

The Bioarchaeology of Leprosy: Learning from the Past

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Introduction

LEPROSY TODAY

Leprosy is an infectious disease caused by a bacillus, *Mycobacterium leprae* or *Mycobacterium lepromatosis* (see Chapter 5.1) (1). It is associated with poverty and poor access to health care and education, all relevant for people with leprosy who lived in the past. The disease is thought to be transmitted from human to human via bacteria-laden droplets exhaled from the lungs of those affected (see Chapter 2.1; <http://www.who.int/mediacentre/factsheets/fs101/en/>). The nine-banded armadillo (see Chapter 10.2) is the main animal, other than humans, that can harbor the bacillus (2), but non-human primates and, as recently discovered, red squirrels appear to be able to contract leprosy (3, 4). Of interest is that *M. lepromatosis* has been associated with red squirrels in the UK, and nine-banded armadillos have North African/European strains of the bacteria introduced over the last few hundred years (5). While not a focus of this chapter, it would be interesting to explore whether these animals were leprosy sources for humans in the past.

Leprosy affects the peripheral nerves, skin, and other parts of the body, including the skeleton. The early signs of the disease are often skin lesions and flexion contractures of the hands and feet. While early diagnosis and treatment today may prevent damage to the soft tissues and bones of the hands, feet, and face (see Chapter 4.2; Chapter 2.4), treatment was not an option in the past. Thus, impairment, disability (see Chapter 4.3), stigma (see Chapter 4.5), and segregation could have been consequences (6).

LEPROSY IN THE PAST

Leprosy has had a long history, as seen in both the archaeological record and studies of the modern genome of the bacillus. Using molecular genotyping techniques, Monot and colleagues have suggested that leprosy originated as a human disease in East Africa or the Near East around 100,000 years ago, spreading east via people migrating along two routes, including the Silk Road, and west to the Americas via colonialism and the slave trade (7, 8). Although historians and bioarchaeologists have documented leprosy's presence in various parts of the world at particular time periods, this type of evidence has its limitations. For example, human remains from the two potential origins of the infection are often poorly preserved; systematic paleopathological studies are not as well developed in those areas as in other parts of the world; and paleopathological training is lacking. However, Monot et al. have provided a baseline of data that allows us to consider whether the scenario suggested above can be supported by other evidence, such as archaeological human remains. As human remains with leprosy continue to be found around the world, adding to our knowledge about the disease, the testing of Monot et al.'s ideas in the archaeological record is currently ongoing and will develop in the future.

This chapter focuses on the primary evidence for leprosy in the past, meaning that found in the bones (and teeth) of skeletons buried in archaeological cemetery sites. Bioarchaeologists study skeletons found in archaeological contexts and preserved bodies where conditions are conducive to their survival (9). One of the main foci of bioarchaeological studies is the origin, evolution, and history of disease (paleopathology), and leprosy has been an area of interest for many years (10). In the following sections, the evidence of disease in skeletons, specifically leprosy, is outlined, along with the methods used for diagnosis and the limitations of the data. This discussion is followed by a survey of the bioarchaeological data for leprosy around the world and what it tells us about its history and impact on populations (11).

LEPROSY IN THE ARCHAEOLOGICAL RECORD

The two main sources of evidence for leprosy in the archaeological record are skeletons and, sometimes, the remains of leprosaria (leprosy asylums) (Table 1; Figure 1). The former are more common and the latter relatively scarce. More recently, skeletons and preserved bodies have also revealed biomolecular evidence of the person being infected with leprosy through the identification of DNA and lipids specific to the bacteria (12).

LEPROSARIA

Leprosaria remains are surprisingly rare in the archaeological record, considering that historical texts suggest they were very common, especially in Medieval Europe (Figure 1). Perhaps the most well known leprosarium is the one excavated in Medieval Aaderup, near Naestved, Zealand, Denmark (1250–1550 AD) during the 1940s–1960s (13). This excavation not only was important

TABLE 1 Medieval leprosaria where skeletons with leprosy have been excavated

Site name	Location
England	
Sts James & Mary Magdalene	Chichester, Sussex
St Bartholomew	Cowley, Oxford, Oxfordshire
St Margaret's	High Wycombe, Buckinghamshire
St Mary Magdalen	Winchester, Hampshire
St John	Timberhill, Norfolk
Denmark	
St. Jørgen, Naestved	Zealand
St Jorgensgard	Odense
Stubbekobing	Falster
France	
St Thomas d'Azier	Calvados
Chappelle Saint-Lazare	Tours
Germany	
Melaten	Aachen
Hungary	
Szombathely-Ferences	Templom
Norway	
St Laurentius	Oslo
Portugal	
Valle de Gafara	Lagos, Algarve
Sweden	
St Jörgen	Malmö
St Jörgen	Lund
Caribbean	
St Eustatius	Netherland Antilles

