11), pp. 1295-1304.

Connell, B. (2012) *Human Osteology Method Statement*. London: Museum of London Archaeology, published online Feb 2012.

Constantine, of Africa (1515) *Viaticum*, Wolfenbüttel: Herzog August Bibliothek. Published online: http://diglib.hab.de/drucke/ma-4f-35/start.htm?image=00801

Cook, D. C. (2002) 'Rhinomaxillary syndrome in the absence of leprosy: an exercise in differential diagnosis', *The Past and Present of Leprosy: Archaeological, Historical, Palaeopathological and Clinical Approaches*, pp. 81-88.

Courtright, P. and Lewallen, S. (1995) 'Current concepts in the surgical management of lagophthalmos in leprosy', *Leprosy Review,* 66(3), pp. 220-223.

Covey, H. C. (2001) 'People with leprosy (Hansen's disease) during the Middle Ages', *The Social Science Journal,* 38(2), pp. 315-321.

Crawford, C. (2010) 'Leprosy in Brazil', *International journal of dermatology,* 49(5), pp. 596-7.

Crespo, F. A., Klaes, C. K., Switala, A. E. and DeWitte, S. N. (2017) 'Do leprosy and tuberculosis generate a systemic inflammatory shift? Setting the ground for a new dialogue between experimental immunology and bioarchaeology', *American Journal of Physical Anthropology,* 162(1), pp. 143-156.

Crespo, F., White, J. and Roberts, C. (2019) 'Revisiting the tuberculosis and leprosy cross-immunity hypothesis: Expanding the dialogue between immunology and paleopathology', *International Journal of Paleopathology,* 26, pp. 37-47.

Cunha, C., Silva, A. M., Irish, J., Scott, G. R., Tomé, T. and Marquez, J. (2012) 'Hypotrophic roots of the upper central incisors–a proposed new dental discrete trait', *Dental Anthropology,* 25(1).

Da Cruz Junior, A. T. V., Vasconcelos, B. H. B., Barroso, T. G. C. P., Souza, G. S., Monteiro, L. C. P., Xavier, M. B. and Callegari, B. (2024) 'Plantar pressure distribution and altered postural control in multibacillary leprosy patients', *BMC Infectious Diseases,* 24(1), pp. 130.

Daffner, R. (1984) 'Anterior tibial striations', *American Journal of Roentgenology,* 143(3), pp. 651-653.

Dahiru, T., Iliyasu, Z., Mande, A. T., van't Noordende, A. T. and Aliyu, M. H. (2022) 'Community perspectives on leprosy and related stigma in northern Nigeria: a qualitative study', *Leprosy Review,* 93(1), pp. 48-62.

Danielsen, K. (1968) 'Leprogenic odontodysplasia ('dens leprosus')', *International Journal of Leprosy,* 36, pp. 666-667.

Danielsen, K. (1970) 'Odontodysplasia leprosa in Danish mediaeval skeletons', *Tandlaegebladet,* 74, pp. 603-625.

Dastur, D. (1983) 'Pathology and pathogenesis of predilective sites of nerve damage in leprous neuritis: nerves in the arm and the face', *Neurosurgical Review,* 6, pp. 139-152.

Dautel, G. (2003) 'Camptodactylies', *Chirurgie de la Main,* 22(3), pp. 115-124.

Dave, B. and Bedi, R. (2013) 'Leprosy and its dental management guidelines', *International Dental Journal,* 63(2), pp. 65-71.

Dave, S., Nori, A. V., Thappa, D. M. and Siddaraju, N. (2004) 'Leprous osteitis presenting as bone cyst and erosions', *Dermatology Online Journal,* 10(1), [online].

Davey, T. and Rees, R. (1974) 'The nasal discharge in leprosy: clinical and bacteriological aspects', *Leprosy Review,* 45(2), pp. 121-34.

De Cáceres, M., Font, X. and Oliva, F. (2008) 'Assessing species diagnostic value in large data sets: A comparison between phi-coefficient and Ochiai index', *Journal of Vegetation Science,* 19(6), pp. 779-788.

de Freitas, M. R., Nascimento, O. J., Quaglino, E. A., Oliveira, A. and Hahn, M. D. (2003) 'Small-fiber polyneuropathy in leprosy without skin changes: study of 17 cases', *Arquivos de Neuro-psiquiatria,* 61(3a), pp. 542-6.

Demaitre, L. (1996) 'The Relevance of Futility: Jordanus de Turre (fl. 1313–1335) on the Treatment of Leprosy', *Bulletin of the History of Medicine,* 70(1), pp. 25-61.

Demaitre, L. (2007) *Leprosy in Premodern Medicine: A Malady of the Whole Body.* Baltimore: Johns Hopkins University Press.

Deogaonkar, M. (2004) 'Socio-economic inequality and its effect on healthcare delivery in India: inequality and healthcare', *Electronic Journal of Sociology,* 11(2), pp. 25-35.

Deps, P. and Collin, S. M. (2021) 'Mycobacterium lepromatosis as a Second Agent of Hansen's Disease', *Frontiers in Microbiology*, 12, pp. 1-7.

Deps, P. and Cruz, A. (2020) 'Why we should stop using the word leprosy', *The Lancet Infectious Diseases,* 20(4), pp. e75-e78.

deShazo, R. D., O'Brien, M., Justice, W. K. and Pitcock, J. (1999) 'Diagnostic criteria for sarcoidosis of the sinuses', *Journal of Allergy and Clinical Immunology,* 103(5), pp. 789-795.

Devi, C. S. and Kulkarni, P. (2019) 'Fine Needle Aspiration Cytology, a Useful Tool for the Diagnosis of Specific Leprous Osteitis', *Indian Journal of Leprosy,* 91, pp. 239-242.

DeWitte, S. N. and Stojanowski, C. M. (2015) 'The osteological paradox 20 years later: past perspectives, future directions', *Journal of Archaeological Research,* 23(4), pp. 397-450.

Dijkstra, J. I. and van Elteren, M. (2017) 'Gender and leprosy-related stigma in endemic areas: A systematic review', *Leprosy Review,* 88(3), pp. 419-440.

Ding, J. Z. and Legua, P. (2019) 'Visibly enlarged peripheral nerves in lepromatous leprosy', *Neurology,* 92(13), pp. 627-628.

Dols, M. W. (1983) 'The leper in medieval Islamic society', *Speculum,* 58(4), pp. 891-916.

Donaghy, M. (2003) 'Enlarged peripheral nerves', *Practical Neurology,* 3(1), pp. 40-45.

Dong, G. and Jia, Y. (2022) 'Facies Leonine in Lepromatous Leprosy', *Journal of Cutaneous Medicine and Surgery,* 26(4), pp. 439-439.

Donoghue, H. D., Marcsik, A., Matheson, C., Vernon, K., Nuorala, E., Molto, J. E., Greenblatt, C. L. and Spigelman, M. (2005) 'Co–infection of Mycobacterium tuberculosis and Mycobacterium leprae in human archaeological samples: a possible explanation for the historical decline of leprosy', *Proceedings of the Royal Society B: Biological Sciences,* 272(1561), pp. 389-394.

Donoghue, H. D. (2019) 'Tuberculosis and leprosy associated with historical human population movements in Europe and beyond–an overview based on mycobacterial ancient DNA', *Annals of Human Biology,* 46(2), pp. 120-128.

Doubleday, A. H., Page W. (eds.)(1903) Hospitals: St Mary Magdalen, Winchester. In: *A History of the County of Hampshire: Volume 2*, Victoria County History: London, pp. 197-200. *British History Online* http://www.british-history.ac.uk/vch/hants/vol2/pp197-200 [accessed 27 April 2021].

Duncan, M. (1986) 'Leprosy in children one year of age and under', *International Journal of Leprosy and Other Mycobacterial Diseases,* 54(4), pp. 646.

Duncan, M. E., Melsom, R., Pearson, J. M., Menzel, S. and Barnetson, R. (1983) 'A clinical and immunological study of four babies of mothers with lepromatous leprosy, two of whom developed leprosy in infancy', *International Journal of Leprosy and Other Mycobacterial Diseases,* 51(1), pp. 7-17.

Duncan, M. E. (1993) 'An historical and clinical review of the interaction of leprosy and pregnancy: A cycle to be broken', *Social Science & Medicine,* 37(4), pp. 457-472.

Dupras, T. L., Williams, L. J., De Meyer, M., Peeters, C., Depraetere, D., Vanthuyne, B. and Willems, H. (2010) 'Evidence of amputation as medical treatment in ancient Egypt', *International Journal of Osteoarchaeology,* 20(4), pp. 405-423.

El-Gendy, H., El-Gohary, R. M., Shohdy, K. S. and Ragab, G. (2016) 'Leprosy masquerading as systemic rheumatic diseases', *JCR: Journal of Clinical Rheumatology,* 22(5), pp. 264-271.

El Muttardi, N., Kulendren, D. and Jemec, B. (2010) 'Madura foot-mind the soil', *Journal of Plastic, Reconstructive & Aesthetic Surgery,* 63(7), pp. e576-e578.

Emerson, R. W. (2020) 'Bonferroni correction and type I error', *Journal of Visual Impairment & Blindness,* 114(1), pp. 77-78.

Esfandbod, M. (2011) 'Tuberculoid Leprosy', *New England Journal of Medicine*, 364(17), pp. 1657.

Falys, C. G., Schutkowski, H. and Weston, D. A. (2005) 'The distal humerus-a blind test of Rogers' sexing technique using a documented skeletal collection', *Journal of Forensic Sciences,* 50(6), pp. 1289.

Falys, C. and Lewis, M. (2011) 'Proposing a way forward: a review of standardisation in the use of age categories and ageing techniques in osteological analysis (2004–2009)', *International Journal of Osteoarchaeology,* 21(6), pp. 704-716.

Fenves, A. Z., Emmett, M., White, M. G., Greenway, G. and Michaels, D. B. (1986) 'Carpal tunnel syndrome with cystic bone lesions secondary to amyloidosis in chronic hemodialysis patients', *American Journal of Kidney Diseases,* 7(2), pp. 130-134.

Fernandes, T. R. M. d. O., Korinfskin, J. P., Espíndola, M. M. M. and Corrêa, L. M. d. O. (2014) 'Arthritis and diagnosis of leprosy: a case report and review of the literature', *Anais Brasileiros de Dermatologia,* 89, pp. 323-325.

Filipek, K. L., Roberts, C. A., Montgomery, J., Gowland, R. L., Moore, J., Tucker, K. and Evans, J. A. (2022) 'Creating communities of care: Sex estimation and mobility histories of adolescents buried in the cemetery of St. Mary Magdalen leprosarium (Winchester, England)', *American Journal of Biological Anthropology,* 178(1), pp. 108-123.

Fink, I., Pastakia, B. and Barranger, J. (1984) 'Enlarged phalangeal nutrient foramina in Gaucher disease and beta-thalassemia major', *American Journal of Roentgenology,* 143(3), pp. 647-649.

Fischer, M. (2017) 'Leprosy–an overview of clinical features, diagnosis, and treatment', *JDDG: Journal der Deutschen Dermatologischen Gesellschaft,* 15(8), pp. 801-827.

Fite, G. L. and Wade, H. (1955) 'The contribution of Neisser to the establishment of the Hansen bacillus as the etiologic agent of leprosy and the so-called Hansen-Neisser controversy', *International Journal of Leprosy,* 23(4; Pt. 1), pp. 418-28.

Fonseca, E. K. U., Nogueira, F. M., Santos, S. S. d., Lerner, T. G. and Castro, A. d. A. (2018) 'Thickening of the greater auricular nerve in leprosy: clinical correlation by ultrasound', *Radiologia Brasileira,* 51, pp. 339-340.

Forno, C., Häusermann, P., Hatz, C., Itin, P. and Blum, J. (2010) 'The difficulty in diagnosis and treatment of leprosy', *Journal of Travel Medicine,* 17(4), pp. 281-283.

Frank, S. A. (2002) 'Immune response to parasitic attack: evolution of a pulsed character', *Journal of Theoretical Biology,* 219(3), pp. 281-290.

Frykberg, R. G., Sage, R. A., Wukich, D. K., Pinzur, M. S. and Schuberth, J. M. (2012) 'Charcot arthropathy', *Foot & Ankle Specialist,* 5(4), pp. 262-271.

Fufa, D. T., Chuang, S.-S. and Yang, J.-Y. (2014) 'Postburn contractures of the hand', *The Journal of Hand Surgery,* 39(9), pp. 1869-1876.

Fujiwara, T., Yanai, H. and Hagiya, H. (2023) 'Like a shot-through manubrium: A rare presentation of skeletal tuberculosis', *Clinical Case Reports,* 11(5), pp. e7119.

Galanis, G. and Hanieh, A. (2021) 'Incorporating social determinants of health into modelling of COVID-19 and other infectious diseases: a baseline socio-economic compartmental model', *Social Science & Medicine,* 274, pp. 113794.

Garland, F. C., Garland, C. F., Doyle Jr, E. J., Balazs, L. L., Levine, R., Pugh, W. M. and Gorham, E. D. (1996) 'Carpal tunnel syndrome and occupation in US Navy enlisted personnel', *Archives of Environmental Health: An International Journal,* 51(5), pp. 395-407.

George, E., Richie, M. B. and Glastonbury, C. M. (2020) 'Facial nerve palsy: clinical practice and cognitive errors', *The American Journal of Medicine,* 133(9), pp. 1039-1044.

Getz, F. (2004) Gilbert the Englishman [Gilbertus Anglicus, Gilbertus de Aquila, Gilbert de l' Egle] (d. c. 1250), priest and medical writer. *Oxford Dictionary of National Biography.* Retrieved 16 Jun. 2021, from https://www.oxforddnb.com/view/10.1093/ref:odnb/9780198614128.001.0001/odnb-9780198614128-e-10679.

Getz, F. M. (2010) *Healing and society in medieval England: a Middle English translation of the pharmaceutical writings of Gilbertus Anglicus.* University of Wisconsin Press.

Ghunawat, S., Relhan, V., Mittal, S., Sandhu, J. and Garg, V. K. (2018) 'Childhood leprosy: A retrospective descriptive study from Delhi', *Indian Journal of Dermatology,* 63(6), pp. 455.

Gilmore, J. (2008) 'Leprosy at the Lazaretto on St Eustatius, Netherlands Antilles', *International Journal of Osteoarchaeology,* 18(1), pp. 72-84.

Glaziou, P., Cartel, J.-L., Moulia-Pelat, J.-P., Ngoc, L. N., Chanteau, S., Plichart, R. and Grosset, J.-H. (1993) 'Tuberculosis in leprosy patients detected between 1902 and 1991 in French Polynesia', *International Journal of Leprosy and Other Mycobacterial Diseases,* 61, pp. 199-199.

Glennie, M., Gardner, K., Dowden, M. and Currie, B. J. (2021) 'Active case detection methods for crusted scabies and leprosy: A systematic review', *PLoS Neglected Tropical Diseases,* 15(7), pp. e0009577.

Goldman, L. and Schafer, A. I. (2020) *Goldman-Cecil Medicine.* Elsevier Saunders: Philadelphia.

Goldstein, B. D. (2012) 'John Snow, the Broad Street pump and the precautionary principle', *Environmental Development,* 1(1), pp. 3-9.

González-Hernández, A. and Domínguez-Rodríguez, M. V. (2008) 'Migraine in Gilbertus Anglicus' Compendium medicinae. The cases of MS sloane 3486 and Wellcome MS 537', *Journal of the History of the Neurosciences,* 17(2), pp. 147-159.

Gopinath, D., Thappa, D. and Jaishankar, T. (2004) 'A clinical study of the involvement of cranial nerves in leprosy', *Indian Journal of Leprosy,* 76(1), pp. 1-9.

Goulart, I. M. B., Araujo, S., Filho, A. B., de Paiva, P. H. R. and Goulart, L. R. (2015) 'Asymptomatic leprosy infection among blood donors may predict disease development and suggests a potential mode of transmission', *Journal of Clinical Microbiology,* 53(10), pp. 3345-3348.

Graham, A., Furlong, S., Margoles, L. M., Owusu, K. and Franco-Paredes, C. (2010) 'Clinical management of leprosy reactions', *Infectious Diseases in Clinical Practice,* 18(4), pp. 235-238.

Grassi, W., De Angelis, R., Lamanna, G. and Cervini, C. (1998) 'The clinical features of rheumatoid arthritis', *European Journal of Radiology,* 27, pp. S18-S24.

Green, M. A., Dorling, D. and Mitchell, R. (2018) 'Updating Edwin Chadwick's seminal work on geographical inequalities by occupation', *Social Science & Medicine,* 197, pp. 59-62.

Greenspan, A. 'Erosive osteoarthritis'. *Seminars in Musculoskeletal Radiology*, 7(2), pp. 155-160.

Gunawan, H., Haryati, N. S. and Suwarsa, O. (2018) 'Swan neck deformity mimicking claw hand caused by arthritis in leprosy', *Case Reports in Dermatology,* 9(3), pp. 231-235.

Gunawan, H., Wulansari, Y., Achdiat, P. A. and Hindritiani, R. (2021) 'Leprosy-Related Chronic Arthritis with an Abundance of Mycobacterium Leprae in the Synovial Fluid: A Rare Case', *International Medical Case Reports Journal,* 14, pp. 371.

Gussow, Z. and Tracy, G. S. (1970) 'Stigma and the leprosy phenomenon: the social history of a disease in the nineteenth and twentieth centuries', *Bulletin of the History of Medicine,* 44(5), pp. 425-449.

Hackett, C. J. (1975) 'An introduction to diagnostic criteria of syphilis, treponarid and yaws (treponematoses) in dry bones, and some implications', *Virchows Archiv A,* 368, pp. 229-241.

Hajar, R. (2012) 'The air of history (part II) medicine in the middle ages', *Heart Views,* 13(4), pp. 158-162.

Hamard, A., Burns, R., Miquel, A., Sverzut, J., Chicheportiche, V., Wybier, M. and Bousson, V. (2020) 'Dactylitis: a pictorial review of key symptoms', *Diagnostic and Interventional Imaging,* 101(4), pp. 193-207.

Han, X. Y., Seo, Y.-H., Sizer, K. C., Schoberle, T., May, G. S., Spencer, J. S., Li, W. and Nair, R. G. (2008) 'A new Mycobacterium species causing diffuse lepromatous leprosy', *American Journal of Clinical Pathology,* 130(6), pp. 856-864.

Han, X. Y., Sizer, K. C., Velarde-Félix, J. S., Frias-Castro, L. O. and Vargas-Ocampo, F. (2012) 'The leprosy agents Mycobacterium lepromatosis and Mycobacterium leprae in Mexico', *International Journal of Dermatology,* 51(8), pp. 952-959.