in its own right, but also led to the establishment of diagnostic criteria for leprosy in skeletons by Vilhelm Møller-Christensen (14). Thus, it was a significant milestone in the study of leprosy in bioarchaeology. More recently, two other Medieval leprosaria have been excavated, both in England: the hospital of St James and St Mary Magdalene in Chichester, Sussex, (15) and St Mary Magdalen in Winchester, Hampshire (16), both dating to the late Medieval period (12th century onwards). Leprosaria cemeteries have been found to contain skeletons both with and without evidence of leprosy, but skeletons with leprosy have also been found in funerary contexts that are not related to leprosaria. These findings have implications for interpreting how communities managed people with leprosy in the past.



FIG 1 The 19th Century Leprosarium in Bergen, Norway.

Identification of Leprosy in Human Remains

The most common human remains archaeologists find, excavate, and study are skeletons and, to date, almost 100% of the evidence for leprosy has been found in skeletons. Preserved bodies are much more rare and are found in environments that promote preservation (i.e., very hot or cold but dry climates). Once a skeleton has been excavated, it is cleaned and then laid out in an anatomical position for analysis. Bioarchaeologists thus must be skilled in identifying complete and well-preserved skeletons as well as fragmentary bones and teeth. Prior to trying to diagnose diseases in a skeleton, the bioarchaeologist estimates the sex of the person, mainly by examining the features of the pelvis which reflect the childbearing capacity of women (9). The sex of skeletons of people who had not passed puberty at death cannot be reliably estimated unless ancient DNA analysis can be successfully used (17). Age at death is estimated for those who have not reached adulthood through analyzing the development of their teeth and bones, and for adult skeletons through analyzing the parts of their skeletons that show age-related changes (9). Measurements are also taken, for example to estimate height, and then evidence of disease is considered.

DIAGNOSIS OF LEPROSY

The diagnosis of leprosy in human remains excavated from archaeological sites is challenging, especially when the skeleton is not well preserved. It is fortunate for bioarchaeologists that leprosy can affect the skeleton, although this effect only occurs in 3–5% of people with untreated leprosy (18). This percentage is, of course, a very small proportion of the potential people who would have had the disease in the past. Today, WHO data indicate that Grade 2 deformities affect more than 5% of people diagnosed. However, pre-treatment (i.e., pre 1950), many of these cases would have progressed, so we would expect that a greater percentage would have bone involvement. It should also be remembered that a person might have had leprosy when they died, but their bones may not have been affected at that time.

BONE CHANGES ASSOCIATED WITH LEPROSY

Bone changes from disease, including leprosy, consist of bone formation, bone destruction, or a mixture. The facial bones (and developing incisors) are believed to be affected by leprosy because the bacillus is inhaled directly into the respiratory tract, impacting the integrity of the nasal and maxillary bones and the development of teeth in non-adults. A low temperature is also needed for the bacilli to survive (19). The hand and foot bones are affected because the bacillus invades the sensory, motor, and autonomic nerves of the peripheral nervous system (see Chapter 2.5) (20). It is possible that ulceration of the soft tissues in leprosy, for example on the legs and scalp, can cause underlying bone damage (21).

As mentioned above, Møller-Christensen first described the bone changes of leprosy in archaeological skeletons, changes that had not really been described in detail before. His descriptions form the basis of diagnosis in paleopathology but have been further developed, particularly by Johs Andersen and Keith Manchester (22, 23, 24, 25, 26). The first step for diagnosing disease in a skeleton is to record the evidence across all preserved bones and teeth. The skeleton can only react in a limited number of ways to disease, that is, form or destroy bone (27). The recording of the distribution of these changes around the skeleton allows a paleopathologist to develop differential diagnostic options. The latter are essential because individual bone changes usually have many potential diagnoses.

Baseline clinical data are used to understand what patterning and characteristics of bone change would be expected for different diseases and which bones would be affected. However, some bone changes are so subtle that they are not described in the clinical literature and may not even be visualized clearly on a radiograph (e.g., those representing respiratory disease, for example, on the ribs; Figure 3B) (28). Thus, at times, archaeological skeletons can provide data reflecting the bony response to a disease that is not really visible clinically. Furthermore, clinical data may not always be an appropriate comparison for what is seen in a skeleton (29).

The evidence for leprosy observed in past skeletons is most often the result of chronicity (a person has to have had the infection for some time). Most importantly, the expression of the evi-

dence on the bones should be unaffected by the impact of modern treatment regimes, such as drug therapy. Of great relevance to diagnosis are the immune system strength of the person exposed to the infection (see Chapter 6.1; Chapter 6.2) and the immune spectrum of leprosy (see Chapter 2.4) (30). If a person is highly resistant to the bacteria, then he or she is likely to develop tuberculoid leprosy (TT); if not, lepromatous leprosy (LL) will likely occur. Most bioarchaeological evidence identified is of the LL type. Paleopathological diagnostic criteria for TT have not yet been published but have been researched (31). It has been suggested that rhinomaxillary syndrome (RMS, or bone changes of the face) and the involvement of hand and foot bones are characteristic of LL, and that bilateral or unilateral hand and foot bone involvement and no RMS indicate TT. This suggestion was based on patient records from a 20th century Portuguese leprosarium (32). It is not yet known whether *M. lepromatosis* affects the skeleton in ways similar to either LL or TT.

CRANIAL BONE CHANGES

The bone changes in the face include absorption and remodeling of the nasal aperture (Figure 2), absorption and recession of the bone of the anterior part of the maxilla (upper jaw) and loss of the anterior teeth, and absorption/loss of the anterior nasal spine. The oral and nasal surfaces of the maxilla may become pitted (inflamed) and the maxilla could become perforated. This suite of changes is called the “rhinomaxillary syndrome” (24), formerly referred to as “facies leprosa” (14). The roots of the anterior teeth of the upper jaw can develop as short “stumps”, thus contributing to their loss (leprogenic odontodysplasia) (33). The maxillary sinuses have also been seen to be inflamed in both living and past people with leprosy (34). Finally, leprosy has been associated with middle ear (35) and lung infections (Figures 3A, 3B) (36).



FIG 2 Facial Bone Changes.

Loss of the anterior nasal spine, widening of the nasal aperture, and remodeling of the nasal aperture edges of a person who had experienced leprosy during life.



FIG 3 Evidence of Respiratory Disease.

A. New bone formation on the floor of the sinus.

B. New bone formation on the visceral surfaces of the ribs.

POSTCRANIAL BONE CHANGES

As a result of the effect of the bacillus on the peripheral nerves, the hand and foot bones can be damaged, too (Figure 4; Figure 5). In life, ulceration can occur on the hands and feet due to sensory nerve damage, and a compromised sense of touch due to skin anesthesia occurs (see Chapter 2.5). If not treated, the bones may be affected; absorption of the bone structure then ensues, with an eventual collapse of the normal architecture of the extremities. Flexion contractions of the fingers and toes can further develop as a result of motor nerve damage, creating “grooves” in the phalanges. Finally, autonomic nervous system damage can lead to an imbalance in bone formation and destruction and the consequent concentric remodeling of the metatarsals, metacarpals, and phalanges. Involvement of the feet and consequent bone changes may lead to further damage to the lower leg bones as periosteal new bone formation (Figure 6) (37). Other

related diseases that may be seen in a skeleton include osteopenia and osteoporosis and poor oral health, as described in the clinical literature (38, 39).

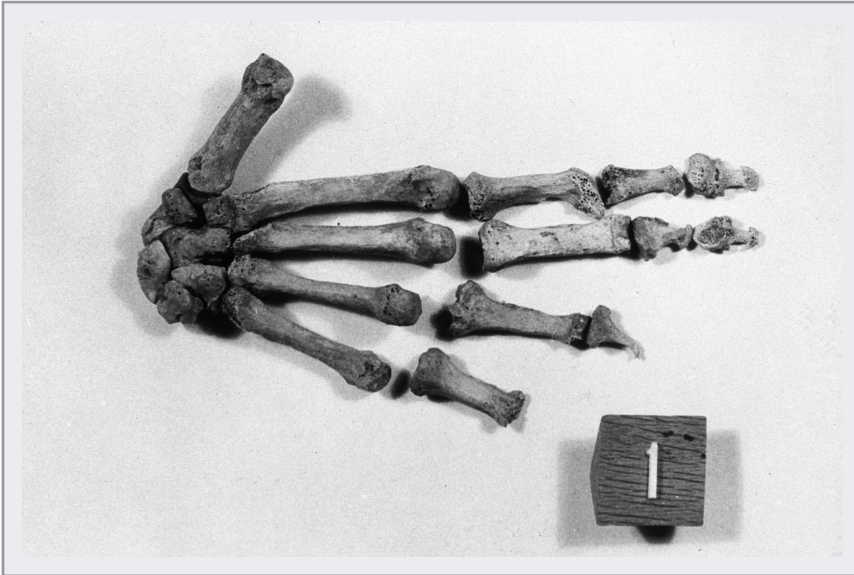


FIG 4 Hand Bone Changes.

Absorption and remodeling of some of the left hand bones of a person who had experienced leprosy during life (Medieval Denmark).



FIG 5 Foot Bone Changes.

Absorption of the distal ends of the 2nd to 4th metatarsals and concentric remodeling of proximal phalanges of the left foot of a person who had experienced leprosy during life (Medieval France).