Han, X. Y., Aung, F. M., Choon, S. E. and Werner, B. (2014) 'Analysis of the leprosy agents Mycobacterium leprae and Mycobacterium lepromatosis in four countries', *American Journal of Clinical Pathology,* 142(4), pp. 524-532.

Han, X. Y. and Silva, F. J. (2014) 'On the age of leprosy', *PLoS Neglected Tropical Diseases,* 8(2), pp. e2544.

Handerson, H. (1918) 'Gilbertus Anglicus Medicine of the thirteenth century', *Cleveland: Cleveland Medical Association Library*.

Harper, K. N., Zuckerman, M. K., Harper, M. L., Kingston, J. D. and Armelagos, G. J. (2011) 'The origin and antiquity of syphilis revisited: An Appraisal of Old World pre-Columbian evidence for treponemal infection', *American Journal of Physical Anthropology,* 146(S53), pp. 99-133.

Harverson, G. and Warren, A. G. (1979) 'Tarsal bone disintegration in leprosy', *Clinical Radiology,* 30(3), pp. 317-322.

Heath, C., Gantner, C. and Manarini, E. (2021) 'Introduction: movement and mobility in the medieval Mediterranean: changing perspectives from Late Antiquity to the long-twelfth century', *Medieval Worlds,* 13, pp. 3-11.

Henry, M., Galan, N., Teasdale, K., Prado, R., Amar, H., Rays, M. S., Roberts, L., Siqueira, P., De Wildt, G. and Virmond, M. (2016) 'Factors contributing to the delay in diagnosis and continued transmission of leprosy in Brazil–an explorative, quantitative, questionnaire based study', *PLoS neglected tropical diseases,* 10(3), pp. e0004542.

Hill, J., Little, J. and Ford, T. (2013) 'Bone wax: a foreign body/giant cell reaction in the foot', *Foot & Ankle Specialist,* 6(3), pp. 236-238.

Hogan, A., Heppert, V. G. and Suda, A. J. (2013) 'Osteomyelitis', *Archives of Orthopaedic and Trauma Surgery,* 133, pp. 1183-1196.

Honap, T. P., Pfister, L.-A., Housman, G., Mills, S., Tarara, R. P., Suzuki, K., Cuozzo, F. P., Sauther, M. L., Rosenberg, M. S. and Stone, A. C. (2018) 'Mycobacterium leprae genomes from naturally infected nonhuman primates', *PLoS Neglected Tropical Diseases,* 12(1), pp. e0006190.

Horta-Baas, G., Hernández-Cabrera, M., Barile-Fabris, L., del S Romero-Figueroa, M. and Arenas-Guzmán, R. (2015) 'Multibacillary leprosy mimicking systemic lupus erythematosus: case report and literature review', *Lupus,* 24(10), pp. 1095-1102.

Huang, P.-H., Liao, H.-T. and Tsai, C.-Y. (2019) 'Severe Raynaud's phenomenon and Sjögren's syndrome with ferocious gangrene change and auto-amputation', *Clinical Medicine,* 19(1), pp. 85-85.

Hutchison, R. L., Miller, H. M. and Michalke, S. K. (2019) 'The use of tPA in the treatment of frostbite: a systematic review', *Hand,* 14(1), pp. 13-18.

Inskip, S. A., Taylor, G. M., Zakrzewski, S. R., Mays, S. A., Pike, A. W., Llewellyn, G., Williams, C. M., Lee, O. Y., Wu, H. H. and Minnikin, D. E. (2015) 'Osteological, biomolecular and geochemical examination of an early Anglo-Saxon case of lepromatous leprosy', *PLoS One,* 10(5), pp. e0124282.

Irgens, L. M. (1984) 'The discovery of Mycobacterium leprae. A medical achievement in the light of evolving scientific methods', *The American Journal of Dermatopathology,* 6(4), pp. 337-343.

Işcan, M. Y., Loth, S. R. and Wright, R. K. (1984) 'Metamorphosis at the sternal rib end: a new method to estimate age at death in white males', *American Journal of Physical Anthropology,* 65(2), pp. 147-156.

Jaiswal, N., Chakraborti, S., Nayak, K., Pai, S., Shelley, B., Sreeram, S. P., Rakshith, K., Suresh, B., Misri, Z. and Alva, H. (2018) 'Hansen's neuritis revisited–A clinicopathological study', *Journal of Neurosciences in Rural Practice,* 9(01), pp. 042-055.

Jardim, M. R., Chimelli, L., Faria, S. C.-r., Fernandes, P. V., Néri, J. A. D. C., Sales, A. M., Sarno, E. N. and Antunes, S. L. G. (2004) 'Clinical, electroneuromyographic and morphological studies of pure neural leprosy in a Brazilian referral centre', *Leprosy Review,* 75(3), pp. 242-253.

Jayakumar, K. L. and Lipoff, J. B. (2017) 'Albert Ludwig Sigesmund Neisser, MD—A Life of Discovery and Controversy in Dermatology', *JAMA Dermatology,* 153(6), pp. 574-574.

Jeffcoate, W. (2015) 'Charcot foot syndrome', *Diabetic Medicine,* 32(6), pp. 760-770.

Job, C. K., Jayakumar, J., Kearney, M. and Gillis, T. P. (2008) 'Transmission of leprosy: a study of skin and nasal secretions of household contacts of leprosy patients using PCR', *The American Journal of Tropical Medicine and Hygiene,* 78(3), pp. 518-521.

John, of Gaddesden and Scillacio (1502) *Rosa anglica practica medicinae / [Johannes de Gaddesden]*. Venice: Locatelli, Boneto, fl. 1486-1523 (Early European books).

Kahawita, I. and Lockwood, D. (2008) 'Towards understanding the pathology of erythema nodosum leprosum', *Transactions of the Royal Society of Tropical Medicine and Hygiene,* 102(4), pp. 329-337.

Kama, G., Huang, G., Taune, M., Arura, R., Morris, L., Kombuk, B., Marome, A. and O'Brien, D. (2019) 'Tuberculosis treatment unmasking leprosy: management of drug-resistant tuberculosis and leprosy co-infection', *Public Health Action,* 9(Suppl 1), pp. S83.

Kapoor, A. and Sibbitt Jr, W. L. 'Contractures in diabetes mellitus: the syndrome of limited joint mobility'. *Seminars in Arthritis and Rheumatism*, 18(3), pp. 168-180.

Kar, B. R. and Job, C. (2005) 'Visible deformity in childhood leprosy-a 10-year study', *International Journal of Leprosy and Other Mycobacterial Diseases,* 73(4), pp. 243.

Kassimi, E., Khadir, A., Elbouchikhi, M., Lmidmani, F., Elfatimi, A., Elhyaoui, H., Messoudi, A., Hassoun, J. and Garch, A. (2013) 'Mycetoma or Madura foot: A case report', *Annals of Physical and Rehabilitation Medicine,* (56), pp. e32.

Kattamis, A., Kwiatkowski, J. L. and Aydinok, Y. (2022) 'Thalassaemia', *The Lancet*, 399(10343), pp. 2310-2324.

Kaushik, J., Jain, V. K., Parihar, J. K. S., Dhar, S. and Agarwal, S. (2017) 'Leprosy presenting with iridocyclitis: A diagnostic dilemma', *Journal of Ophthalmic & Vision Research,* 12(4), pp. 437.

Kaynak, G., Birsel, O., Fatih Güven, M. and Öğüt, T. (2013) 'An overview of the Charcot foot pathophysiology', *Diabetic Foot & Ankle,* 4(1), pp. 21117.

Kemp, B. (1985) 'Maiden Bradley priory, Wiltshire, and Kidderminster church, Worcestershire', *Reading Medieval Studies,* 11, pp. 87-120.

Khambati, F., Shetty, V., Ghate, S. and Capadia, G. (2009) 'Sensitivity and specificity of nerve palpation, monofilament testing and voluntary muscle testing in detecting peripheral nerve abnormality, using nerve conduction studies as gold standard; A study in 357 patients', *Leprosy Review,* 80, pp. 34-50.

Khan, S. L., Parikh, R., Mooncai, T., Sandhu, S., Jawa, R. and Farber, H. W. (2019) 'Barriers to frostbite treatment at an academic medical center', *The American Journal of Emergency Medicine,* 37(8), pp. 1601. e3-1601. e5.

Kilpatrick, D., Sampath, R., Jones, A., Movaghar, S., Kelly, R. and Costic, D. (2017) 'Tuberculosis and Leprosy Co-Infection: A Perspective on Diagnosis and Treatment'. *Open Forum Infectious Diseases*, 4 (Suppl. 1), p. S671.

Kjellström, A. (2012) 'Possible cases of leprosy and tuberculosis in medieval Sigtuna, Sweden', *International Journal of Osteoarchaeology,* 22(3), pp. 261-283.

Köhler, K., Marcsik, A., Zádori, P., Biro, G., Szeniczey, T., Fábián, S., Serlegi, G., Marton, T., Donoghue, H. D. and Hajdu, T. (2017) 'Possible cases of leprosy from the Late Copper Age (3780-3650 cal BC) in Hungary', *PLoS One,* 12(10), pp. e0185966.

Konishiike, T., Hashizume, H., Nishida, K., Inoue, H. and Moriwaki, K. (1994) 'Cubital tunnel syndrome in a patient in long-term haemodialysis', *The Journal of Hand Surgery: British & European Volume,* 19(5), pp. 636-637.

Krause-Kyora, B., Nutsua, M., Boehme, L., Pierini, F., Pedersen, D. D., Kornell, S.-C., Drichel, D., Bonazzi, M., Möbus, L. and Tarp, P. (2018) 'Ancient DNA study reveals HLA susceptibility locus for leprosy in medieval Europeans', *Nature Communications,* 9(1), pp. 1569.

Kricun, M. E. (1985) 'Red-yellow marrow conversion: its effect on the location of some solitary bone lesions', *Skeletal radiology,* 14, pp. 10-19.

Kucuk, E. (2014) A Rare Nasal Bone Fracture: Anterior Nasal Spine Fracture. *Journal of Clinical and Analytical Medicine*, 143, pp. 176-178.

Kulkarni, V. and Mehta, J. (1983) 'Tarsal disintegration (TD) in leprosy', *Leprosy in India,* 55(2), pp. 338-370.

Kumar, B. (2016) 'Pure or primary neuritic leprosy (PNL)', *Leprosy Review,* 87(4), pp. 450-455.

Kumar, R. B., Singhasivanon, P., Sherchand, J. B., Mahaisavariya, P., Kaewkungwal, J., Peerapakorn, S. and Mahotarn, K. (2004) 'Gender differences in epidemiological factors associated with treatment completion status of leprosy patients in the most hyperendemic district of Nepal', *Southeast Asian Journal of Tropical Medicine and Public Health,* 35(2), pp. 334-9.

Kumar, S., Alexander, M. and Gnanamuthu, C. (2006) 'Cranial nerve involvement in patients with leprous neuropathy', *Neurology India,* 54(3), pp. 283.

Lackie, J. (2010) Dupuytren's contracture. In: Lackie, J. (ed.) *A Dictionary of Biomedicine*. Oxford University Press: Oxford. [Online edition accessed via https://solo.bodleian.ox.ac.uk].

Laine, V. A., Sairanen, E. and VainIo, K. (1957) 'Finger deformities caused by rheumatoid arthritis', *Journal of Bone and Joint Surgery,* 39(3), pp. 527-533.

Lambert, S. M., Walker, S. L. and Harnisch, J. P. (2017) 'Chapter 40 - Leprosy (Hansen's Disease)', in Sanford, C.A., Pottinger, P.S. and Jong, E.C. (eds.) *The Travel and Tropical Medicine Manual (Fifth Edition)*, pp. 513-523. Elsevier: Oxford.

Lastória, J. C. and Abreu, M. A. M. M. d. (2014) 'Leprosy: review of the epidemiological, clinical, and etiopathogenic aspects-part 1', *Anais Brasileiros de Dermatologia,* 89, pp. 205-218.

Launer, J. (2007) 'Hansen's disease', *QJM: An International Journal of Medicine,* 100(7), pp. 467-468.

Lee, F. and Magilton, J. (1989) 'The cemetery of the hospital of St James and St Mary Magdalene, Chichester-a case study', *World Archaeology,* 21(2), pp. 273-282.

Lee, F. and Magilton, J. (2008) Discussion, in Magilton, J., Lee, F. and Boylston, A. (eds.) ‘*"Lepers Outside the Gate": Excavations at the Cemetery of the Hospital of St James and St Mary*

Magdalene, Chichester, 1986-87 and 1993'. York: Council for British Archaeology, pp. 263-69.

Lee, F. and Manchester, K. (2008) Leprosy: a review of the evidence in the Chichester sample, in Magilton, J., Lee, F. and Boylston, A. (eds.) *'"Lepers Outside the Gate": Excavations at the Cemetery of the Hospital of St James and St Mary Magdalene, Chichester, 1986-87 and 1993'.* York: Council for British Archaeology, pp. 208-209.

Leite, J. A. D., Sampaio, A. C. D., Leite, C. M. G. d. S., Leite, J. G. d. S., Sampaio, M. V. and Lima, D. A. d. (2023) 'Endoscopic Cubital Tunnel Release in Leprosy Neuritis of the Ulnar Nerve', *Revista Brasileira de Ortopedia,* 58, pp. 114-120.

Leon, K. E., Jacob, J. T., Franco-Paredes, C., Kozarsky, P. E., Wu, H. M. and Fairley, J. K. (2016) 'Delayed diagnosis, leprosy reactions, and nerve injury among individuals with Hansen's disease seen at a United States clinic'. *Open Forum Infectious Diseases*: Oxford University Press, ofw063.

Lew, D. P. and Waldvogel, F. A. (2004) 'Osteomyelitis', *The Lancet,* 364(9431), pp. 369-379.

Lewis M. (2008) The children. In: Magilton, J., Lee, F. and Boylston, A. (eds.) *'"Lepers outside the gate": excavations at the cemetery of the hospital of St. James and St. Mary Magdalene*, Chichester, 1986-87 and 1993'. York: Council for British Archaeology, pp. 174-87.

Lewis, M. (2017) 'Paleopathology of children: Identification of pathological conditions in the human skeletal remains of non-adults'. London: Elsevier.

Lewis, M. E. (2022) 'Exploring adolescence as a key life history stage in bioarchaeology', *American Journal of Biological Anthropology,* 179(4), pp. 519-534.

Lewis, M. E., Roberts, C. A. and Manchester, K. (1995) 'Inflammatory bone changes in leprous skeletons from the medieval hospital of St. James and St. Mary Magdalene, Chichester, England', *International Journal of Leprosy and Other Mycobacterial Diseases,* 63, pp. 77-85.

Li, J., Fu, X. a., Sun, L., Xue, X., Liu, H. and Zhang, F. (2023) 'Case report: lepromatous leprosy and psoriasis: an uncommon coincidence', *The American Journal of Tropical Medicine and Hygiene,* 108(2), pp. 317.

Lin, P. L. and Flynn, J. L. (2010) 'Understanding latent tuberculosis: a moving target', *The Journal of Immunology,* 185(1), pp. 15-22.

Lind, V. (1972) 'Short root anomaly', *European Journal of Oral Sciences,* 80(2), pp. 85-93.

Liu, J., Wen, Y., Xing, Y. and Wang, S. (2018) 'Borderline tuberculoid leprosy mimicking sarcoidosis: a case report', *Medicine,* 97(32).

Liu, Y. Y., Yu, M. W., Ning, Y. and Wang, H. (2018) 'A study on gender differences in newly detected leprosy cases in Sichuan, China, 2000–2015', *International Journal of Dermatology,* 57(12), pp. 1492-1499.

Lockwood, D. N. (2004) 'Commentary: leprosy and poverty', *International Journal of Epidemiology,* 33(2), pp. 269-270.

Long, B. (2015) *Body and soul: The production and reception of medical translations from Arabic in the long twelfth century.* Notre Dame: University of Notre Dame.

Lories, R. J. and Baeten, D. (2009) 'Differences in pathophysiology between rheumatoid arthritis and ankylosing spondylitis', *Rheumatology,* 4, pp. 218.

Loth, S. R. and Henneberg, M. (1996) 'Mandibular ramus flexure: a new morphologic indicator of sexual dimorphism in the human skeleton', *American Journal of Physical Anthropology,* 99(3), pp. 473-485.

Lovejoy, C. O., Meindl, R. S., Mensforth, R. P. and Barton, T. J. (1985a) 'Multifactorial determination of skeletal age at death: a method and blind tests of its accuracy', *American Journal of Physical Anthropology,* 68(1), pp. 1-14.

Lovejoy, C. O., Meindl, R. S., Pryzbeck, T. R. and Mensforth, R. P. (1985b) 'Chronological metamorphosis of the auricular surface of the ilium: a new method for the determination of adult skeletal age at death', *American Journal of Physical Anthropology,* 68(1), pp. 15-28.

Lugão, H. B., Nogueira-Barbosa, M. H., Marques Jr, W., Foss, N. T. and Frade, M. A. C. (2015) 'Asymmetric nerve enlargement: a characteristic of leprosy neuropathy demonstrated by ultrasonography', *PLoS Neglected Tropical Diseases,* 9(12), pp. e0004276.

Lunt, D. A. (2013) 'The first evidence for leprosy in early Mediaeval Scotland: two individuals from cemeteries in St. Andrews, Fife, Scotland, with evidence for normal burial treatment', *International Journal of Osteoarchaeology,* 23(3), pp. 310-318.

Lusli, M., Peters, R., van Brakel, W., Zweekhorst, M., Iancu, S., Bunders, J., Irwanto and Regeer, B. (2016) 'The impact of a rights-based counselling intervention to reduce stigma in people affected by leprosy in Indonesia', *PLoS Neglected Tropical Diseases,* 10(12), pp. e0005088.

Magilton, J. (2008) The Hospital of St James and St Mary Magdalene, Chichester, in Magilton, J., Lee, F. and Boylston, A.(eds.) *'"Lepers Outside the Gate": Excavations at the Cemetery of the Hospital of St James and St Mary Magdalene, Chichester, 1986-87 and 1993'.* York: Council for British Archaeology, pp. 57-66.

Magilton, J., Lee, F. and Boylston, A. (2008) *'"Lepers Outside the Gate": Excavations at the Cemetery of the Hospital of St James and St Mary Magdalene, Chichester, 1986-87 and 1993'.* York: Council for British Archaeology.

Manchester, K. (1981) 'A leprous skeleton of the 7th century from Eccles, Kent, and the present evidence of leprosy in early Britain', *Journal of Archaeological Science,* 8(2), pp. 205-209.