FIG 6 Lower Leg Bone Changes.

Extensive new bone formation on the tibiae and fibulae of the skeleton of a person who had experienced leprosy in life (Medieval England).

DIFFERENTIAL DIAGNOSIS

Some facial bone changes may also be seen in treponemal disease, neoplastic disease, leishmaniasis, and tuberculosis, and hand and foot bone changes may be seen in psoriatic arthritis, diabetes, and frostbite. Essentially, there are more and less specific indicators of leprosy visible in a skeleton, with facial bone changes often being relied upon for a diagnosis. Less specific bone changes that can occur may result from the collapse of the foot architecture (new bone formation on the dorsal surfaces of the tarsals due to foot drop and stress on attached ligaments) or from flexion contractures of the fingers and toes due to motor nerve damage (grooves on the palmar surfaces of the phalanges). These changes can, of course, suggest several diagnostic options. For example, the latter might be the result of paralysis due to many causes (e.g., a stroke).

An understanding of the context of the remains being studied is very important in the process of developing a differential diagnosis. Context is not only important for paleopathological analysis in general, but also for studying leprosy in particular. For example, leishmaniasis is not a disease expected in Northern Europe and, therefore, would not be likely to be considered a diagnostic option in this region. The loss of anterior teeth can also be the result of a cultural norm, for example in places where teeth are deliberately extracted or lost due to dental disease (40).

Limitations of the Data

ANALYTICAL METHODS

Most bioarchaeologists use macroscopic techniques for identifying leprosy (e.g., visual identification), which have limitations. However, imaging methods ranging from plain film and micro radiographs to CT scanning are also available, although not often used, and there have been studies that try to identify histological alterations in bones with lesions and associate them with leprosy (41, 42). The most recent advance in diagnosis has been the use of biomolecular methods. The enormous amount of research in modern genomics is providing baseline data about diseases such as leprosy that can be used and applied in bioarchaeology and history (7, 8). Ancient DNA (aDNA) and mycolic acids (lipids) specific to *M. leprae* can potentially survive the burial process and be extracted and identified with biomolecular methods that are used in clinical medicine (43, 12). In recent years, the modern genome of *M. leprae* has been sequenced (44) (see Chapter 8.2), as well as the first ancient *M. leprae* genome (45), allowing for comparisons between the two. This type of analysis is changing our ideas about leprosy's origins and its spread around the world.

Monot et al.'s research (7, 8), which is mainly based on modern leprosy data, has indicated that leprosy originated in the near East or Africa around 100,000 years ago, spreading east and west along migration routes. Donoghue et al. have synthesized Medieval Eastern and Central European biomolecular data to understand how leprosy spread across these regions (46). Furthermore, Monot et al.'s data have indicated which genotypes/subtypes are associated with which regions of the world today (see Chapter 8.2). Along with chemical (stable isotope) analyses, it is now possible to explore the effect of migration on leprosy's history. For example, a skeleton with subtype 3I has been found in Sweden (47), and subtype 3I is found in the Americas and Morocco today.

Furthermore, the skeleton of a Medieval pilgrim has been found in a cemetery associated with a leprosy hospital in the 11th–12th century AD in Winchester, England. The skeleton, which exhibits the bone changes of leprosy and was buried with a scallop shell, has revealed preserved *M. leprae* DNA of a strain associated with South-Central and Western Asia today (16). Chemical (stable isotope) analysis for strontium and oxygen indicated that the person was not born or raised in the local Winchester area, and the cranial features seemed to have affinities with southern European or North African populations. Scallop shells are associated with pilgrims traveling to Spain, specifically to Santiago de Compostela, a practice that dates back to the 12th century. Further aDNA (if preserved for analysis) and stable isotope analyses of other skeletons with leprosy worldwide will either corroborate or change our ideas of leprosy's origin, evolution, and transmission pathways.

WHERE HUMAN REMAINS ARE EXCAVATED

Historical sources suggest that leprosy was common in the past, but this assertion does not correlate with the evidence found in human remains, especially from the Medieval period. However,

it should be noted that archaeological human remains are regularly discovered and excavated in many parts of the world, usually in advance of modern developments such as building houses, roads, hospitals, etc. For example, in England and Wales, laws regulate new development and all areas targeted for building have to be surveyed for archaeological evidence; if any is found, it has to be excavated (48). Inevitably, new developments are most common in towns and cities. Considering that *Homo sapiens* evolved in Africa 200,000 years ago, many millions of humans have lived and died on our planet. It would therefore be expected that archaeologists would find remains (as they do) in a variety of funerary contexts, from prehistoric barrows to more formal parish cemeteries in later periods.

PRESERVATION OF HUMAN REMAINS

The most common human remains found and studied are skeletons, which makes it challenging to diagnose diseases because only a small percentage of them affect the skeleton. In addition, the method used to diagnose leprosy in skeletal remains is very different from the methods used in living patients. Ideally, a complete well-preserved skeleton is needed for diagnosis. While human remains can survive burial for thousands of years and be relatively well preserved, burial conditions can be so poor that analysis by a bioarchaeologist reveals very little information (9).

As is well known with respect to the skeleton, leprosy affects the facial, hand, and foot bones. However, in an archaeological burial context, a body will be subject to many factors that lead to its decay over the time span of the burial—from when the person was buried to when the body (and usually the skeleton) was excavated (9). These factors are classified as internal or external to the person (49, 50, 51). Internal factors might include the person's age: younger people's bones are smaller, more fragile, and less well developed and may not survive as well as an adult's bones. Diseased bones are also weaker and more susceptible to decay. External factors include a huge range of variables, including the pH of the burial soil (acidic soils are not good for preservation), the depth of the burial (the deeper the better for the best preservation), and the activities of scavengers within the burial environment (insects, rodents, etc.). External factors also include how well the skeleton was excavated and how much care was taken when cleaning it before analysis. Thus, the quality of preservation can be affected by what caused the person's death, what happened to the body after death, how it was laid to rest, and what happened during the burial period before excavation. For example, the funerary ritual of cremation leads to very fragmentary bones in the archaeological record, making them hard to identify and analyze.

When considered together, all of these factors can have a major impact on the preservation of the human remains that represent a once living person. In relation to leprosy, the facial bones are very fragile and may not survive burial well, but they can also be damaged during the excavation and cleaning of that part of the skeleton. Similarly, the small bones of the hands and feet may not be preserved for analysis and may be overlooked during the excavation process. Leprosy can also affect the roots of the developing anterior maxillary teeth (leprogenic odontodysplasia), but because these teeth are single rooted, they can easily fall out from the maxilla while the body is in the grave and thus be lost to the excavator.

AVAILABILITY OF TRAINING

Bioarchaeologists need to be fully aware of potential bone changes due to leprosy and, therefore, need adequate training to effectively diagnose leprosy in human remains. Training for people in some parts of the world needs development, which is especially true in regions where we might expect more evidence of leprosy. Monot et al. (7, 8) highlighted areas in which evidence might be found, but so far findings are rare (e.g., Africa and the Middle East, but also China). Training also makes people aware of possible diagnostic options for the bone changes in leprosy. More evidence will be found as more trained people work across the world's countries.

CONTEXT

Studying people who had leprosy in the past is not limited to the actual diagnosis of human remains. Ideally, it takes cognizance of context, an approach that is not always taken. This awareness means taking into account the lives of these people as gleaned from other archaeological evidence. Living conditions, diet, and work, for example, all potentially impacted whether a person was more susceptible to contracting leprosy. Today, leprosy is associated with poverty, and it remains a stigmatized infection that can lead to ostracism and segregation, all relevant to studying leprosy's past. Thankfully, a huge amount of work, including educating people about the disease (see Chapter 4.5), is slowly decreasing the stigma we see today.

In relation to stigma in the past, we should take heed of historical data that have so often painted a gloomy picture of the lives of people with leprosy, although, again, our understanding of the historical context is changing, particularly with the work of Rawcliffe (52) and Demaitre (53). It is well known that leprosy hospitals were founded in Medieval Europe as places to segregate people with leprosy. Some of those leprosy hospital cemeteries have been excavated, the most well known being those in Winchester and Chichester (Hampshire and Sussex, England, respectively) and in Denmark (Naestved). These sites have revealed skeletons with evidence of leprosy, sometimes at high frequencies (54). Sites such as these are considered likely locations for the discovery of skeletons with leprosy but, at times, a large proportion of skeletons without leprosy are found (15). As most evidence for leprosy comes from non-leprosaria sites, context is also important for understanding attitudes to people with leprosy in the past.

DATING

In an ideal world, it would be useful to have well-dated human remains because dating helps to contribute to our understanding of leprosy's origin, evolution, and history. Radiocarbon dating is the most common method used but can be out of reach for bioarchaeologists who lack a large analytical budget. Quite often, sites are organized into general "periods". In Europe, the periods might be the Paleolithic, Mesolithic, Neolithic, Bronze and Iron Ages, Roman, early, late, and post-medieval. In Britain, many of these periods span a long time. Therefore, calculating realistic fre-

quency rates over time for a cemetery (e.g., late Medieval, 12th–16th century) is very challenging if the dates of its use are not available.