Manchester, K. (1984) 'Tuberculosis and leprosy in antiquity: an interpretation', *Medical History,* 28(2), pp. 162-173.

Mandal, S. K., Sarkar, R., Sarkar, P., Datta, S., Bandyopadhyay, R., Bandyopadhyay, D. and Pain, S. (2008) 'Rheumatological manifestations of leprosy', *Journal of the Indian Medical Association,* 106(3), pp. 165-166.

Mandel, S. L. (1987) 'Of asklepiads, quacks, and early caretakers of the skin', *International Journal of Dermatology,* 26(9), pp. 610-613.

Mangum, L., Kilpatrick, D., Stryjewska, B. and Sampath, R. (2018) 'Tuberculosis and leprosy coinfection: A perspective on diagnosis and treatment'. *Open Forum Infectious Diseases*, 5(7) p. 133.

Mann, R. A. (1983) 'Acquired flatfoot in adults', *Clinical Orthopaedics and Related Research,* 181, pp. 46-51.

Marcombe, D. (2003) *Leper Knights: The Order of St. Lazarus of Jerusalem in England, C.1150-1544.* Martlesham: Boydell Press.

Marks Jr, S. C. (1979) 'The cellular basis for extremity bone loss in leprosy', *International Journal of Leprosy,* 47, pp. 26-32.

Marmor, M. F. (2002) 'The ophthalmic trials of GHA Hansen', *Survey of ophthalmology,* 47(3), pp. 275-287.

Martel, W., Stuck, K. J., Dworin, A. and Hylland, R. (1980) 'Erosive osteoarthritis and psoriatic arthritis: a radiologic comparison in the hand, wrist, and foot', *American Journal of Roentgenology,* 134(1), pp. 125-135.

Matos, V. (2011) 'Leprogenic odontodysplasia: new evidence of a rare and poorly understood malformation from the St. Jorgen's medieval leprosarium cemetery (Odense, Denmark)', *American Journal of Physical Anthropology,* 52, pp. 208.

Matos, V. M. and Santos, A. L. (2013) 'Leprogenic odontodysplasia: new evidence from the St. Jørgen's medieval leprosarium cemetery (Odense, Denmark)', *Anthropological Science,* 121(1), pp. 43-47.

Mattern, S. (2011) 'Galen and his patients', *The Lancet,* 378(9790), pp. 478-479.

Matthias, A. E., McWhinney, L. A. and Carpenter, K. (2016) 'Pathological pitting in ankylosaur (Dinosauria) osteoderms', *International Journal of Paleopathology,* 13, pp. 82-90.

Mays, S., Watt, I. and Loe, L. (2017) 'An unusual erosive arthropathy from Medieval England', *International Journal of Osteoarchaeology,* 27(4), pp. 693-699.

McDougall, A., Rees, R., Weddell, A. and Kanan, M. W. (1975) 'The histopathology of lepromatous leprosy in the nose', *The Journal of Pathology,* 115(4), pp. 215-226.

McKeon, K. E. and Lee, D. H. (2015) 'Posttraumatic boutonnière and swan neck deformities', *Journal of the American Academy of Orthopaedic Surgeons,* 23(10), pp. 623-632.

Meindl, R. S., Lovejoy, C. O., Mensforth, R. P. and Walker, R. A. (1985) 'A revised method of age determination using the os pubis, with a review and tests of accuracy of other current methods of pubic symphyseal aging', *American Journal of Physical Anthropology,* 68(1), pp. 29-45.

Mendum, T. A., Schuenemann, V. J., Roffey, S., Taylor, G. M., Wu, H., Singh, P., Tucker, K., Hinds, J., Cole, S. T. and Kierzek, A. M. (2014) 'Mycobacterium leprae genomes from a British medieval leprosy hospital: towards understanding an ancient epidemic', *BMC Genomics,* 15(1), pp. 1-8.

Meredith, A., Del Pozo, J., Smith, S., Milne, E., Stevenson, K. and McLuckie, J. (2014) 'Leprosy in red squirrels in Scotland', *The Veterinary Record,* 175(11), pp. 285.

Messner, R. P. (1997) Arthritis due to mycobacteria, fungi and parasites. In: Koopman, WJ., McCarthy, DJ (eds.) *Arthritis and Allied Conditions*, *13th Edition*, Philadelphia: Williams and Wilkins, pp. 2305-20.

Mi, Z., Liu, H. and Zhang, F. (2020) 'Advances in the immunology and genetics of leprosy', *Frontiers in Immunology,* 11, pp. 567.

Miller, T. S. and Nesbitt, J. W. (2014) *Walking corpses: Leprosy in Byzantium and the medieval West.* New York: Cornell University Press.

Mills, T (2017) Scurvy Dogs? A Reassessment of Scurvy Rates in the Crescent, Plymouth Skeletal Assemblage, *Unpublished Masters Dissertation: University of Reading (MA Archaeology)*.

Møller-Christensen, V. and Andersen, H. (1953) *Ten Lepers from Næstved in Denmark: A Study of Skeletons from a Medieval Danish Leper Hospital. With Preface by Erik Waaler, Bergen, Norway: Transl. from Danish.* Copenhagen: Danish Science Press.

Møller-Christensen, V. (1961) *Bone Changes in Leprosy.* Copenhagen: Munksgaard.

Møller-Christensen, V. (1967) 'Evidence of leprosy in earlier peoples', in Brothwell, D.R. and Sandison, A.T. (eds) *Diseases in Antiquity: A Survey of the Diseases, Injury and Surgery of Early Populations,* Charles C. Springfield: Thomas, pp. 295-306.

Møller-Christensen, V. (1978) *Leprosy Changes of the Skull*. Odense: Odense University Press.

Møller-Christensen, V., and Sandison, T (1963) *Usura orbitae* (*Cribra orbitalia*) in the collection of crania in the Anatomy Department of the University of Glasgow. *Pathological Microbiology*. 26, pp. 175-183.

Monot, M., Honoré, N., Garnier, T., Araoz, R., Coppée, J.-Y., Lacroix, C., Sow, S., Spencer, J. S., Truman, R. W. and Williams, D. L. (2005) 'On the origin of leprosy', *Science*, 308(5724), pp. 1040-1042.

Moonot, P., Ashwood, N. and Lockwood, D. (2005) 'Orthopaedic complications of leprosy', *The Journal of Bone and Joint Surgery. British volume,* 87(10), pp. 1328-1332.

Moorrees, C. F., Fanning, E. A. and Hunt Jr, E. E. (1963a) 'Age variation of formation stages for ten permanent teeth', *Journal of Dental Research,* 42(6), pp. 1490-1502.

Moorrees, C. F., Fanning, E. A. and Hunt Jr, E. E. (1963b) 'Formation and resorption of three deciduous teeth in children', *American Journal of Physical Anthropology,* 21(2), pp. 205-213.

Munday, W. R., Klett, Z., McNiff, J. M. and Ko, C. (2014) 'Foreign body giant cell reaction to tarSys™ xenograft', *Journal of Cutaneous Pathology,* 41(10), pp. 771-774.

Murphy, E. and Manchester, K. (1998) ''Be Thou Dead To The World'-Palaeopathological evidence for leprosy in Ireland from Armoy, Co. Antrim', *Archaeology Ireland,* 12, pp. 12-14.

Muthuvel, T., Govindarajulu, S., Isaakidis, P., Shewade, H. D., Rokade, V., Singh, R. and Kamble, S. (2017) '"I Wasted 3 Years, Thinking It's Not a Problem": Patient and Health System Delays

in Diagnosis of Leprosy in India: A Mixed-Methods Study', *PLoS Neglected Tropical Diseases,* 11(1), pp. e0005192.

Nagral, A. (2014) 'Gaucher disease', *Journal of Clinical and Experimental Hepatology,* 4(1), pp. 37-50.

Nair, S. P. (2017) 'A clinico-epidemiological study of pediatric leprosy in the urban leprosy center of a tertiary care institute', *Indian Journal of Paediatric Dermatology,* 18(1), pp. 24-27.

Nascimento, O. J. (2013) 'Leprosy neuropathy: clinical presentations', *Arquivos de Neuro-Psiquiatria,* 71, pp. 661-666.

Nery, J. A. d. C., Bernardes Filho, F., Quintanilha, J., Machado, A. M., Oliveira, S. d. S. C. and Sales, A. M. (2013) 'Understanding the type 1 reactional state for early diagnosis and treatment: a way to avoid disability in leprosy', *Anais Brasileiros de Dermatologia,* 88, pp. 787-792.

Netscher, D. T., Hamilton, K. L. and Paz, L. (2015) 'Soft-tissue surgery for camptodactyly corrects skeletal changes', *Plastic and Reconstructive Surgery,* 136(5), pp. 1028-1035.

Nguyen, V. D., Keh, R. A. and Daehler, R. W. (1991) 'Freiberg's disease in diabetes mellitus', *Skeletal Radiology,* 20, pp. 425-428.

Nickerson, D. S. (2010) 'A review of therapeutic nerve decompression for neuropathy in Hansen's disease with research suggestions', *Journal of Reconstructive Microsurgery,* 26(04), pp. 277-284.

Ooi, W. W. and Srinivasan, J. (2004) 'Leprosy and the peripheral nervous system: basic and clinical aspects', *Muscle & Nerve,* 30(4), pp. 393-409.

Ooi, W. W. and Srinivasan, J. (2021) 'Chapter 41 - Leprosy', in Aminoff, M.J. and Josephson, S.A. (eds.) *Aminoff's Neurology and General Medicine (Sixth Edition)*, Boston: Academic Press, pp. 727-740.

Oriel, J. (1989) 'Eminent venereologists. 1. Albert Neisser', *Genitourinary Medicine,* 65(4), pp. 229.

Ortiz, B. D. M., Sánchez, M. L., Valiente, C., Martínez, G., Masi, M. R., Knopfelmacher, O. and de Lezcano, L. B. (2016) 'Chilhood leprosy: Clinical and epidemiological study in the Department of Dermatology, Clinicas Hospital, Faculty of Medical Sciences, National University of Asuncion-Paraguay, 2005-2014', *Our Dermatology Online,* 7(1), pp. 17.

Ortner, D. J. (2003) *Identification of pathological conditions in human skeletal remains.* Boston: Academic Press.

Ortner, D. (2008) Skeletal manifestations of leprosy, in Magilton, J., Lee, F. and Boylston, A. (eds.) ‘*"Lepers Outside the Gate": Excavations at the Cemetery of the Hospital of St James and St Mary Magdalene, Chichester, 1986-87 and 1993*’. York: Council for British Archaeology, pp. 198- 206.

Page, W (1907) *Victoria County History Sussex 2*, London: Institute of Historical Research.

Palmer, B. A. and Hughes, T. B. (2010) 'Cubital tunnel syndrome', *The Journal of Hand Surgery,* 35(1), pp. 153-163.

Papavramidou, N. (2018) 'The ancient history of dementia', *Neurological Sciences,* 39, pp. 2011-2016.

Pavezzi, P. D., do Prado, R. B., Boin Filho, P. Â., Gon, A. d. S., Tuma, B., Fornazieri, M. A., Scalone, F. d. M., Alves, L. R. M., Montero, R. H. and Casella, A. M. B. (2020) 'Evaluation of ocular involvement in patients with Hansen's disease', *PLoS Neglected Tropical Diseases,* 14(9), pp. e0008585.

Payne, R., Baccon, J., Dossett, J., Scollard, D., Byler, D., Patel, A. and Harbaugh, K. (2015) 'Pure neuritic leprosy presenting as ulnar nerve neuropathy: a case report of electrodiagnostic, radiographic, and histopathological findings', *Journal of Neurosurgery,* 123(5), pp. 1238-1243.

Pearn, J. (2012) 'Master John of Arderne (1307–1380): a founder of modern surgery', *ANZ Journal of Surgery,* 82(1-2), pp. 46-51.

Pearn, J. (2013) 'Two medieval doctors: Gilbertus Anglicus (c1180–c1250) and John of Gaddesden (1280–1361)', *Journal of Medical Biography,* 21(1), pp. 3-7.

Pedraza Hueso, M. I., Hinojosa Mena-Bernal, C., Hernández-Laín, A. and Guerrero Peral, A. L. (2014) 'Mononeuritis multiplex due to leprosy: A case of atypical presentation', *Neurología (English Edition),* 29(5), pp. 313-314.

Peeling, R. W. and Hook III, E. W. (2006) 'The pathogenesis of syphilis: the Great Mimicker, revisited', *The Journal of Pathology,* 208(2), pp. 224-232.

Penna, M. L. F., De, M. L. V. D. R. and Penna, G. O. (2009) 'The epidemiological behaviour of leprosy in Brazil', *Leprosy Review,* 80(3), pp. 332-344.

Penna, M. L. F., Grossi, M. A. D. F. and Penna, G. O. (2013) 'Country profile: leprosy in Brazil', *Leprosy Review,* 84(4), pp. 308-315.

Perry, M. A. and Gowland, R. L. (2022) 'Compounding vulnerabilities: Syndemics and the social determinants of disease in the past', *International Journal of Paleopathology,* 39, pp. 35-49.

Petrone, P., Kuncir, E. and Asensio, J. A. (2003) 'Surgical management and strategies in the treatment of hypothermia and cold injury', *Emergency Medicine Clinics,* 21(4), pp. 1165-1178.

Petrova, N. and Edmonds, M. (2013) 'Medical management of Charcot arthropathy', *Diabetes, Obesity and Metabolism,* 15(3), pp. 193-197.

Pettitt, D. and McArthur, P. (2012) 'Clinical review: Volkmann's ischaemic contracture', *European Journal of Trauma and Emergency Surgery,* 38, pp. 129-137.

Pfinsgraff, J., Buckingham, R. B., Killian, P. J., Keister, S. R., Brereton, W. F., Weinblatt, M. E., George, D. L. and Arnett, F. C. (1986) Palmar fasciitis and arthritis with malignant neoplasms: a paraneoplastic syndrome, *Seminars in arthritis and rheumatism*, 16(2), pp. 118-125.

Phenice, T. W. (1969) 'A newly developed visual method of sexing the os pubis', *American Journal of Physical Anthropology,* 30(2), pp. 297-301.

Pfrengle, S., Neukamm, J., Guellil, M., Keller, M., Molak, M., Avanzi, C., Kushniarevich, A., Montes, N., Neumann, G. U. and Reiter, E. (2021) 'Mycobacterium leprae diversity and population dynamics in medieval Europe from novel ancient genomes', *BMC biology,* 19, pp. 1-18.

Pickert, A. J. and Nguyen, X. (2012) 'Madura foot', *New England Journal of Medicine,* 366(1), pp. e2.

Pisquiy, J. J., Chan, A. G., Prabhakar, G., Kusnezov, N. and Dunn, J. C. (2019) 'Incidence of cubital tunnel syndrome in the US military population', *The Journal of Hand Surgery,* 44(6), pp. 516. e1-516. e7.

Plemons, A. and Hefner, J. T. (2016) 'Ancestry estimation using macromorphoscopic traits', *Academic Forensic Pathology,* 6(3), pp. 400-412.

Pocaterra, L., Jain, S., Reddy, R., Muzaffarullah, S., Torres, O., Suneetha, S. and Lockwood, D. N. (2006) 'Clinical course of erythema nodosum leprosum: an 11-year cohort study in Hyderabad, India', *The American Journal of Tropical Medicine and Hygiene,* 74(5), pp. 868-879.

Pradhan, S., Nayak, B. P. and Dash, G. (2019) 'Childhood leprosy: a review', *Indian Journal of Paediatric Dermatology,* 20(2), pp. 112-116.

Pugh, R., Crittall, E. (1956) 'Houses of Augustinian canons: Priory of Maiden Bradley', in *A History of the County of Wiltshire: Volume 3*, London: Victoria County History, pp. 295-302. [Accessed online at https://www.british-history.ac.uk/vch/wilts/vol3/pp295-302 - 12 March 2024]

Puranik, C., Hill, A., Henderson Jeffries, K., Harrell, S., Taylor, R. and Frazier-Bowers, S. (2015) 'Characterization of short root anomaly in a Mexican cohort–hereditary idiopathic root malformation', *Orthodontics & Craniofacial Research,* 18, pp. 62-70.

Raff, M. C., Sangalang, V. and Asbury, A. K. (1968) 'Ischemic mononeuropathy multiplex associated with diabetes mellitus', *Archives of Neurology,* 18(5), pp. 487-499.

Ragsdale, B. D., Campbell, R. A. and Kirkpatrick, C. L. (2018) 'Neoplasm or not? General principles of morphologic analysis of dry bone specimens', *International Journal of Paleopathology,* 21, pp. 27-40.

Rawcliffe, C. (2006) *Leprosy in Medieval England.* Martlesham: Boydell Press.

Rayan, G.M., Upton III J. (2014) Camptodactyly, in Rayan, G.M. and Upton III, J. (eds.) *Congenital Hand Anomalies and Associated Syndromes*. Berlin: Springer.

Reed, M. W. and Reed, D. N. (2012) 'Acute ulnar nerve entrapment after closed reduction of a posterior fracture dislocation of the elbow: a case report', *Pediatric Emergency Care,* 28(6), pp. 570-572.

Reichart, P. (1976) 'Facial and oral manifestations in leprosy: An evaluation of seventy cases', *Oral Surgery, Oral Medicine, Oral Pathology,* 41(3), pp. 385-399.

Renault, C. A. and Ernst, J. D. (2015) 'Mycobacterium leprae (leprosy)', in Bennett, J.E., Dolin, R., and Blaser M. J. (eds.) *Mandell, Douglas, and Bennett's Principles and Practice of Infectious Diseases*, New York: Elsevier, pp. 2819-2831. e2.

Resnick, D. and Niwayama, G. (1988) 'Rheumatoid arthritis and the seronegative spondyloarthropathies', in Resnick, D. and Niwayama, G. (eds.) *Diagnosis of bone and joint disorders. Second edition. Volumes 1-6*. Philadelphia: WB Saunders and Co.

Richard, B., Khatri, B., Knolle, E., Lucas, S. and Turkof, E. (2001) 'Leprosy affects the tibial nerves diffusely from the middle of the thigh to the sole of the foot, including skip lesions', *Plastic and Reconstructive Surgery,* 107(7), pp. 1717-1724.

Ridley, D. and Jopling, W. (1962) 'A classification of leprosy for research purposes', *Leprosy Review,* 33(2), pp. 119-28.

Ridley, D. and Jopling, W. (1966) 'Classification of leprosy according to immunity', *International Journal of Leprosy,* 34(3), pp. 255-273.

Roberts, C. (1986) 'Leprosy and leprosaria in medieval Britain', *MASCA Journal,* 4(1), pp. 15-21.

Roberts, C. A. (2020) '*Leprosy: Past and present*', Gainesville: University Press of Florida.

Roberts, C. A. and Brickley, M. (2018) 'Infectious and Metabolic Diseases', in Katzenburg, M. A. and Grauer, A. L. (eds.) *Biological Anthropology of the Human Skeleton*, Hoboken: John Wiley and Sons, pp. 415-446.

Roberts, C (2012) 'Keith Manchester (1938 -)', in Buikstra, J. and Roberts, C. (eds.) *The Global History of Paleopathology: Pioneers and Prospects*. Oxford: Oxford University Press.

Roffey, S. (2012) 'Medieval leper hospitals in England: an archaeological perspective', *Medieval Archaeology,* 56(1), pp. 203-233.

Roffey, S. (2017) 'Charity and Conquest: *Leprosaria* in Early Norman England', in Hadley, D.M. and Dyer C. (eds.) *The Archaeology of the 11th Century: Continuities and Transformations*. London: Routledge, pp. 159-180.

Roffey, S. (2020) 'Sanctity and suffering: The sacred world of the medieval leprosarium. A Perspective from St Mary Magdalen, Winchester' in Langlands, A. J. and Lavelle, R. (eds.) *The Land of the English Kin*, Leiden: Brill, pp. 538-554.

Roffey, S. and Marter, P. (2010a) Recent Excavations at St Mary Magdalen, Winchester. *Medieval Archaeology*, 54, pp. 404–8

Roffey, S. and Marter, P. (2010b) Excavations at St Mary Magdalen, Winchester. *Monastic Research Bulletin*, 16, pp. 43–9.

Roffey, S. and Marter, P. (2014) Excavations at the medieval leprosy hospital of St Mary Magdalen, Winchester, 2008–2013. *Church Archaeology*, 16, pp. 39–44.

Roffey, S. and Tucker, K. (2012) 'A contextual study of the medieval hospital and cemetery of St Mary Magdalen, Winchester, England', *International Journal of Paleopathology,* 2(4), pp. 170-180.

Roffey, S., Tucker, K., Filipek-Ogden, K., Montgomery, J., Cameron, J., O'Connell, T., Evans, J., Marter, P. and Taylor, G. M. (2017) 'Investigation of a medieval pilgrim burial excavated from the leprosarium of St Mary Magdalen Winchester, UK', *PLoS Neglected Tropical Diseases,* 11(1), pp. e0005186.

Rogers, J. and Waldron, T. (1989) 'Infections in palaeopathology: the basis of classification according to most probable cause', *Journal of Archaeological Science,* 16(6), pp. 611-625.

Rogers, J. and Waldron, T. (1995) *A Field Guide to Joint Disease in Archaeology.* Hoboken: Wiley.

Rogers, T. L. (1999) 'A visual method of determining the sex of skeletal remains using the distal humerus', *Journal of Forensic Sciences,* 44(1), pp. 57-60.

Ross, C. A. and Margolis, R. L. (2018) 'Research domain criteria: cutting edge neuroscience or Galen's humors revisited?', *Complex Psychiatry,* 4(3), pp. 158-163.

Rothschild, B. M. and Heathcote, G. M. (1995) 'Characterization of gout in a skeletal population sample: Presumptive diagnosis in a micronesian population', *American Journal of Physical Anthropology,* 98(4), pp. 519-525.

Rothschild, B. and Behnam, S. (2005) 'The often overlooked digital tuft: clues to diagnosis and pathophysiology of neuropathic disease and spondyloarthropathy', *Annals of the Rheumatic Diseases*, 64(2), pp. 286-290.

Rothschild, B. M. and Martin, L. (1993) *Paleopathology: Disease in the Fossil Record*. London: CRC Press.

Rothschild, B. M. and Rothschild, C. (2001) 'Skeletal manifestations of leprosy: analysis of 137 patients from different clinical settings in the Pre-and Postmodern treatment eras', *JCR: Journal of Clinical Rheumatology,* 7(4), pp. 228-237.

Rubini, M. and Zaio, P. (2009) 'Lepromatous leprosy in an early mediaeval cemetery in Central Italy (Morrione, Campochiaro, Molise, 6th–8th century AD)', *Journal of Archaeological Science,* 36(12), pp. 2771-2779.

Salgado, C. G. and Barreto, J. G. (2012) 'Leonine Facies: Lepromatous Leprosy', *New England Journal of Medicine,* 366(15), pp. 1433.

Salvi, S. and Chopra, A. (2013) 'Leprosy in a rheumatology setting: a challenging mimic to expose', *Clinical Rheumatology,* 32, pp. 1557-1563.

Santos, D. F. d., Mendonca, M. R., Antunes, D. E., Sabino, E. F. P., Pereira, R. C., Goulart, L. R. and Goulart, I. M. B. (2017) 'Revisiting primary neural leprosy: Clinical, serological, molecular, and neurophysiological aspects', *PLoS Neglected Tropical Diseases,* 11(11), pp. e0006086.

Sarno, E. N. and Pessolani, M. C. V. (2001) 'Oldest and most feared disease', *The Lancet,* 358, pp. S39.

Schaefer, M., Black, S. M., Schaefer, M. C. and Scheuer, L. (2009) '*Juvenile Osteology*', London: Academic Press.

Scholz, A. and WĄsik, F. (1985) 'Albert Neisser, 1855–1916', *International Journal of Dermatology,* 24(6), pp. 373-377.

Schrenk, F. (2013) 'Earliest homo', in Begun, D. (ed.) *A Companion to paleoanthropology*, Hoboken: Blackwell, pp. 479-496.

Schug, G. R. (2016) 'Begotten of corruption? Bioarchaeology and “othering” of leprosy in South Asia', *International Journal of Paleopathology,* 15, pp. 1-9.

Schutkowski, H. (1993) 'Sex determination of infant and juvenile skeletons: I. Morphognostic features', *American journal of physical anthropology,* 90(2), pp. 199-205.

Sen, D., Satija, L., Chatterji, S., Majumder, A., Gupta, A. and Kumar, A. (2016) 'Ultrasonography and magnetic resonance imaging of ulnar nerve abscess in leprosy', *Medical Journal Armed Forces India,* 72(1), pp. 78-81.

Sharma, A., Narang, T., Mehta, H., Mahajan, R., Takkar, A., Prakash, M. and Dogra, S. (2023) 'Intra-cranial involvement of trigeminal nerve in a patient with borderline tuberculoid leprosy in type 1 lepra reaction', *Australasian Journal of Dermatology,* 64(1), pp. e87-e89.

Sharma, P., Kumar, A., Tuknayat, A., Thami, G. P. and Kundu, R. (2019) 'Lucio phenomenon: A rare presentation of Hansen’s disease', *The Journal of Clinical and Aesthetic Dermatology,* 12(12), pp. 35.

Shennan, S. (1997) *Quantifying Archaeology.* Iowa City: University of Iowa Press.

Shin, R. and Ring, D. (2007) 'The ulnar nerve in elbow trauma', *Journal of Bone and Joint Surgery,* 89(5), pp. 1108-1116.

Shrivastava, S. (2014) 'Using Campaigns to De-stigmatize Leprosy in India: Stories from the Field', *Journal of Creative Communications,* 9(1), pp. 1-21.

Siddaraju, N., Roy, S. K., Bundele, M. M., Badhe, B. A. and Thappa, D. M. (2007) 'Fine Needle Aspiration Cytologic Diagnosis of Erythema Nodosum Leprosum', *Acta Cytologica,* 51(5), pp. 800-802.

Sigerist, H. E. (1936) 'Rare Books in the Welch Medical Library: 3. The Crummer Manuscript', *Bulletin of the Institute of the History of Medicine,* 4(4), pp. 335-339.

Silva, D. S. d., Teixeira, L. A. C., Beghini, D. G., Ferreira, A. T. d. S., Pinho, M. d. B. M., Rosa, P. S., Ribeiro, M. R., Freire, M. D. C., Hacker, M. A. and Nery, J. A. d. C. (2018) 'Blood coagulation abnormalities in multibacillary leprosy patients', *PLoS Neglected Tropical Diseases,* 12(3), pp. e0006214.

Singh, A. V., Pawar, H. S., Yadav, R. and Chauhan, D. S. (2020) 'Intact Mycobacterium leprae Isolated from Placenta of a Pregnant Woman, China', *Emerging Infectious Diseases,* 26(8), pp. 1961-1961.

Smith, B., Lisman, R. D., Simonton, J. and Rocca, R. D. (1984) 'Volkmann's contracture of the extraocular muscles following blowout fracture', *Plastic and Reconstructive Surgery,* 74(2), pp. 200-209.

Smolen, J. S. and Aletaha, D. (2015) 'Rheumatoid arthritis therapy reappraisal: strategies, opportunities and challenges', *Nature Reviews Rheumatology,* 11(5), pp. 276-289.

Sołtysiak, A. (2015) 'The osteological paradox, selective mortality, and stress markers revisited', *Current Anthropology,* 56(4), pp. 569-570.

Somar, P., Waltz, M. and van Brakel, W. (2020) 'The impact of leprosy on the mental wellbeing of leprosy-affected persons and their family members–a systematic review', *Global Mental Health,* 7, pp. e15.

Souza, C. F., Bornhausen-Demarch, E., Prata, A. G., de Andrade, F. C., Fernandes, M. P., Lopes, M. R. and Nery, J. A. (2013) 'Syphilis, leprosy, and human immunodeficiency virus coinfection: a challenging diagnosis', *Cutis,* 92(2), pp. 71-76.

Spekker, O., Tihanyi, B., Kis, L., Váradi, O. A., Donoghue, H. D., Minnikin, D. E., Szalontai, C., Vida, T., Pálfi, G. and Marcsik, A. (2022) 'The two extremes of Hansen's disease—Different manifestations of leprosy and their biological consequences in an Avar Age (late 7th century CE) osteoarchaeological series of the Duna-Tisza Interfluve (Kiskundorozsma–Daruhalom-dűlő II, Hungary)', *Plos one,* 17(6), pp. e0265416.

Stanbury, S. J. and Hammert, W. C. (2011) 'Dupuytren contracture', *Journal of Hand Surgery,* 36(12), pp. 2038-2040.

Stelmack, R. M. and Stalikas, A. (1991) 'Galen and the humour theory of temperament', *Personality and Individual Differences,* 12(3), pp. 255-263.

Suzuki, K., Akama, T., Kawashima, A., Yoshihara, A., Yotsu, R. R. and Ishii, N. (2012) 'Current status of leprosy: epidemiology, basic science and clinical perspectives', *The Journal of Dermatology,* 39(2), pp. 121-129.

Talhari, C., Talhari, S. and Penna, G. O. (2015) 'Clinical aspects of leprosy', *Clinics in Dermatology,* 33(1), pp. 26-37.

Taylor, G. M. and Donoghue, H. D. (2011) 'Multiple loci variable number tandem repeat (VNTR) analysis (MLVA) of Mycobacterium leprae isolates amplified from European archaeological human remains with lepromatous leprosy', *Microbes and infection,* 13(11), pp. 923-929.

Taylor, G. M., Murphy, E. M., Mendum, T. A., Pike, A. W., Linscott, B., Wu, H., O'Grady, J., Richardson, H., O'Donovan, E. and Troy, C. (2018) 'Leprosy at the edge of Europe—Biomolecular, isotopic and osteoarchaeological findings from medieval Ireland', *PLoS One,* 13(12), pp. e0209495.

Teijaro, J. R., Walsh, K. B., Rice, S., Rosen, H. and Oldstone, M. B. (2014) 'Mapping the innate signaling cascade essential for cytokine storm during influenza virus infection', *Proceedings of the National Academy of Sciences,* 111(10), pp. 3799-3804.

Thakkar, S. and Patel, S. V. (2014) 'Clinical profile of leprosy patients: a prospective study', *Indian Journal of Dermatology,* 59(2), pp. 158.

Thappa, D., Sharma, V., Kaur, S. and Suri, S. (1992) 'Radiological changes in hands and feet in disabled leprosy patients: a clinico-radiological correlation', *Indian Journal of Leprosy,* 64(1), pp. 58-66.

Tomimori-Yamashita, J., Ogawa, M. M., Hirata, S. H., Fischman, O., Michalany, N. S., Yamashita, H. K. and Alchorne, M. M. (2002) 'Mycetoma caused by Fusarium solani with osteolytic lesions on the hand: case report', *Mycopathologia,* 153, pp. 11-14.

Torun, S. and Karaman, I. (2021) 'Leprosy suspect presenting at a chest clinic', *Tropical Doctor,* 51(4), pp. 655-658.

Uğurlu, Ü. and Özdoğan, H. (2016) 'Effects of serial casting in the treatment of flexion contractures of Proximal Interphalangeal joints in patients with rheumatoid arthritis and juvenile idiopathic arthritis: A retrospective study', *Journal of Hand Therapy,* 29(1), pp. 41-50.

Utino, F. L., Damiani, G. V., Garcia, M., Soares, T. C. B., Stelini, R. F., Velho, P. E. N. F., de Souza, E. M. and Cintra, M. L. (2018) 'Histomorphometric approach to differentiate skin lesions of tuberculoid leprosy from sarcoidosis', *Journal of Cutaneous Pathology,* 45(2), pp. 111-117.

Van Brakel, W. H., Nicholls, P. G., Das, L., Barkataki, P., Maddali, P., Lockwood, D. N. and Wilder-Smith, E. (2005) 'The INFIR Cohort Study: assessment of sensory and motor neuropathy in leprosy at baseline', *Leprosy Review,* 76(4), pp. 277-295.

Van Der Giesen, F., Van Lankveld, W., Kremers-Selten, C., Peeters, A., Stern, E., Le Cessie, S., Nelissen, R. and Vliet Vlieland, T. (2009) 'Effectiveness of two finger splints for swan neck deformity in patients with rheumatoid arthritis: a randomized, crossover trial', *Arthritis Care & Research,* 61(8), pp. 1025-1031.

Van der Giesen, F., Nelissen, R., Van Lankveld, W., Kremers-Selten, C., Peeters, A., Stern, E., Le Cessie, S. and Vliet Vlieland, T. (2010) 'Swan neck deformities in rheumatoid arthritis: a qualitative study on the patients' perspectives on hand function problems and finger splints', *Musculoskeletal Care,* 8(4), pp. 179-188.

Van Smeden, M., de Groot, J. A., Moons, K. G., Collins, G. S., Altman, D. G., Eijkemans, M. J. and Reitsma, J. B. (2016) 'No rationale for 1 variable per 10 events criterion for binary logistic regression analysis', *BMC medical research methodology,* 16, pp. 1-12.

Varjú, C., Péntek, M., Lóránd, V., Nagy, G., Minier, T. and Czirják, L. (2017) 'Musculoskeletal involvement in systemic sclerosis: an unexplored aspect of the disease', *Journal of Scleroderma and Related Disorders,* 2(1), pp. 19-32.

Vera-Cabrera, L., Escalante-Fuentes, W. G., Gomez-Flores, M., Ocampo-Candiani, J., Busso, P., Singh, P. and Cole, S. T. (2011) 'Case of diffuse lepromatous leprosy associated with "Mycobacterium lepromatosis"', *Journal of Clinical Microbiology,* 49(12), pp. 4366-4368.

Verma, J. and Abdel-Salam, A.-S. G. (2019) *Testing Statistical Assumptions in Research.* Hoboken: John Wiley & Sons.

Vieira, M. C. A., Nery, J. S., Paixão, E. S., Freitas de Andrade, K. V., Oliveira Penna, G. and Teixeira, M. G. (2018) 'Leprosy in children under 15 years of age in Brazil: A systematic review of the literature', *PLoS Neglected Tropical Diseases,* 12(10), pp. e0006788.

Vital, R. T., Illarramendi, X., Antunes, S. L. G., Nascimento, M., Da Costa Nery, J. A., Nascimento, O., Sarno, E. N. and Jardim, M. R. (2013) 'Isolated median neuropathy as the first symptom of leprosy', *Muscle & Nerve,* 48(2), pp. 179-184.

Vollmann, J. and Winau, R. (1996) 'Informed consent in human experimentation before the Nuremberg code', *British Medical Journal,* 313(7070), pp. 1445-1447.

Vora, R. V., Pilani, A. P., Jivani, N. and Kota, R. K. (2015) 'Leprosy mimicking psoriasis', *Journal of Clinical and Diagnostic Research: JCDR,* 9(9), pp. WJ01.

Waldron, T. (2008) '*Palaeopathology*', Cambridge: Cambridge University Press.

Waldron, T. (2019) '*Joint Disease*', in, Buikstra, J. (ed): Ortner's Identification of Pathological Conditions in Human Skeletal Remains. London: Elsevier, pp. 719-748.

Walker, D., Powers, N., Connell, B. and Redfern, R. (2015) 'Evidence of skeletal treponematosis from the medieval burial ground of S t. Mary Spital, London, and implications for the origins of the disease in Europe', *American Journal of Physical Anthropology,* 156(1), pp. 90-101.

Walker, S. L. and Lockwood, D. N. (2008) 'Leprosy type 1 (reversal) reactions and their management', *Leprosy Review,* 79(4), pp. 372-386.

Walker, S. L., Sales, A. M., Butlin, C. R., Shah, M., Maghanoy, A., Lambert, S. M., Darlong, J., Rozario, B. J., Pai, V. V. and Balagon, M. (2017) 'A leprosy clinical severity scale for erythema nodosum leprosum: An international, multicentre validation study of the ENLIST ENL Severity Scale', *PLoS Neglected Tropical Diseases,* 11(7), pp. e0005716.

Wan, E. L., Rivadeneira, A. F., Jouvin, R. M. and Dellon, A. L. (2016) 'Treatment of peripheral neuropathy in leprosy: the case for nerve decompression', *Plastic and Reconstructive Surgery Global Open,* 4(3).

Wang, Z., Sun, Y., Fu, X. a., Yu, G., Wang, C., Bao, F., Yue, Z., Li, J., Sun, L. and Irwanto, A. (2016) 'A large-scale genome-wide association and meta-analysis identified four novel susceptibility loci for leprosy', *Nature Communications,* 7(1), pp. 13760.

Weston, D. A. (2008) 'Investigating the specificity of periosteal reactions in pathology museum specimens', *American Journal of Physical Anthropology: The Official Publication of the American Association of Physical Anthropologists,* 137(1), pp. 48-59.

Weston, D. A. (2011) 'Nonspecific Infection in Paleopathology: Interpreting Periosteal Reactions', in Grauer, A. (ed.) *A Companion to Paleopathology*, Hoboken, Blackwell, pp. 492-512.

Widiatma, R. R. and Sukanto, H. (2019) 'Diffuse lepromatous leprosy caused by dual infection of mycobacterium leprae and mycobacterium lepromatosis: A case report', *Dermatology Reports,* 11(s1).