FREQUENCY RATES

Thus, another challenge for bioarchaeologists is to produce frequency rates for leprosy over time. Because of the vagaries of the archaeological record, and because the skeletons being studied may not realistically represent the once living population (55, 56), providing frequency rates is extremely difficult. Bioarchaeologists need to consider other archaeological data to form expectations for a disease like leprosy. For example, the advent of farming led to larger population sizes and the establishment of towns and cities. The resulting urban areas would be expected to produce higher frequencies of leprosy in populations, considering how the disease is transmitted from human to human via closer contact through higher population density. This scenario is supported by the evidence of leprosy, most of which is found in human remains in urban contexts (11). It is well known that most skeletons are excavated from urban rather than rural contexts, but these urban skeletons represent people who were reliant on farming for their existence, whether they lived in urban or rural contexts, given that the country supplied the city (57).

IMPAIRMENT

As there is much published literature documenting the impairments, disability, and handicaps experienced by people with leprosy today, the question might be asked about evidence found in the bioarchaeological record. Inferring impairment, and its possible effects on the lived experience, based on skeletons is very tricky, but methods are being developed that allow bioarchaeologists to start thinking about these effects for individual skeletons (58). However, it is worth remembering that each person with leprosy may be affected differently both mentally and physically, as is true today, and that the combination of damage to the skeleton and potential impairments in different parts of the body vary between clinical studies. The progression of leprosy and the development of impairment are affected by a variety of factors, including type of leprosy, biological sex, and occupation. Furthermore, bone damage is not necessary for impairment to develop and, if it does, impairment does not necessarily lead to disability and handicap. Finally, there is a range of possible signs and symptoms associated with leprosy that not all people with leprosy would develop (see Chapter 2.1). Analyzing skeletons devoid of soft tissue and lacking the ability to view and listen to the person's experience of the infection are key disadvantages of bioarchaeology. How can we realistically infer what the living person experienced?

The Bioarchaeological Evidence for Leprosy

In a recent global survey of the bioarchaeological evidence for leprosy, three of the seven continents (Africa, Asia, and Europe) have revealed leprosy-affected human remains. Australasia, North and South America, and Antarctica have yet to reveal such evidence, although possible evidence has been found in North America (11). There has only been one preserved body diagnosed with leprosy, that of a Coptic Christian mummy from El Bigha, Northern Sudan, dated to c. 500 AD (59, 60, 61). Thus, virtually all evidence of leprosy has been found in skeletons (see Table 2 for countries represented in the data).

Likewise, there is very little evidence of leprosy in people who had not reached adulthood before they died, although skeletons of non-adults have been located in the Czech Republic, Hungary, Italy, Sweden, Turkey, and the UK. Some examples in this age group include adolescent skeletons at a post-1066 AD site in Scarborough, East Yorkshire, England (62) and at a 13th–14th century AD site at Deerness, in the Orkney Islands, Scotland (63). However, at the St James and St Mary Magdalene Medieval leprosarium in Chichester, England, none of the 104 non-adult (perinatal to 17 years old) skeletons that were excavated showed specific bone changes consistent with leprosy (64). This finding might have several explanations. For example, children would not necessarily have survived for long in the past and, therefore, skeletal lesions would not have been evident at death. The maxillary bones are fragile, so observing facial damage would be difficult. The bones of the hands and feet are very small, meaning that they might not survive burial and are not necessarily recognized or excavated by archaeologists. Children may have developed the high resistance form of leprosy and had no bone changes at death, or they may have had high resistance leprosy, survived into adulthood, and then developed bone changes. Finally, the incubation period could be very long, so the children may have died before bone damage occurred.

The amount of evidence of leprosy found in skeletons varies considerably in different regions of the world, but it is highly unlikely that this variability will remain in the future. As more bioarchaeological work and excavations occur, and as training improves to help bioarchaeologists effectively diagnose leprosy, more evidence will be found. To date, most of the evidence has been found in the Old World, specifically in Northern Europe from the later Medieval period (12th–16th centuries AD). Britain (defined as England, Wales, and Scotland), Denmark, and Hungary have revealed the most evidence, and in Britain and Hungary, in particular, this evidence stretches over a long time period. The evidence of leprosy in Britain probably dates from around the 3rd–2nd millennium BC to the 19th century AD. In Hungary, the evidence dates from the 4th millennium BC to the 19th century AD.