Wilkinson, G. (2019) 'Ishaq Ibn Imran... Constantine the African, De Melancholia... De Coitu and Chaucer–Psychiatry in history', *The British Journal of Psychiatry,* 215(3), pp. 527-527.

Wood, J. W., Milner, G. R., Harpending, H. C., Weiss, K. M., Cohen, M. N., Eisenberg, L. E., Hutchinson, D. L., Jankauskas, R., Cesnys, G. and Česnys, G. (1992) 'The osteological paradox: problems of inferring prehistoric health from skeletal samples [and comments and reply]', *Current Anthropology,* 33(4), pp. 343-370.

Yamamura, M., Uyemura, K., Deans, R. J., Weinberg, K., Rea, T. H., Bloom, B. R. and Modlin, R. L. (1991) 'Defining protective responses to pathogens: cytokine profiles in leprosy lesions', *Science,* 254(5029), pp. 277-279.

Yasuda, H., Shima, N., Nakagawa, N., Yamaguchi, K., Kinosaki, M., Mochizuki, S.-i., Tomoyasu, A., Yano, K., Goto, M. and Murakami, A. (1998) 'Osteoclast differentiation factor is a ligand for osteoprotegerin/osteoclastogenesis-inhibitory factor and is identical to TRANCE/RANKL', *Proceedings of the National Academy of Sciences,* 95(7), pp. 3597-3602.

Young, A., Namas, R., Dodge, C. and Khanna, D. (2016) 'Hand impairment in systemic sclerosis: various manifestations and currently available treatment', *Current Treatment Options in Rheumatology,* 2, pp. 252-269.

Zampella, J. G., Kwatra, S. G., Kazi, N. and Aguh, C. (2017) 'Madura foot caused by Gordonia terrae misdiagnosed as Nocardia', *Australasian Journal of Dermatology,* 58(3), pp. e129-e131.

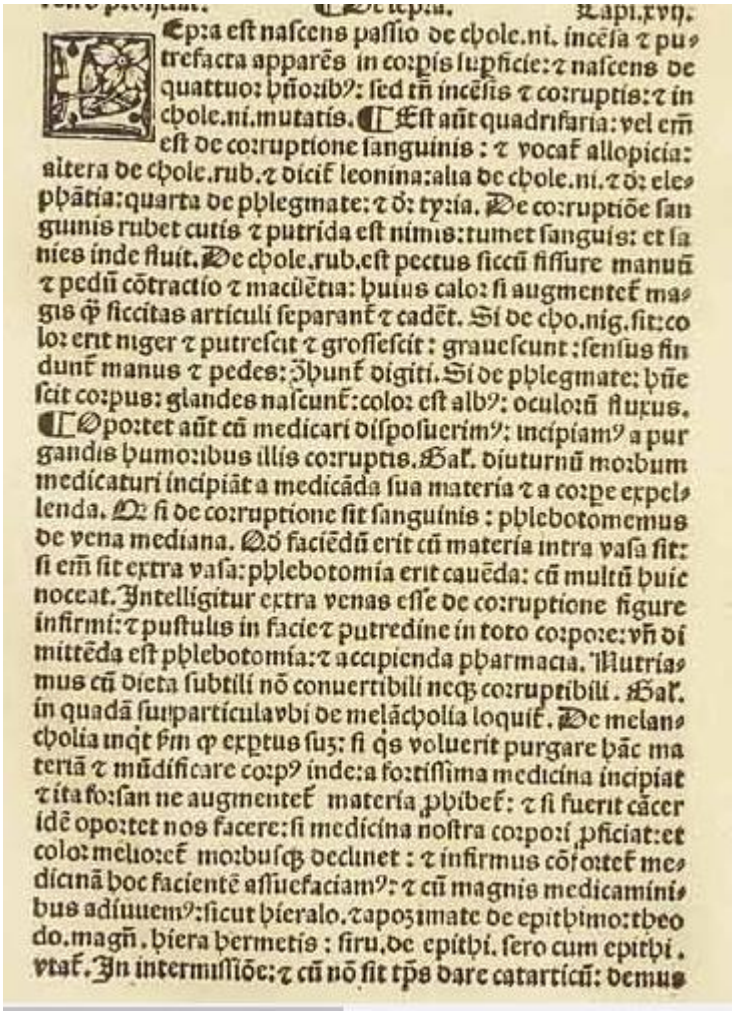
Zhao, G. Z., Venkatesh, S., Zheng, L. and Nguyen, C. V. (2024) 'Claw Hand Deformity in Leprosy', *The American Journal of Medicine,* 137(2), pp. 110-112.

Zijlstra, E. E., Van De Sande, W. W., Welsh, O., Goodfellow, M. and Fahal, A. H. (2016) 'Mycetoma: a unique neglected tropical disease', *The Lancet Infectious Diseases,* 16(1), pp. 100-112.

Zuckerman, M. K., Harper, K. N. and Armelagos, G. J. (2016) 'Adapt or die: Three case studies in which the failure to adopt advances from other fields has compromised paleopathology', *International Journal of Osteoarchaeology,* 26(3), pp. 375-383.

Appendix A: Latin Transcriptions

Transcription of Sections on leprosy from the Viaticum



Lepra est nascens passio de cholera nigreo incensa et putrefacta apparens in corporis superficie: et nascens de quattuor humoribus sed tamen incencis et corruptis: et in choler nigreo mutatis. Cap. est autem quadrifaria: vel eum est de corruptione sanguinis: et vocatur allopicia: altera de choler rubet. Et dicitur leonine: altera de cholera nigreo. Et dicitur elephantia: quarta de phlegmate: et dicitur tyria. De corruption sanguinis rubet cutis et putrida est nimis: tumet sanguis: et sanies inde

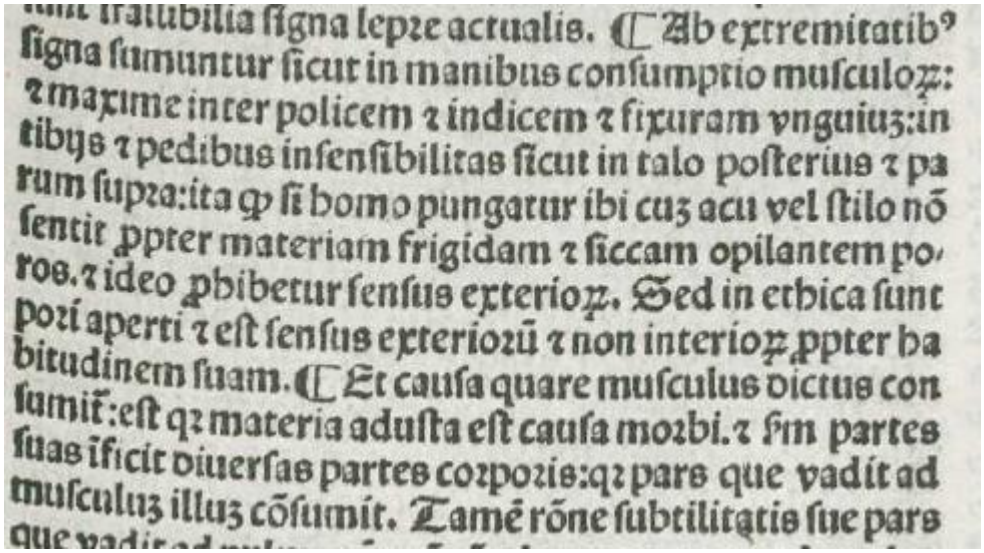
fluit. De choler rube test pectus siccum fissure manus et pedus contraction et macilentia: huius calor si augmentetur magis primam siccitas articuli separantur et cadent. Si de choler nigreos sit color erit niger et putrescit et grossescit gravescunt: Sensus finduntur manus et pedes; [sbunt] contrabuntur(?) digitiae. Si de phlegmate humescit corpus: glandes nascuntur: color est album: oculorti fluxus.

Cap. Oportet autem cum medicari disposuerimus incipiamus a purgandis humoribus illis corruptis. Salutem diuturnum morbum medicaturi incipiant a medicanda sua materia et a corpre expellenda. Dr si de corruptione sit sanguinis, phlebotomemus de vena mediana. Quod faciendum erit cum materia intra vasa sit si eum sit extra vasa, phlebotomia erit cavenda. Cum multum huic noceat. Intelligitur extra venas esse de corruption figure infirmi et pustulis in facie et putredine in toto corpore vh di mittenda est phlebotomia, et accipienda pharmacia. Putriamus cum dieta subtili nota convertibili nequam corruptibili.

Salutem Galen? in quadam sur particularibus de melancholia loquit. De melancholia inquit habum quam expectus suestexpertus suus, si quis voluerit purgare habeathanc materiam et mundisicare corpus inde, a fortissimo medicina incipiat et ita forsan ne augmentetur materia prohibitor, et si fuerit cancer idem oportet nos facere, si medicina nostra corpori proficiat, et color melioretur morbus quam declinet, et infirmus comfortetur medicinam hoc facientem assuesaciamus, et cum magnis medicaminibus adiuumus, ficit hieralo. Et apo estimate de epithimo theo dominium magni. Hiera hermetis. Sirum de epithi. Sero cum epithi vtater. In intermissione, et sum nota sit tempus dare catarticum, demus tyriacam magnam factam cum pinguedine et carne tyri. Salutem nunquam inquit, vidi in vita mea hoiem hac infirmitate plenarie liberatum mfi quia biberit vinum in quo tyrus ceciderit, et ibi corpuererit, hunc enim vidi excoriari, et cute expoliari cum vinum illud ebiberit, vnde certificam cum testimonio visuali quod dixerunt antique de carne tyri, vel de pinguedine et sui innamenti magnitundine in hac et in oi dura passione. Cum purgato autem corpore supradicto medicamine, demum selithe tyriacam et similia corpus custodientia, putredinem mundisicantia, precipiater ut balneetur, sed non tamen aquis dulcibus. Iterum iuuat incensio et diete obseruatio, et cibi paruitas. Interrogatur autem. Salutem que medicina summa habeatur inquit abstinentia.

Passages from Rosa Anglica

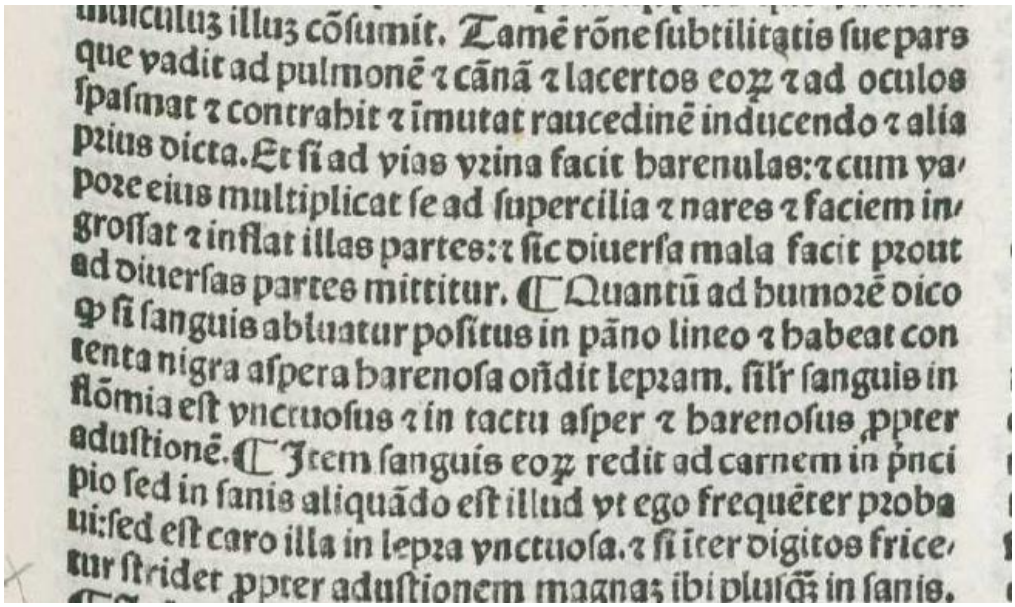
Section 1



Cap. ab extremitatibus signa sumuntur sicut in manibus consumption musculorum. Et maxime inter policem et indicem et fixuram vnguiuz [sanguis]?: in tibys et pedibus insensibilitas sicut in talo posterious et parum supra, ita quod si homo pungatur ibi cus acu vel stilo non sentit propter materiam frigidam et siccam opilatem poros et ideo prohibitur sensus exteriorum. Sed in ethica sunt pori aperti et est sensus exteriorum et non interiorum propter habitudinem suam.

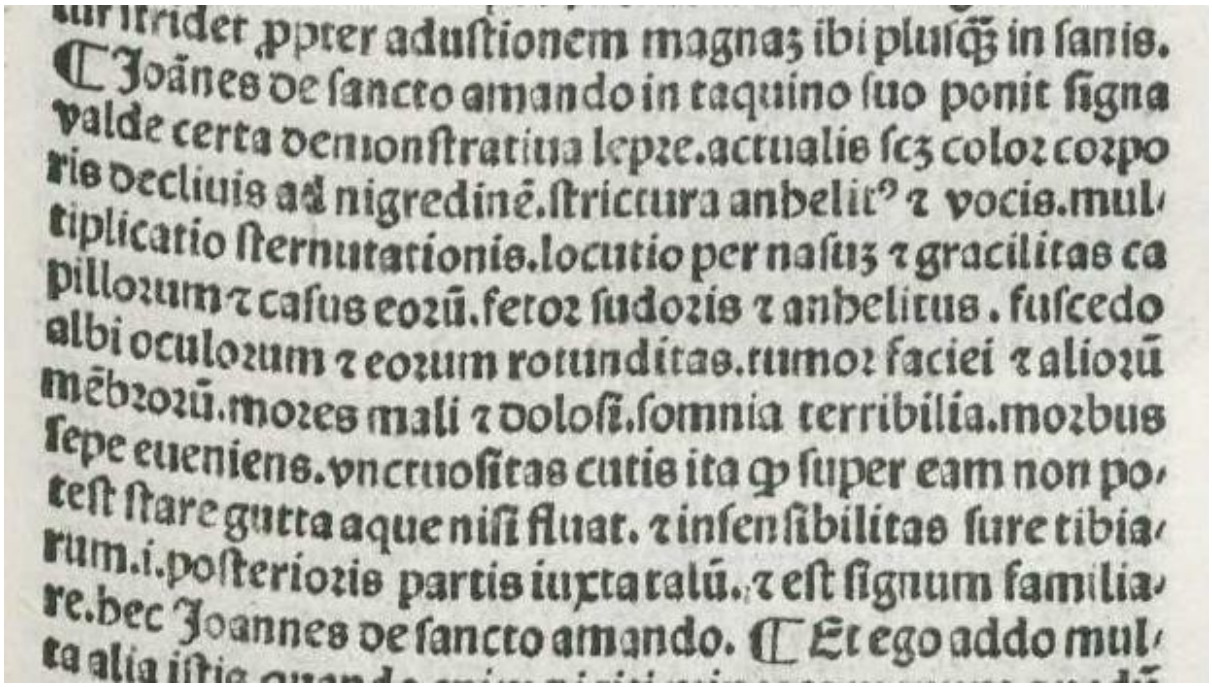
Cum et causa quare musculus dictus con sumitur, est quia materia adusta est causa morbi, et signam partes suas ificit diversas partes corporis, quia pars que vadit ad musculus illus consumit.

Section 2


musculuz illuz cõsumit. Tamẽ rõne subtilitatis sue pars
que vadit ad pulmonẽ ⁊ cãnã ⁊ lacertos eoꝝ ⁊ ad oculos
spasmat ⁊ contrahit ⁊ imutat raucedinẽ inducendo ⁊ alia
prius dicta. Et si ad vias vrina facit barenulas: ⁊ cum va-
pore eius multiplicat se ad supercilia ⁊ nares ⁊ faciem in-
grossat ⁊ inflat illas partes: ⁊ sic diuersa mala facit prout
ad diuersas partes mittitur. ℂ Quantũ ad humorẽ dico
ꝙ si sanguis abluatur positus in pãno lineo ⁊ habeat con
tenta nigra aspera barenosa oñdit lepram. silr sanguis in
flõmia est vncruosus ⁊ in tactu asper ⁊ barenosus ꝓpter
adustionẽ. ℂ Item sanguis eoꝝ redit ad carnem in ꝓnci
pio sed in sanis aliquãdo est illud vt ego frequẽter proba
ui: sed est caro illa in lepra vnctuosa. ⁊ si iter digitos frice-
tur strider ꝓpter adustionem magnaz ibi pluraq̃ in sanis.

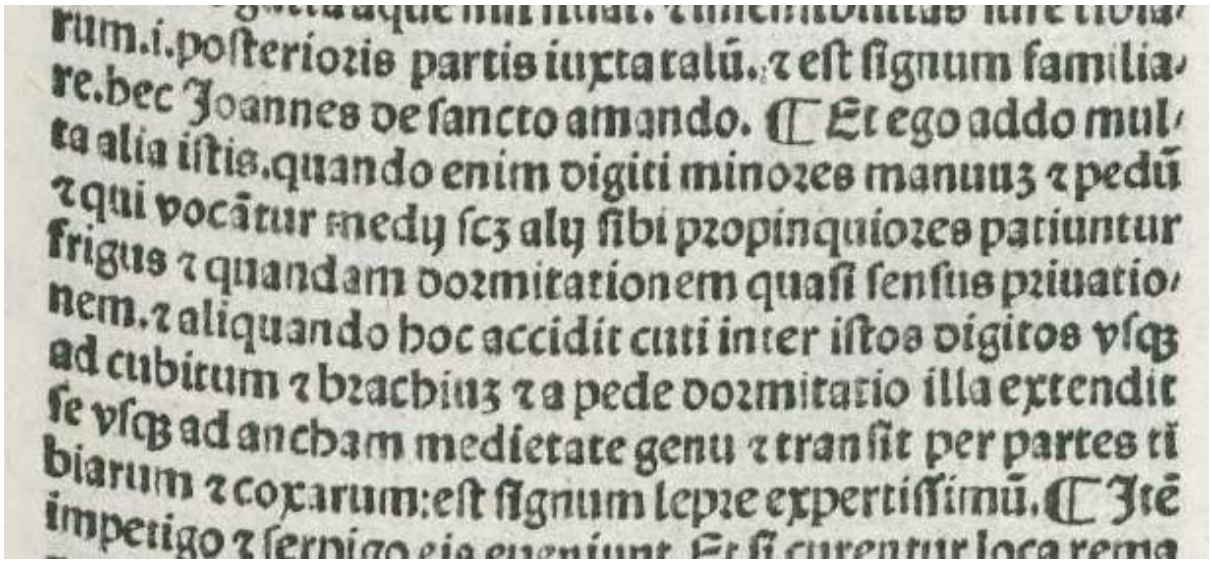
Came ronne subtilitatis sue pars que vadit ad pulmonem et canan et lacertos eorum et ad oculos spasmat et contrabit et imutat raucedinem inducendo et alia prius dicta. Et si ad vias vrina facit harenulas: et cum vapore eius multiplicat se ad supercilia et nares et faciem ingrossat et inflat illas partes: et sic diverta mala facit prout ad divertas partes mittitur. Cap Quantam ad humorem dico quia si sanguis abluatur positus in panno lineo et habeat contenta nigra aspera harenosa onemdit lepram. Silr sanguis in flonmia est uncruousus et in tactu asper et harenosus propter adustionem. Cap item sanguis eorum redit ad carnem in principio sed in sanis aliquando est illus ut efo frequenter probui: sed est caro illa in lepra unctuosa. Et si iter digitos fricetur strider propter adustionem magnam ini pluraguam in sanis.

Section 3


ſur ſtridet ꝓpter aduſtionem magnaz ibi pluſq̄z in ſanis.
¶ Joãnes de ſancto amando in taquino ſuo ponit ſigna
valde certa demonſtratiua lepre.actualis ſcz colorcorpo
ris decliuis ad nigredinẽ.ſtrictura anbelitꝰ ⁊ vocis.mul/
tiplicatio ſternutationis.locutio per naſuz ⁊ gracilitas ca
pillorum ⁊ caſus eorũ.fetor ſudoris ⁊ anbelitus. fuſcedo
albi oculorum ⁊ eorum rotunditas.rumor faciei ⁊ aliorũ
mẽbrorũ.mores mali ⁊ doloſi.ſomnia terribilia.morbus
ſepe eueniens.vnctuoſitas cutis ita ꝙ ſuper eam non po/
teſt ſtare gutta aque niſi fluat. ⁊ inſenſibilitas ſure tibia/
rum.i.poſterioris partis iuxta talũ. ⁊ eſt ſignum familia/
re.hec Joannes de ſancto amando. ¶ Et ego addo mul/
ta alia iſtis.quando enim digiti minores manuuz ⁊ pedũ
⁊ qui vocãtur medy ſcz aly ſibi propinquiores patiuntur
frigus ⁊ quandam dormitationem quaſi ſenſus priuatio/
nem. ⁊ aliquando hoc accidit cuti inter iſtos digitos vſq̄z
ad cubitum ⁊ brachiuz ⁊ a pede dormitatio illa extendit
ſe vſq̄z ad anchas medietate genu ⁊ tranſit per partes ti
biarum ⁊ coxarum:eſt ſignum lepre expertiſſimũ. ¶ Itẽ
impetigo ⁊ ſerpigo eis eueniunt. Et ſi curentur loca rema

Cap. Joannes de sancto amando in taquino suo ponit signa valde certa demonstrativa lepre actualis ic3 color corporis decliuis ad nigredinem. Strictura anbeliterum et vocis multiplicicatio sternutationis. Locutio per nasurum et gracilitas capillorum et casus eorum sudoris et anbelitus. Fuscedo albi oculorum et eorum rotunditas. Tumor faciei et aliorum membrorum. Mores mali et dolosi somnia terribilia. Morbus sepe eveniens. Unctuositas cutis ita quia super eam non potest stare gutta aque nisi fluat. et insensibilitas sure tibiarum i posterioris partis iuxtatlum. Et est signum familiare hec Joannas de sancto amando.

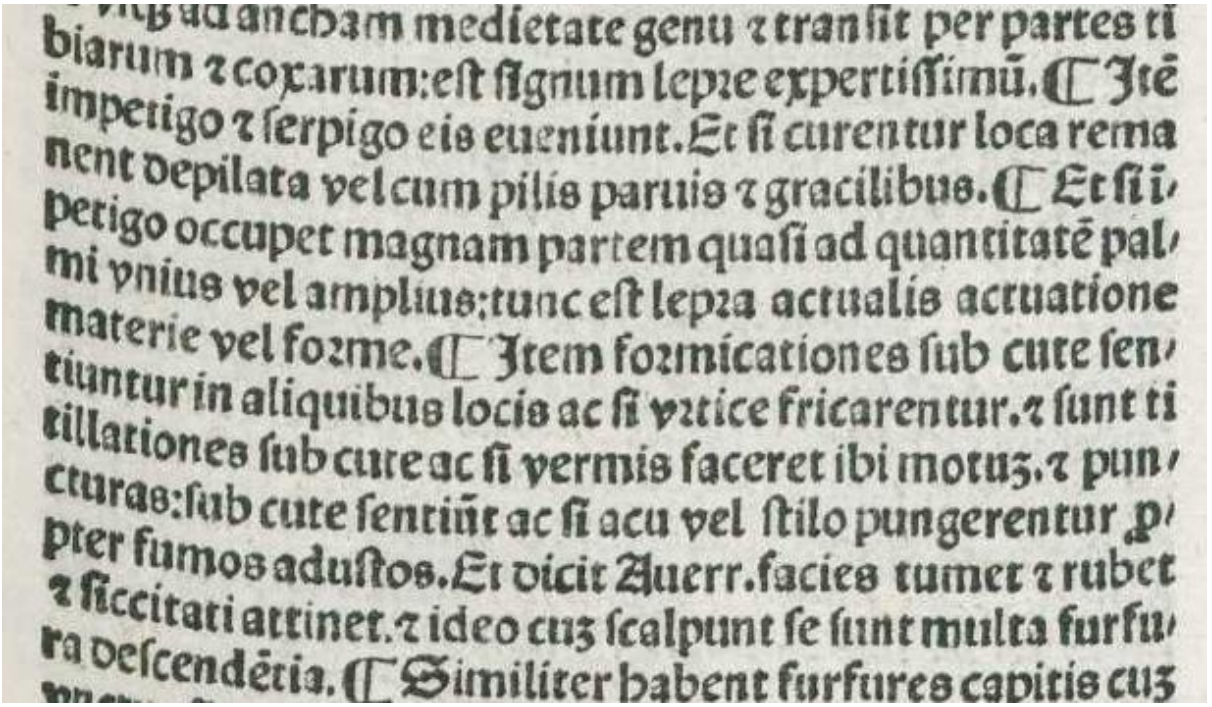
Section 4


rum.i.poſterioris partis iuxta talũ. ⁊ eſt ſignum familia/
re.hec Joannes de ſancto amando. ¶ Et ego addo mul/
ta alia iſtis.quando enim digiti minores manuuz ⁊ pedũ
⁊ qui vocãtur medy ſcz aly ſibi propinquiores patiuntur
frigus ⁊ quandam dormitationem quaſi ſenſus priuatio/
nem. ⁊ aliquando hoc accidit cuti inter iſtos digitos vſq̄z
ad cubitum ⁊ brachiuz ⁊ a pede dormitatio illa extendit
ſe vſq̄z ad anchas medietate genu ⁊ tranſit per partes ti
biarum ⁊ coxarum:eſt ſignum lepre expertiſſimũ. ¶ Itẽ
impetigo ⁊ ſerpigo eis eueniunt. Et ſi curentur loca rema

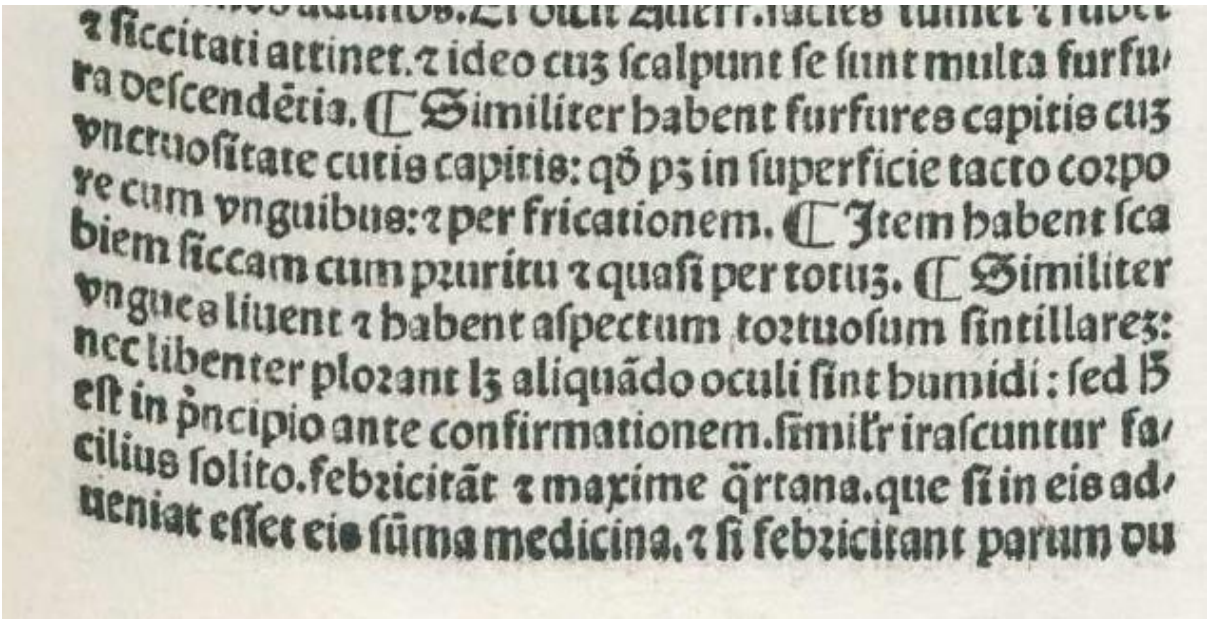
Cap Et ego addo multa alia istis. Quando enim digiti minores manuu3 et pedum et qui vocantur medorum ficam sibi propinquiores patiuntur frigus et quandam dormitationem quasi sensus privationem. Et aliquando hoc accidit cuti inter istos digitos visiquam? Ad cubitum et hrachiuem et

a pede dormitation illa extendit se visiquam ad ancham mediete genu et transit per partes tibiarum et coxarum: est signum lepre expertissimum.

Section 5



Cap. Item impetigo et serpigo eis eveniunt. Et si curentur loca remanent depilata velcum pilis paruis et gracilibus. Cap et si impetigo occupet magnam partem quasi ad quantitate palmi unius vel amplius: tunc est lerpa actualis actuatione materie vel forme. Cap Item formicationes sub cute sentiuntur in aliquibus locis ac si vrtice fricarentur. Et sunt ti tillationes sub cure ac si vernis faceret ibi moturum. Et puncturas: sub cute sentient ac si acu vel stilo pungerentur propter sumos adustos. Et dicit Averr. Facies tumet et rubet et siccitati attinet. Et ideo cuam scalpunt se sunt multa surfura descendentia.



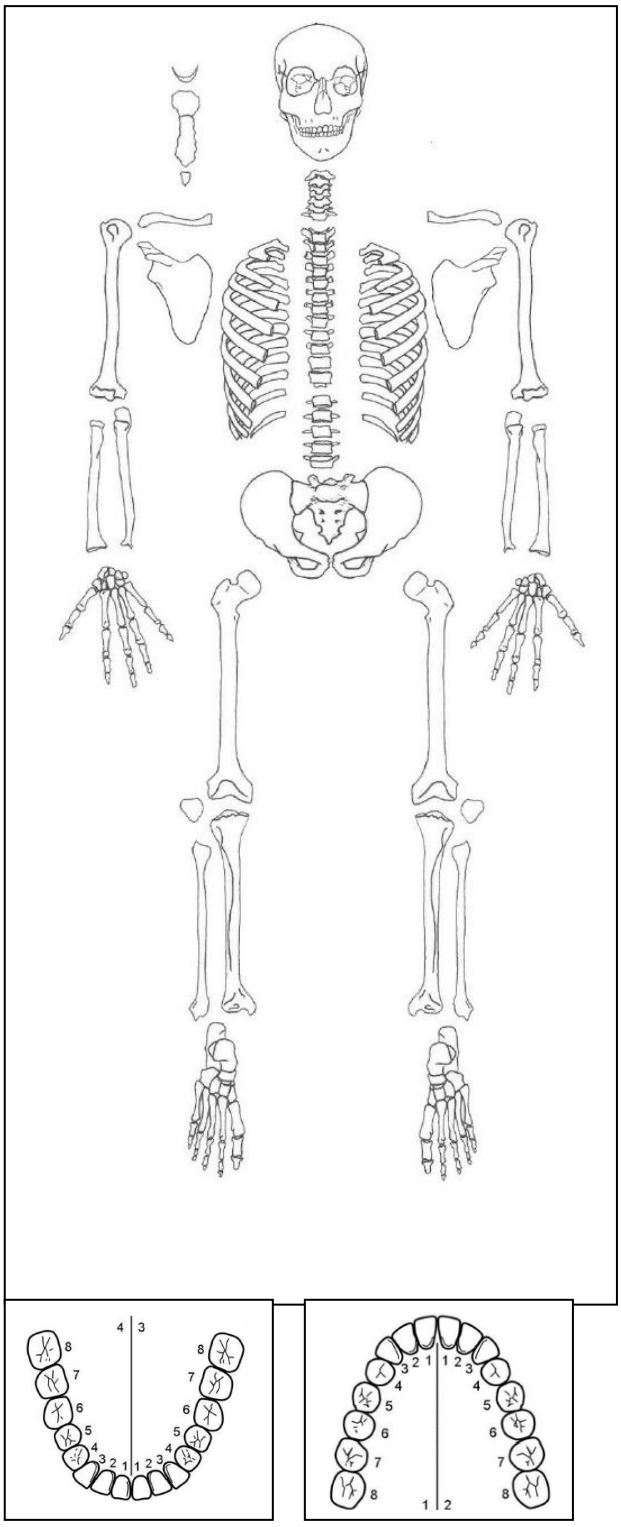
Cap. Similiter habent surfures capitis cuam unctuositate cutis capitis: quod patet in superficie tacto corpore sum unguibus: et per fricationem. Cap. Item habent scabiem siccam cum pruritu et quasi per totum. Cap. Similiter ungues liuent et habent aspectum toruosum sintillare3: nec libentuer plorant liam aliquando oculi sint humidi: sed Iicet est in principio ante confirmationem. Similitur irascuntur facilius solito. Febricitant et maxime quortana. Que si in eis adveniat effet eis sunma medicina. Et si febricitant parum durant eorum febres.

Appendix B: Recording Form Used in Research

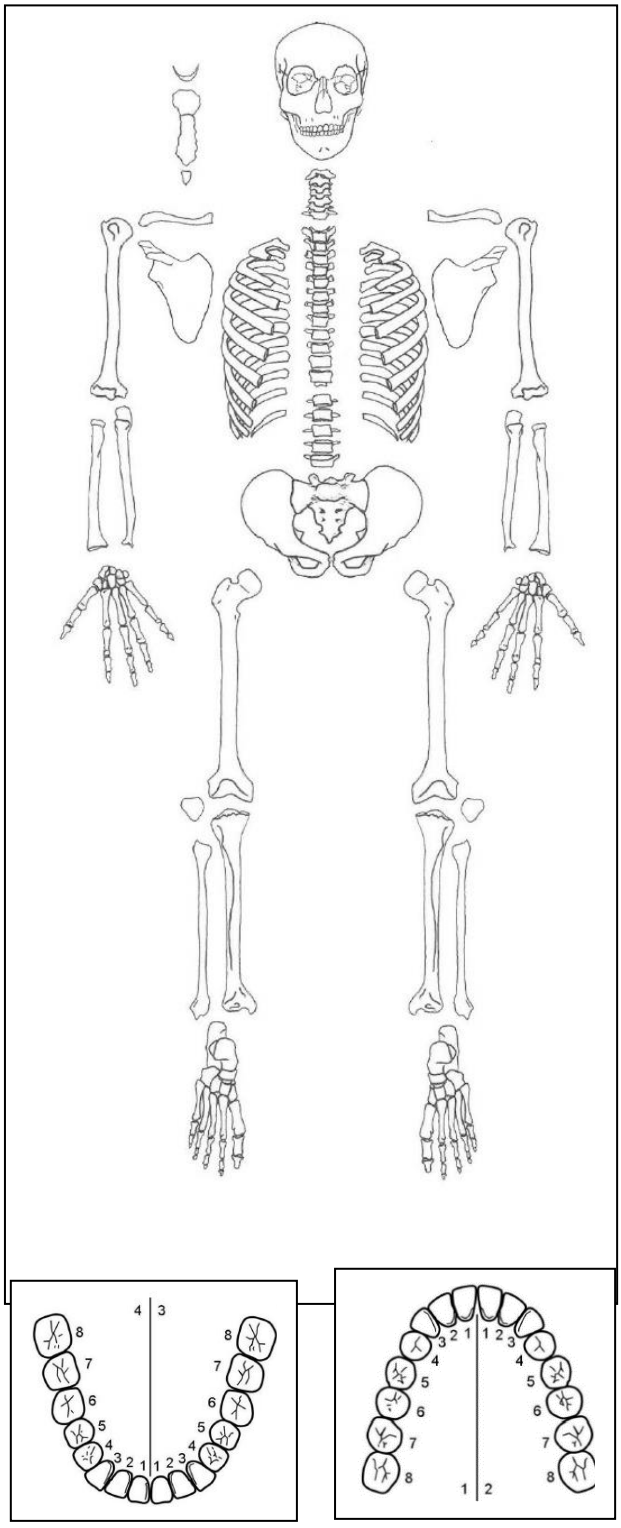
Leprosy Recording Form for Skeletons

Site: St Mary Magdalen, Winchester	**Individual:**
Age:	**Sex:**

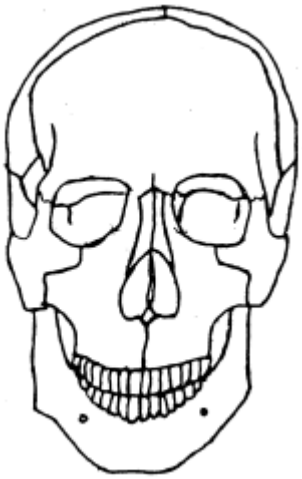
Preservation



Pathology



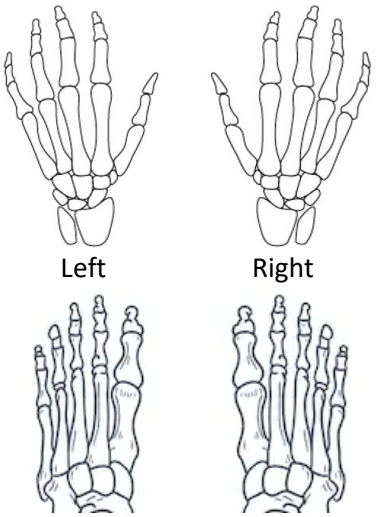
Lesions



Lesion will be scored as 0 = Not Present, 1 = Present. Side will be noted if lesions are unilateral (L = left, R = right). PNBF = Periosteal new bone formation, and will be noted as either active (A), or healed (H).