Generally, very little evidence of leprosy has been found in Asia, Australasia (the Pacific, Australia, and New Zealand), the Middle East, or the New World, despite the fact that the highest new case rates for leprosy are found in Brazil, India, and Indonesia today (65). Interestingly, relatively sparse

TABLE 2 Modern countries where leprosy has been identified in skeletons, with their earliest dates

Country	Date
Austria	7th–8th century AD
Britain	5th century AD
Croatia	8th–9th century AD
Cyprus	15th century AD
China	200BC–200AD
Czech Republic	9th–10th century AD
Denmark	1046–1163 AD
Egypt	250 BC
France	4th century AD
Germany	5th century AD – c. 680
Greece	5th–6th century AD
Hungary	3700–3600 BC
Iceland	pre–1000 AD
India	2500–2000BC
Israel	1st century AD
Italy	2nd–4th century AD
Japan	1200–1600 AD
Netherlands Antilles	19th century AD
Norway	11th–16th century AD
Poland	12th–13th century AD
Portugal	14th–16th century AD
South Africa	1910–1999 AD
Spain	2nd–4th century AD
Sweden	0–400 AD
Sudan	c. 500 AD
Thailand	300BC–500 AD
Turkey	8th–10th century AD
Ukraine	10th century AD
Uzbekistan	1st–4th century AD

evidence of leprosy is found in Europe today (18 new cases in 2014), and no cases were registered in the first quarter of 2015. The lack of evidence in parts of the world where leprosy is common today is a paradox—in the past, leprosy seems to have been contracted more frequently in colder climates in the northern hemisphere. Today, leprosy is more frequently found in warmer climates in the southern parts of the northern hemisphere and in the southern hemisphere. The question arises as to whether this difference between past and present distribution reflects a lack of ac-

cess to needed resources and infrastructure (health care) in the regions where leprosy is more common today.

Virtually all the skeletal evidence for leprosy is found in the northern and eastern hemispheres. The data from the Old World are biased towards Northern Europe. The number of skeletons (and preserved bodies) that have been excavated in general is large, but the proportion of those diagnosed with leprosy is very small. Possible factors may include the lack of development of paleopathology and training in some regions; environmental conditions and the methods of burial that affect the preservation of human remains, e.g., cremation; burial of people with leprosy outside of the usual burial ground for the community; or a genuine lack of evidence. Furthermore, if sites containing human remains with evidence of leprosy are not excavated, then that evidence will not be identified. People in some countries may also have been buried in leprosy hospital cemeteries, which are as yet undiscovered and unexcavated.

The skeletal evidence to date indicates that, early on, leprosy was focused in Hungary, India, and, possibly/probably, Iran, Nubia, Scotland, and Turkey, but the evidence in the latter four countries needs to be confirmed and published in the peer-reviewed literature. In addition, these data need to be related to the conclusions drawn from the genomic data for geographically related subtypes of *M. leprae* produced by Monot et al. (7, 8). It is also important to note that, globally, the majority of skeletons with leprosy have been found in non-leprosy hospital cemeteries, buried normally for their communities according to region and time period. However, few leprosy hospital sites have been excavated (see above).

Furthermore, there is scarce evidence of people being buried in a different way or in isolated places, such as on islands, as seen in the past (e.g., Spinalonga, northeast Crete, Greece; Figure 7). However, in some cases, special burials are described for people with leprosy, suggesting that



FIG 7 Spinalonga Island, Crete, Greece, Where People with Leprosy Were Segregated.

these people were not treated poorly within their communities. For example, at Edix Hill in Cambridgeshire, England, a woman with leprosy was afforded a “bed burial”, a funerary practice in the Anglo-Saxon period (early Medieval) reserved for high status people (66). Overall, this example, at least, suggests that communities were generally accepting of people with leprosy, contrary to the historical evidence. However, it should be remembered that individual experiences of leprosy would have varied in time and place, as would community reactions to those with leprosy. If leprosy was as common as the historical data show, it may have been considered normal to have the infection in Medieval Europe. Thus, people with leprosy may not have had to contend with stigma.

OVERVIEW OF THE EVIDENCE

Some of the earliest skeletal evidence of leprosy comes from India (2000 BC), possibly Iran (6200–5700 BC), possibly Sudan (2300 BC), and possibly Turkey (2700–2300 BC), suggesting early foci of the disease. Compared to accepted historical data on leprosy, some of the bioarchaeological evidence dates are earlier, for example in Britain, India, and Turkey, whereas some dates are later, for example in Greece and China. There are also places that provide a lot of documentary data for leprosy but little or no bioarchaeological evidence (e.g., Finland, Iceland, and Norway). In many respects, these discrepancies do show that there is much value in bioarchaeology for reconstructing the history of leprosy alongside historical documents. In relation to Monot et al.’s research documenting the origin and spread of leprosy, more comprehensive analyses of skeletal remains in China and India for evidence of leprosy would contribute to better understanding the history of leprosy, as would work on human remains in the Middle East.

It is instructive to briefly consider the bioarchaeological presence of leprosy in the past in relation to epidemiological transitions. The first transition occurred 10,000 years ago, when a shift to farming led to a population increase and more sedentary living. Leprosy does not appear in the bioarchaeological evidence until this transition in Hungary and India (but also possibly in Britain, Iran, Sudan, and Turkey), if the skeletal data are accepted (see above). As people started to live in urban environments, leprosy increased, likely in association with increased population numbers and poverty, all of which contributed to bacterial transmission and contraction of the infection. Trade and mobility also increased. By the second transition, which occurred in the 19th–20th centuries, infectious diseases were starting to decline. Leprosy, in particular, was common in the 19th century but has since become more rare.