Lesion	**Score**	📷
RMS - Rounding and absorption of nasal aperture		
RMS - Absorption of anterior nasal spine		
RMS – Diffuse pitting of palatine process (oral)		
RMS – Diffuse pitting of palatine process (nasal)		
RMS - Absorption of anterior maxillary alveolus		
Additional - Primary granuloma – Nasal/Oral?		

Other leprosy Lesions

Lesion	**Score**	📷	**Notes**
Palmar grooving of distal proximal phalanx			
Arthropathy (Note location and describe) *Lytic*			
Blastic			
Location:			
Acroosteolysis			
Absorption of Phalanges Hand			 Left Right
Foot			
Concentric remodelling Hand			
Foot			
Knife-edge remodelling Metacarpal			
Metatarsal			
^^^Radiographs Available? (Y/N)			
Leprogenic Odontodysplasia			
Ulnar nerve hypertrophy: Lesion on posterior medial epicondyle of humerus			
Lesion on proximal antero-medial ulna			
PNBF around nutrient foramina			
Enlargement of nutrient foramina			
PNBF on distal tibia (note any additional ossification)			
PNBF on distal fibula (note any additional ossification)			
Dorsal tarsal exostoses			
Navicular squeezing			
Carpal and tarsal disintegration (describe below)			
Ossification of intraosseous membrane			

Dactylitis			

Non-specific Lesions

Maxillary Sinusitis			
Osteomyelitis			
Osteitis (xray may indicate osteomyelitis)			
Bone Cyst (note location and describe below)			
Other PNBF (note location and describe below)			
Osteoporosis/Osteopenia [Radiographs available? Y/N] – Make note of this for non-adult individuals			
Fracture/subluxation/dislocation			

Other: (Please note any other lesions not above, and any additional comments about individual.)

Appendix C: Postcranial Lesion Phi-coefficient Values When Compared to Each Other

Coefficients

		PALM GROOVE	ARTHL	ARTHB	ACROO	ABPHALH	ABPHALF	CREMODH	CREMODF	KNEDGEH	KNEDGEF	LEPODONT	PMEDHUM	PROXMEDULN	PNBFNF	ENF	PNBFDISTT	PNBFDISTF
PALMGROOVE	Phi coefficient	1	.231**	.143*	.212**	.284**	.142*	-.020	.163*	.[c]	.160*	-.014	-.026	.139*	.055	.044	.229**	.259**
	Sig. (2-tailed)		<.001	.034	.004	<.001	.047	.767	.019	.	.022	.853	.709	.048	.423	.516	.001	<.001
	N	218	217	218	181	213	196	214	205	215	205	180	204	203	218	218	201	202
ARTHL	Phi coefficient	.231**	1	.443**	.268**	.255**	.369**	.235**	.372**	.[c]	.207**	-.035	.016	.151*	.135*	.105	.270**	.252**
	Sig. (2-tailed)	<.001		<.001	<.001	<.001	<.001	<.001	<.001	.	.002	.629	.818	.027	.037	.106	<.001	<.001
	N	217	240	240	186	219	208	220	217	223	217	189	216	215	239	239	216	218
ARTHB	Phi coefficient	.143*	.443**	1	.250**	.193**	.306**	.164*	.273**	.[c]	.163*	-.049	.198**	.136*	.143*	.064	.072	.021
	Sig. (2-tailed)	.034	<.001		<.001	.004	<.001	.015	<.001	.	.016	.502	.003	.046	.027	.321	.292	.763
	N	218	240	241	187	220	208	221	217	224	217	189	216	216	240	240	216	218
ACROO	Phi coefficient	.212**	.268**	.250**	1	.243**	.390**	.086	.228**	.[c]	.032	-.046	-.063	.333**	.158*	.073	.303**	.255**
	Sig. (2-tailed)	.004	<.001	<.001		<.001	<.001	.249	.002	.	.672	.567	.407	<.001	.030	.324	<.001	<.001
	N	181	186	187	188	184	174	183	179	186	178	157	176	176	187	187	174	177
ABPHALH	Phi coefficient	.284**	.255**	.193**	.243**	1	.368**	.297**	.372**	.[c]	.264**	-.017	-.029	.116	.147*	-.030	.209**	.245**

	Sig. (2-tailed)	<.001	<.001	.004	<.001		<.001	<.001	<.001	.	<.001	.820	.680	.097	.029	.658	.003	<.001
	N	213	219	220	184	222	202	220	207	221	207	182	205	206	221	221	203	205
ABPHALF	Phi coefficient	.142*	.369**	.306**	.390**	.368**	1	.153*	.493**	.c	.323**	-.029	.075	.170*	.167*	.004	.252**	.234**
	Sig. (2-tailed)	.047	<.001	<.001	<.001	<.001		.030	<.001	.	<.001	.706	.303	.020	.016	.955	<.001	<.001
	N	196	208	208	174	202	209	201	207	203	206	167	189	189	208	208	197	200
CREMODH	Phi coefficient	-.020	.235**	.164*	.086	.297**	.153*	1	.215**	.c	-.028	-.010	-.015	-.030	.178**	-.048	.048	.028
	Sig. (2-tailed)	.767	<.001	.015	.249	<.001	.030		.002	.	.683	.898	.833	.666	.008	.476	.495	.691
	N	214	220	221	183	220	201	223	209	223	209	183	205	206	222	222	204	206
CREMODF	Phi coefficient	.163*	.372**	.273**	.228**	.372**	.493**	.215**	1	.c	.493**	-.027	-.042	.049	.150*	.143*	.203**	.128
	Sig. (2-tailed)	.019	<.001	<.001	.002	<.001	<.001	.002		.	<.001	.727	.559	.494	.027	.035	.003	.065
	N	205	217	217	179	207	207	209	217	212	216	174	196	196	217	217	206	208
KNEDGEH	Phi coefficient	.c	.c	.c	.c	.c	.c	.c	.c	.c	.c	.c	.c	.c	.c	.c	.c	.c
	Sig. (2-tailed)	.	.	.	.	.	.	.	.		.	.	.	.	.	.	.	.
	N	215	223	224	186	221	203	223	212	226	212	184	207	208	225	225	207	209
KNEDGEF	Phi coefficient	.160*	.207**	.163*	.032	.264**	.323**	-.028	.493**	.c	1	-.017	-.027	-.056	.195**	.184**	.182**	.216**
	Sig. (2-	.022	.002	.016	.672	<.001	<.001	.683	<.001	.		.827	.704	.435	.004	.007	.009	.002

	tailed)																	
	N	205	217	217	178	207	206	209	216	212	217	174	196	196	217	217	205	207
LEPODONT	Phi coefficient	-.014	-.035	-.049	-.046	-.017	-.029	-.010	-.027	.[c]	-.017	1	-.008	-.019	-.030	-.030	.079	.092
	Sig. (2-tailed)	.853	.629	.502	.567	.820	.706	.898	.727	.	.827		.916	.799	.683	.683	.299	.227
	N	180	189	189	157	182	167	183	174	184	174	189	179	180	188	188	173	175
PMEDHUM	Phi coefficient	-.026	.016	.198**	-.063	-.029	.075	-.015	-.042	.[c]	-.027	-.008	1	.382**	.052	-.057	-.035	-.103
	Sig. (2-tailed)	.709	.818	.003	.407	.680	.303	.833	.559	.	.704	.916		<.001	.442	.405	.630	.148
	N	204	216	216	176	205	189	205	196	207	196	179	219	212	218	218	197	198
PROXMEDULN	Phi coefficient	.139*	.151*	.136*	.333**	.116	.170*	-.030	.049	.[c]	-.056	-.019	.382**	1	.067	-.054	.196**	.153*
	Sig. (2-tailed)	.048	.027	.046	<.001	.097	.020	.666	.494	.	.435	.799	<.001		.327	.432	.006	.032
	N	203	215	216	176	206	189	206	196	208	196	180	212	217	217	217	197	198
PNBFNF	Phi coefficient	.055	.135*	.143*	.158*	.147*	.167*	.178**	.150*	.[c]	.195**	-.030	.052	.067	1	.317**	.267**	.299**
	Sig. (2-tailed)	.423	.037	.027	.030	.029	.016	.008	.027	.	.004	.683	.442	.327		<.001	<.001	<.001
	N	218	239	240	187	221	208	222	217	225	217	188	218	217	245	245	220	220
ENF	Phi coefficient	.044	.105	.064	.073	-.030	.004	-.048	.143*	.[c]	.184**	-.030	-.057	-.054	.317**	1	.084	.091
	Sig. (2-tailed)	.516	.106	.321	.324	.658	.955	.476	.035	.	.007	.683	.405	.432	<.001		.216	.180

	N	218	239	240	187	221	208	222	217	225	217	188	218	217	245	245	220	220
PNBFDISTT	Phi coefficient	.229**	.270**	.072	.303**	.209**	.252**	.048	.203**	.c	.182**	.079	-.035	.196**	.267**	.084	1	.780**
	Sig. (2-tailed)	.001	<.001	.292	<.001	.003	<.001	.495	.003	.	.009	.299	.630	.006	<.001	.216		<.001
	N	201	216	216	174	203	197	204	206	207	205	173	197	197	220	220	221	216
PNBFDISTF	Phi coefficient	.259**	.252**	.021	.255**	.245**	.234**	.028	.128	.c	.216**	.092	-.103	.153*	.299**	.091	.780**	1
	Sig. (2-tailed)	<.001	<.001	.763	<.001	<.001	<.001	.691	.065	.	.002	.227	.148	.032	<.001	.180	<.001	
	N	202	218	218	177	205	200	206	208	209	207	175	198	198	220	220	216	222
DORSTEX	Phi coefficient	.110	.271**	.287**	.205**	.190**	.225**	.229**	.168*	.c	.106	-.038	.033	.058	.145*	.112	.211**	.218**
	Sig. (2-tailed)	.122	<.001	<.001	.006	.007	.001	.001	.016	.	.132	.622	.649	.424	.036	.106	.003	.002
	N	199	210	210	177	200	198	201	205	204	204	173	192	192	211	211	203	205
NAVSQZE	Phi coefficient	.140	.174*	.043	.119	.278**	.181*	-.016	.172*	.c	.131	-.006	-.019	.105	-.058	.044	.078	.026
	Sig. (2-tailed)	.051	.013	.542	.118	<.001	.012	.829	.015	.	.065	.939	.797	.155	.413	.535	.277	.713
	N	194	203	203	175	195	192	196	200	199	199	169	186	186	204	204	198	200
CTARSDIS	Phi coefficient	.130	.296**	.181**	.131	.450**	.313**	.450**	.454**	.c	.453**	-.019	-.035	.005	.237**	.091	.244**	.251**
	Sig. (2-tailed)	.068	<.001	.008	.080	<.001	<.001	<.001	<.001	.	<.001	.805	.629	.941	<.001	.188	<.001	<.001
	N	200	211	212	179	202	198	203	205	206	204	172	194	195	213	213	206	207

OSSMEM	Phi coefficient	.139*	.287**	.186**	.349**	.184**	.386**	.083	.176*	.c	.151*	-.026	-.044	.287**	.183**	.069	.377**	.380**
	Sig. (2-tailed)	.047	<.001	.006	<.001	.008	<.001	.232	.011	.	.029	.731	.534	<.001	.006	.304	<.001	<.001
	N	206	220	220	179	208	201	210	211	213	210	178	202	202	222	222	216	217
DACT	Phi coefficient	-.025	.131	.082	.122	.333**	.108	.402**	.087	.c	-.028	-.008	-.015	.135	-.047	-.048	.047	.062
	Sig. (2-tailed)	.716	.052	.225	.099	<.001	.127	<.001	.209	.	.685	.917	.834	.051	.487	.479	.502	.372
	N	214	223	223	185	218	202	220	212	223	212	184	208	208	224	224	207	208
MAXSIN	Phi coefficient	.138	.076	.016	.140	-.044	.021	-.024	.036	.c	-.041	-.014	.c	.211**	.095	.013	.113	.136
	Sig. (2-tailed)	.063	.293	.827	.078	.554	.783	.751	.631	.	.591	.851	.	.004	.191	.857	.131	.069
	N	182	191	191	158	185	170	185	178	186	178	174	179	180	191	191	180	180
OM	Phi coefficient	.118	.182**	.153*	.065	.097	.092	.113	.116	.c	.155*	-.020	-.038	-.002	.131*	.227**	.133*	.166*
	Sig. (2-tailed)	.081	.005	.018	.379	.152	.186	.093	.088	.	.023	.787	.573	.973	.041	<.001	.049	.014
	N	218	240	241	187	221	208	222	217	225	217	189	219	217	242	242	218	220
OSTEITIS	Phi coefficient	.198**	.109	.046	.201**	.079	.134	.201**	.107	.c	.147*	-.019	-.038	.069	.282**	.060	.214**	.210**
	Sig. (2-tailed)	.003	.092	.475	.006	.244	.054	.003	.116	.	.031	.795	.573	.308	<.001	.352	.001	.002
	N	218	240	241	188	222	209	223	217	226	217	189	219	217	242	242	218	221

OPNBF	Phi coefficient	.113	.136*	.029	.140	-.035	.284**	-.059	.126	.[c]	.126	-.029	-.051	.260**	.250**	.036	.233**	.298**
	Sig. (2-tailed)	.098	.037	.651	.057	.603	<.001	.384	.065	.	.066	.689	.454	<.001	<.001	.575	<.001	<.001
	N	215	237	238	187	220	206	221	214	224	214	187	217	215	239	239	215	218

Coefficients

		DORSTEX	NAVSQZE	CTARSDIS	OSSMEM	DACT	MAXSIN	OM	OSTEITIS	OPNBF
PALMGROOVE	Phi coefficient	.110	.140	.130	.139*	-.025	.138	.118	.198**	.113
	Sig. (2-tailed)	.122	.051	.068	.047	.716	.063	.081	.003	.098
	N	199	194	200	206	214	182	218	218	215
ARTHL	Phi coefficient	.271**	.174*	.296**	.287**	.131	.076	.182**	.109	.136*
	Sig. (2-tailed)	<.001	.013	<.001	<.001	.052	.293	.005	.092	.037
	N	210	203	211	220	223	191	240	240	237
ARTHB	Phi coefficient	.287**	.043	.181**	.186**	.082	.016	.153*	.046	.029
	Sig. (2-tailed)	<.001	.542	.008	.006	.225	.827	.018	.475	.651
	N	210	203	212	220	223	191	241	241	238
ACROO	Phi coefficient	.205**	.119	.131	.349**	.122	.140	.065	.201**	.140
	Sig. (2-tailed)	.006	.118	.080	<.001	.099	.078	.379	.006	.057
	N	177	175	179	179	185	158	187	188	187
ABPHALH	Phi coefficient	.190**	.278**	.450**	.184**	.333**	-.044	.097	.079	-.035
	Sig. (2-tailed)	.007	<.001	<.001	.008	<.001	.554	.152	.244	.603
	N	200	195	202	208	218	185	221	222	220
ABPHALF	Phi coefficient	.225**	.181*	.313**	.386**	.108	.021	.092	.134	.284**
	Sig. (2-tailed)	.001	.012	<.001	<.001	.127	.783	.186	.054	<.001
	N	198	192	198	201	202	170	208	209	206
CREMODH	Phi coefficient	.229**	-.016	.450**	.083	.402**	-.024	.113	.201**	-.059
	Sig. (2-tailed)	.001	.829	<.001	.232	<.001	.751	.093	.003	.384

	N	201	196	203	210	220	185	222	223	221
CREMODF	Phi coefficient	.168*	.172*	.454**	.176*	.087	.036	.116	.107	.126
	Sig. (2-tailed)	.016	.015	<.001	.011	.209	.631	.088	.116	.065
	N	205	200	205	211	212	178	217	217	214
KNEDGEH	Phi coefficient	.c	.c	.c	.c	.c	.c	.c	.c	.c
	Sig. (2-tailed)	.	.	.	.	.	.	.	.	.
	N	204	199	206	213	223	186	225	226	224
KNEDGEF	Phi coefficient	.106	.131	.453**	.151*	-.028	-.041	.155*	.147*	.126
	Sig. (2-tailed)	.132	.065	<.001	.029	.685	.591	.023	.031	.066
	N	204	199	204	210	212	178	217	217	214
LEPODONT	Phi coefficient	-.038	-.006	-.019	-.026	-.008	-.014	-.020	-.019	-.029
	Sig. (2-tailed)	.622	.939	.805	.731	.917	.851	.787	.795	.689
	N	173	169	172	178	184	174	189	189	187
PMEDHUM	Phi coefficient	.033	-.019	-.035	-.044	-.015	.c	-.038	-.038	-.051
	Sig. (2-tailed)	.649	.797	.629	.534	.834	.	.573	.573	.454
	N	192	186	194	202	208	179	219	219	217
PROXMEDULN	Phi coefficient	.058	.105	.005	.287**	.135	.211**	-.002	.069	.260**
	Sig. (2-tailed)	.424	.155	.941	<.001	.051	.004	.973	.308	<.001
	N	192	186	195	202	208	180	217	217	215
PNBFNF	Phi coefficient	.145*	-.058	.237**	.183**	-.047	.095	.131*	.282**	.250**
	Sig. (2-tailed)	.036	.413	<.001	.006	.487	.191	.041	<.001	<.001
	N	211	204	213	222	224	191	242	242	239
ENF	Phi coefficient	.112	.044	.091	.069	-.048	.013	.227**	.060	.036
	Sig. (2-tailed)	.106	.535	.188	.304	.479	.857	<.001	.352	.575
	N	211	204	213	222	224	191	242	242	239
PNBFDISTT	Phi coefficient	.211**	.078	.244**	.377**	.047	.113	.133*	.214**	.233**
	Sig. (2-tailed)	.003	.277	<.001	<.001	.502	.131	.049	.001	<.001
	N	203	198	206	216	207	180	218	218	215

PNBFDISTF	Phi coefficient	.218**	.026	.251**	.380**	.062	.136	.166*	.210**	.298**
	Sig. (2-tailed)	.002	.713	<.001	<.001	.372	.069	.014	.002	<.001
	N	205	200	207	217	208	180	220	221	218
DORSTEX	Phi coefficient	1	.258**	.356**	.219**	.129	-.005	-.028	.100	.045
	Sig. (2-tailed)		<.001	<.001	.002	.065	.950	.686	.148	.517
	N	211	203	208	208	205	175	210	210	207
NAVSQZE	Phi coefficient	.258**	1	.353**	.167*	.276**	-.023	-.041	.095	-.065
	Sig. (2-tailed)	<.001		<.001	.017	<.001	.763	.557	.176	.363
	N	203	204	202	202	200	171	203	203	200
CTARSDIS	Phi coefficient	.356**	.353**	1	.313**	.278**	-.051	.179**	.113	.107
	Sig. (2-tailed)	<.001	<.001		<.001	<.001	.506	.009	.099	.120
	N	208	202	213	211	206	175	213	213	210
OSSMEM	Phi coefficient	.219**	.167*	.313**	1	.080	.144	.240**	.264**	.192**
	Sig. (2-tailed)	.002	.017	<.001		.244	.053	<.001	<.001	.004
	N	208	202	211	222	213	182	222	222	219
DACT	Phi coefficient	.129	.276**	.278**	.080	1	-.023	.260**	-.034	-.051
	Sig. (2-tailed)	.065	<.001	<.001	.244		.751	<.001	.608	.453
	N	205	200	206	213	224	186	224	224	222
MAXSIN	Phi coefficient	-.005	-.023	-.051	.144	-.023	1	.065	.071	.010
	Sig. (2-tailed)	.950	.763	.506	.053	.751		.372	.330	.888
	N	175	171	175	182	186	194	192	192	191
OM	Phi coefficient	-.028	-.041	.179**	.240**	.260**	.065	1	.095	.068
	Sig. (2-tailed)	.686	.557	.009	<.001	<.001	.372		.140	.292
	N	210	203	213	222	224	192	245	245	242
OSTEITIS	Phi coefficient	.100	.095	.113	.264**	-.034	.071	.095	1	.110
	Sig. (2-tailed)	.148	.176	.099	<.001	.608	.330	.140		.088
	N	210	203	213	222	224	192	245	246	243

OPNBF	Phi coefficient	.045	-.065	.107	.192**	-.051	.010	.068	.110	1
	Sig. (2-tailed)	.517	.363	.120	.004	.453	.888	.292	.088	
	N	207	200	210	219	222	191	242	243	243

**. Coefficient is significant at the 0.01 level (2-tailed).

*. Coefficient is significant at the 0.05 level (2-tailed).

c. Cannot be computed because at least one of the variables is constant.