In terms of the transmission of leprosy (7, 8), it has been suggested that leprosy was introduced into West Africa by people of European or North African descent. Leprosy was then transmitted via the slave trade to the New World in the 18th century. Monot et al. (8) linked the 16 subtypes of *M. leprae* they identified to particular parts of the world. As a result of their research, they suggested northern and southern migration routes. The northern route began in the eastern Mediterranean and spread via the Silk Road to Turkey, Iran, China, Korea, and Japan; the southern route incorporated India, Indonesia, and the Philippines. Monot et al. (8) suggest that leprosy was likely to have spread post-colonially to the west, but there is no confirmed evidence of skeletal

leprosy in the Americas. The recent discovery of *M. lepromatosis* in Mexico suggests that leprosy should be found in human remains in that part of the world, as well as further north and south. *M. leprae* genotypes in the Americas also seem to be of European type 3I (also seen archaeologically in Europe). Research focused on *M. leprae* genotypes in archaeological skeletons is increasing, thus adding more nuance to the data concerning modern genotypes. However, it is clearly evident that the mobility/migration of people in the past made a major contribution to leprosy's dissemination over the years, although more data are needed to fill gaps in our knowledge (45, 67).

The Decline of Leprosy

From the 14th century onwards, leprosy was in decline, particularly in Europe. However, more recently, the infection has increased in some parts of the world such as Brazil and southeast Asia. There have been many possible reasons suggested for this decline. Four of the most cited are considered here:

- The segregation of people affected. However, not everyone was segregated, some people were not diagnosed, and some evaded diagnosis.
- The Black Death affecting weaker people, such as those with leprosy. However, leprosy was in decline before the Black Death (68). Furthermore, people with leprosy would have been at no more risk than people with other health challenges.
- The climate in 1300–1500 AD Europe, when temperatures were lower, shortening the survival time of *M. leprae* (69, 70). However, leprosy has been found in human remains in the Old World ranging from the Mediterranean to the cooler North and Baltic seas. This evidence suggests that a decline in temperature is unlikely to have led to the decline of leprosy.
- Tuberculosis (TB), due to the nature of cross immunity between the two infections (71, 72, 73). Both TB and leprosy are caused by mycobacteria and, therefore, increasing exposure to TB caused leprosy to die out, making the population immune to leprosy. This hypothesis has not been thoroughly tested in the archaeological record, but it is interesting to note that the pattern of bioarchaeological evidence for TB mirrors that for leprosy (74). This hypothesis, therefore, cannot be supported with hard scientific evidence yet.

Donoghue et al. have also suggested that people with LL are more susceptible to TB (75) and that co-infection may be a cause for leprosy's decline (76). Thus, both the cross-immunity and co-infection hypotheses of leprosy's decline could be important.

Conclusions

Research on understanding the origin, evolution, and history of disease benefits from a range of disciplines. Bioarchaeology (and specifically paleopathology) has contributed significantly to this research and continues to do so. The evidence of leprosy revealed in human remains, from the macroscopic to the biomolecular, has shown us where and when it has affected populations; it thus provides an historical perspective. In reconstructing the associated context in which these people lived and died (and were buried), a continuously changing picture emerges of the treatment of affected people by their communities. Bioarchaeologists (and historians) are re-evaluating, and finding new, data, changing our perceptions that have been based on a long line of historians writing about leprosy, often in a biased and poorly informed manner. That said, there is still much more work to be done in bioarchaeology. In particular, evidence of leprosy from more skeletons in areas of the world that have revealed little, if any, evidence so far would be beneficial for advancing our knowledge about the history of this disease. Further research on the impact of migration on the spread of leprosy is also needed, using aDNA analysis of the pathogen preserved in archaeological human remains, along with stable isotope analysis. It is anticipated that this work will contribute to a better understanding of leprosy's history and hopefully inform practitioners working with people with leprosy today of its extensive history. Just appreciating the fact that not all people in the past were stigmatized may help people today adapt to having leprosy.

Acknowledgements

I would like to acknowledge Keith Manchester, my mentor from my previous institution (University of Bradford), who first introduced me to leprosy; my partner, Stewart Gardner, for unreservedly supporting my career in paleopathology; and my colleagues in paleopathology, who have freely shared information on leprosy in archaeological human remains with me over many years.

Additional resources

Websites of key organizations with members who work in bioarchaeology:

<http://www.babao.org.uk/>

<https://paleopathology-association.wildapricot.org/>

<http://www.physanth.org/>

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