Appendix D: Summary of Papers Assessed in Chapter 6

Site Name(s)	Location	Dating	Diagnosis given in paper	Lepro-C Category given after reassessment	Description of Pathology	Published where?	Photos Available?	Reference
St Eustatius	Netherlands Antilles	1866-1923	Skeleton 2 – 'showed changes that are characteristic of leprosy' Skeletons 4 and 5 - 'the changes to the rhinomaxillary area in skeleton 5, combined with the bilaterally symmetrical postcranial bone changes found in both skeletons 4 and 5 are strongly suggestive of the presence of multi-bacillary leprosy'	Skeleton 2 – possibly *highly consistent*, but limited descriptive detail provided for pathology. Needs reassessment. Skeleton 4 – possibly *consistent*, but limited descriptive detail provided for pathology. Needs reassessment. Skeleton 5 – *highly consistent*, but might be *diagnostic* if reassessed to check for nasal pitting, and to confirm RMS as no images are provided	Skeleton 2 - 90% complete, 'probable female' and '20-25' years old. 'Slight remodelling of the nasal aperture and porosity on the interior surface of the nasal aperture'. Palatine process and anterior nasal spine lost post mortem. Palmar grooving of PIP on the 'right hand', concentric remodelling and distal absorption of phalanges and metacarpals (it is not made clear whether all of these bones are affected), healed PNBF on the 'visceral surface of the ribs'. Striated, porous and nodular PNBF (active and healed) on distal surfaces of the tibiae and fibulae, most pronounced on the interosseous border. Knife-edge remodelling of the 'metatarsal diaphyses'. No photos are provided of the lesions for skeleton 2 Skeleton 4 - 80% complete individual (facial bones, lost or damaged post-mortem), indeterminate sex, aged '40-50' years. Post-mortem damage prevented the assessment of cranial lesions. Palmar grooving in PIP joint(s) of the 'right hand', concentric remodelling and distal absorption of phalanges and metacarpals, with ankylosis of right 5 intermediate and distal phalanges. 'Coarse porosity' on left humerus between trochlea and medial epicondyle, and 7.2mm depression in the semilunar notch of the left ulna. Mix of healed and active PNBF that was striated, porous and nodular on the distal surfaces of the tibiae and fibulae, most pronounced on the	International Journal of Osteoarchaeology	Y – but not all pathology	Gilmore (2008)

Site Name(s)	Location	Dating	Diagnosis given in paper	Lepro-C Category given after reassessment	Description of Pathology	Published where?	Photos Available?	Reference
					interosseous border. 'Cyst-like depressions', 'extensive bone destruction' and 'remodelling' of 'feet of Skeleton 4', 'most of the surfaces of the tarsals in particular strongly deformed', with 'changes so severe that the orientation and architecture of the tarsal joints had altered'. It is not disclosed which tarsal bones in particular had been affected, or how precisely the bones were deformed. Knife-edge remodelling of the 'metatarsal diaphyses', with the distal right 5th metatarsal completely absorbed. A photo of the tibial and fibular lesions is provided by Gilmore (2008: 77) for Skeleton 4. Skeleton 5 - 95% complete, indeterminate sex, aged '40-50'. Rounding of nasal aperture, 'some' absorption			

Site Name(s)	Location	Dating	Diagnosis given in paper	Lepro-C Category given after reassessment	Description of Pathology	Published where?	Photos Available?	Reference
					of the anterior maxillary alveolus, 'some' possible absorption of the anterior nasal spine. Inflammatory pitting of oral surface of the maxilla, centred around the midline. Pitting on the left mandibular notch, and left inferior nasal concha. 'Medium coarse' pitting on posterior hyoid body and 3-6 cervical vertebra bodies. Palmar grooving of PIP joint(s) in 'both hands' (Gilmore, 2008: 76). Intermediate and distal phalanges of 'both hands' had 'very narrow shafts' and 'osteophytes' around the joint surfaces. Concentric remodelling and distal absorption of the phalanges and metacarpals, with 90° fusion of left 4th PIP joint. Smooth walled depression (1.5 mm diameter) in radial notch of the right ulna, and 1mm porosity over half of the joint surface on the			

Site Name(s)	Location	Dating	Diagnosis given in paper	Lepro-C Category given after reassessment	Description of Pathology	Published where?	Photos Available?	Reference
					head of the right radius. Left ulna had 'similar changes beneath the radial notch', but they were 'less marked'. Mix of healed and active PNBF that was striated, porous and nodular on the distal surfaces of the tibiae and fibulae, most pronounced on the interosseous border. Non-articular surfaces of the tarsals were 'porous' with 'marked abnormal bone around all joint surfaces'. Healed and active PNBF on the calcanei, cuboids and cuneiforms on both sides. Knife-edge remodelling of the 'metatarsal diaphyses'. A photo of the metatarsals and phalanges are provided.			
Morrione	Italy	6th-8th century	Grave no. 68 and 108 - 'most likely diagnosis is lepromatous leprosy' (p. 2776)	68* - Consistent 108 - Consistent	68 – 'Female, 40-46 years of age'. Almost complete skeleton displaying atrophy of nasal aperture and absorption of anterior nasal	Journal of Archaeological Science	Y	Rubini and Zaio, 2009

Site Name(s)	Location	Dating	Diagnosis given in paper	Lepro-C Category given after reassessment	Description of Pathology	Published where?	Photos Available?	Reference
					spine. No postcranial lesions. 108 – 'Male, 50-55 years of age'. Almost complete skeleton showing absorption of anterior nasal spine and rounding of nasal aperture – could be postmortem damage. Possible lesions to hand and foot phalanges, which original authors ascribe to 'erosive process', but look more taphonomic.			
Sigtune	Sweden	1100-1300 AD	Case 1, 2, 3 – display evidence of systemic infection, possibly leprosy Case 4 – lesions suggestive of leprosy with tuberculosis comorbidity Case 5 – lesions 'imply that	Case 1, 2, 3 – consistent, but tentative as images of some pathology are absent Case 4 – consistent Case 5 – highly consistent, could be diagnostic if reassessed to	Case 1 - Adult individual aged '20-23', anklyosis of an intermediate and distal phalanx of finger bones, PNBF of distal tibia and fibula (longitudinally striated on the lateral and medial aspects respectively, with a pitted surface), concentric remodelling and absorption of phalanges of left MT3, 4, 5, and right MT5, there is also concentric remodelling 'four	International Journal of Osteoarchaeology	Y – but not of all lesions	Kjellstrom, 2012)

Site Name(s)	Location	Dating	Diagnosis given in paper	Lepro-C Category given after reassessment	Description of Pathology	Published where?	Photos Available?	Reference
			individual suffered from lepromatous leprosy' Case 6 – 'the skeletal changes are diffused and could not be confidently associated with a specific disease	clarify some of the evidence presented Case 6 – highly consistent based on descriptions, but consistent based purely on images presented	surviving phalanges', dorsal exostoses on right calcaneus, left talus and lateral cuneiform. No skull. Case 2 - complete female individual aged '20-30', slight acroosteolysis of the hand phalanges, PNBF of distal tibiae and fibulae (longitudinally striated with surface pitting on lateral and medial aspects respectively), destructive remodelling and absorption of distal end of both first metatarsals and corresponding proximal phalanx, with morphology of right side suggesting secondary infection (lateral cloaca present), and left due to neuropathy induced absorption. Destructive remodelling and absorption of ends of both 5th metatarsals. Fragmentary skull, no elements survive to assess RMS			

Site Name(s)	Location	Dating	Diagnosis given in paper	Lepro-C Category given after reassessment	Description of Pathology	Published where?	Photos Available?	Reference
					Case 3 - complete skeleton of a '20-25 year old' male, PNBF on the femora (longitudinally striated along the dorso-medial aspect of the diaphysis), bilateral porous and disorganised bone formation with deep 'vascular grooves' on both tibia and fibulae, with cortical expansion of diaphysis. Destructive remodelling and absorption of the distal end of a right proximal hand phalanx, with destructive remodelling/arthropathy of the proximal end of the corresponding intermediate phalanx. Disintegration of right calcaneus, and blastic and lytic arthropathy of the articular surfaces of the talus. Dorsal exostoses on right cuboid, lateral and intermediate cuneiforms, and left talus, cuboid,			

Site Name(s)	Location	Dating	Diagnosis given in paper	Lepro-C Category given after reassessment	Description of Pathology	Published where?	Photos Available?	Reference
					navicular, lateral and intermediate cuneiforms. Both second, third, fourth and fifth metatarsals show distal concentric remodelling, and knife-edge remodelling, with some resorption of the surviving phalanges and ankylosis of two distal phalanges. No evidence of RMS. Case 4 - adult individual of 'unknown sex'. Destructive lesions in T4-T12 vertebrae with new bone formation, destruction of vertebral bodies, with sharp angular kyphosis and ankylosis of the L1-L3 vertebrae, and large smooth-walled lytic lesions in the remaining lumbar vertebrae. Severe lytic lesions on the upper ventral surface of the sacrum. Longitudinally striated PNBF on distal lateral tibiae, and on diaphysis of the fibulae.			

Site Name(s)	Location	Dating	Diagnosis given in paper	Lepro-C Category given after reassessment	Description of Pathology	Published where?	Photos Available?	Reference
					Ankylosis of both first metacarpophalangeal joints, with proximal phalanx axially oriented. The right ankylosed proximal phalanx shows some concentric remodelling. The right MT2 fused with intermediate cuneiform, cloaca present. Absorption of distal end of 'only remaining proximal phalanx' and fusion with the intermediate phalanx. Case 5 - complete skeleton of an '11-12 year-old child', displaying absorption of anterior nasal spine, rounding of the nasal aperture, absorption of the anterior maxillary alveolar process (with malformation of dental roots of maxillary incisors, and pitting of the oral surface of the palatine process). Fine striated PNBF on distal left fibula, and 15mm long and 4.5mm deep lytic lesion on distal			

Site Name(s)	Location	Dating	Diagnosis given in paper	Lepro-C Category given after reassessment	Description of Pathology	Published where?	Photos Available?	Reference
					right fibula. The first distal phalanx, showed concentric atrophy of the distal end, causing it to taper. Case 6 - complete skeleton of a male aged '35-50 years'. Rounding of the nasal aperture, pitting of the oral and nasal surfaces of the palatine process, as well maxillary sinusitis. Anterior nasal spine and central alveolus of the maxilla lost post-mortem. Slight PNBF on distal left tibia, lytic arthropathy of distal articular surface of right MT5, with articular surface of corresponding proximal phalanx displaying lytic arthropathy. Evidence of septic arthritis in the proximal left hallux.			

Site Name(s)	Location	Dating	Diagnosis given in paper	Lepro-C Category given after reassessment	Description of Pathology	Published where?	Photos Available?	Reference
Zalavar	Hungary	9-13th Century	Burial 228 – 'most likely suffered from a combination of tuberculosis and leprosy, or leprosy and lung cancer, due to the concurrent evidence of HOA, particularly on the left ilium and sacrum'	Consistent	'22-32 year old male' - Extensive PNBF on tibiae and fibulae, focussed on the interosseous border with nodulous osteophytes, suggesting ossification of the interosseous membrane. PNBF along linea aspera of femur and calaceneii also. Osteolysis of left MT3 and right MT2-5.	International Journal of Osteoarchaeology	Y	Christensen et al., 2013.

Site Name(s)	Location	Dating	Diagnosis given in paper	Lepro-C Category given after reassessment	Description of Pathology	Published where?	Photos Available?	Reference
Hallow Hill; Kirkhill	Scotland	6th-9th century	HH Cist 26 – 'pathological bone conditions…would appear to be pathognomonic for lepromatous leprosy' (p. 315) K275A – 'bone changes are clear evidence of facies leprosy' (p. 316)	HH 26 - consistent/Highly consistent K275A – Diagnostic	HH26 – 'Female, 34-38 years of age'. Almost complete skeleton showing absorption of ANS, rounding of nasal aperture, absorption of anterior maxillary process, and inflammatory pitting of oral surface of palate. PNBF of distal tibiae and fibulae, most marked on distal left fibula. K275A – '?F, 25-35 years of age'. Disarticulated skull displaying the full 5 signs of RMS	International Journal of Osteoarchaeology	Y (only cranial lesions)	Lunt, 2013

Site Name(s)	Location	Dating	Diagnosis given in paper	Lepro-C Category given after reassessment	Description of Pathology	Published where?	Photos Available?	Reference
Great Chesterford	United Kingdom	5-6th century	GC96 – 'osteological evidence is typical of leprosy'	Consistent	'21-35 year old male' - Healed longitudinally-striated PNBF on tibiae and fibulae on all aspects. Nodulous osteophytes along interosseous margin. Destructive arthropathy of right tarso-metatarsal joints. Concentric remodelling of right MT3 and 5, ankylosed MT4 and 5, periarticular deformation of MT2, 4th proximal and intermediate phalanx ankylosed. Disorganised active PNBF on midshaft of MT1 and 2.	PLoS One	Y – but not all pathology	Inskip et al., 2015.
Abony-Turja´nyos dűlő	Hungary	3780-3650 cal BC	SK 257 S20 – 'shows strong evidence for the bony manifestation of advanced leprosy''	SK 257 S20 - consistent	18-22 year old male - Absorption of RMS, patchy smooth rounding of nasal aperture, longitudinally striated PNBF on lateral and medial aspects of tibia	PLoS One	Y, Images of skull, and sections of right tibia and fibula, and right MT1 only	Kohler et al., 2017

Site Name(s)	Location	Dating	Diagnosis given in paper	Lepro-C Category given after reassessment	Description of Pathology	Published where?	Photos Available?	Reference
Ardreigh; Golden Lane	Ireland	9-14th Century	SkCXLVII; Sk171; SkCXCV; SkCCXXX	SkCXLVIII - consistent; Sk171 - consistent; SkCXCV - diagnostic; SkCCXXX – diagnostic	SkCXLVIII – '13-18 year old 'probable male'' – concentric remodelling of metatarsals, PNBF on distal tibia and fibula; Sk171 - 'adult, indeterminate sex' – concentric remodelling of metatarsals and tarsals; SkCXCV – '35-50 year old male' – full rhinomaxillary syndrome; SkCCXXX - '35-50 year old male' – full rhinomaxillary syndrome	PLoS One	Y – but not all pathology	Taylor et al., 2018
Armoy	Northern Ireland		SK1494 Individuals display 'probable leprosy'	SK1494 – Consistent	SK1494 – '18-35 year old 'possible male'' – No surviving cranial elements. Diaphyseal remodelling in left MT3, 4, 5, nodular bone formation on dorsal surface of MT4 shaft. Fully absorbed metatarsal heads, osteolysis of corresponding proximal phalanges, with deformation of articular surfaces. Diaphyseal remodelling of right MT3, 4, 5, but much more extensive,			

Site Name(s)	Location	Dating	Diagnosis given in paper	Lepro-C Category given after reassessment	Description of Pathology	Published where?	Photos Available?	Reference
					with full absorption of the distal thirds and deformation of the surviving margins. Right MT4 displays cortical expansion and possible cloaca on dorsal surface of proximal diaphysis. Dorsal tarsal exostoses present on the 'majority of tarsals present', with navicular and cuboid bones most severely affected (no images provided). Diffuse bilateral PNBF with a 'spiculed' and 'healing' appearance on distal half of the tibiae and fibulae. Visible fractures in T11 and L5 vertebrae, and right rib. Only pictures of the metatarsals and phalanges are provided by Taylor et al. (2018).			

Site Name(s)	Location	Dating	Diagnosis given in paper	Lepro-C Category given after reassessment	Description of Pathology	Published where?	Photos Available?	Reference
Bijelo Brdo	Croatia	10-11th century	Skull 83, and Skull 200 – 'diagnosis of lepromatous leprosy is the most probable one''	Skull 83 – highly consistent Skull 200 – consistent	Skull 83, female, age '25-45 years' – absorption of anterior maxillary alveolus, rounding of inferior margins of nasal aperture, possible absorption of anterior nasal spine (but could be post mortem breakage). Inflammatory pitting of oral surface of palatine process Skull 200, 15-17 years of age - absorption of the anterior nasal spine and rounding of the inferior margins of nasal aperture. Descriptions of palatine pitting not detailed enough in original paper to give higher Lepro-C category, but individual may be highly consistent if porosity matches pattern of leprosy	Journal of Archaeological Science	Y – facial bones	Bedic et al., 2019