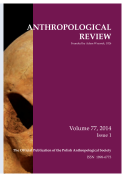
Anthropological Review • Vol. 79 (1), 1–16 (2016)

DE G DE GRUYTER OPEN

Anthropological Review
Available online at: https://doi.org/10.1515/anre-2016-0001



Palaeopathology and its relevance to understanding health and disease today: the impact of the environment on health, past and present

Charlotte Ann Roberts

Department of Archaeology, Durham University, Great Britain

Abstract: This paper considers the discipline of palaeopathology, how it has developed, how it is studied, and what limitations present challenges to analysis. The study of disease has a long history and has probably most rapidly developed over the last 40–50 years with the development of methods, and particularly ancient pathogen DNA analysis. While emphasizing that palaeopathology has close synergies to evolutionary medicine, it focuses then on three 'case studies' that illustrate the close interaction people have had with their environments and how that has impacted their health. Upper and lower respiratory tract disease has affected sinuses and ribs, particularly in urban contexts, and tuberculosis in particular has been an ever present disease throughout thousands of years of our existence. Ancient DNA methods are now allowing us to explore how strains of the bacteria causing TB have changed through time. Vitamin D deficiency and 'phossy jaw' are also described, both potentially related to polluted environments, and possibly to working conditions in the industrial period. Access to UV light is emphasized as a preventative factor for rickets and where a person lives is important (latitude). The painful stigmatizing 'phossy jaw' appears to be a condition related to the match making industries. Finally, thoughts for the future are outlined, and two key concerns: a close consideration of ethical issues and human remains, especially with destructive analyses, and thinking more about how palaeopathological research can impact people beyond academia.

Key words: evolutionary medicine, respiratory disease, 'phossy jaw', rickets, tuberculosis, ancient DNA

Introduction

Studying archaeological human remains (bioarchaeology) forms the primary evidence for past peoples, and is a component of the discipline of archaeology (Roberts 2009). Collecting data from those remains, whether they are skeletons or preserved bodies, provides a direct window on the lives and deaths of our ancestors; "Human remains are the most tangible evidence for under-

Invited Review Article: Received for publication: February 3, 2016
DOI: 10.1515/anre-2016-0001

standing how people lived in the past" (Gowland and Knüsel 2006:ix). Within bioarchaeology, palaeopathology is a key sub-discipline that focuses on health and well being to appreciate how people's lives impacted their health (Roberts and Manchester 2005). Within archaeology, there is a clear trend to using archaeology to inform the present, and bioarchaeology can play, and increasingly is playing, a key role in this respect. Indeed, Kintigh et al. (2014a,b) has highlighted five grand challenges for archaeology: Emergence, communities, and complexity; Resilience, persistence, transformation, and collapse; Movement, mobility, and migration; Cognition, behavior, and identity; and Human-environment interactions. Bioarchaeology, and particularly palaeopathology, can and increasingly does contribute to all these 'challenges'. As they said, "these challenges show an increasing concern with relevance to the modern world" (p. 879). For example, we look at communities of people via their remains, and often we may be looking at very large communities (e.g. the 10,000 skeletons excavated from the St Mary Spital cemetery in London associated with the priory and hospital – Connell et al. 2012); we explore resilience (adaptation) in the face of adversity (e.g. living in urban situations e.g. Roberts and Cox 2003: chapters on health in late and post medieval Britain); increasingly we are tracking the mobility of people in the past (e.g. Groves et al. 2013), and their identity (e.g. Roberts in press); finally, we constantly and particularly consider the data on health from our ancestors' remains in relation to the environments in which they resided (e.g. Roberts and Cox 2003; Roberts 2010).

This paper specifically focuses on the last 'challenge', that of exploring the interaction of people with their environments through the lens of palaeopathology. It first considers the value of palaeopathology for understanding the past, the methods of analysis used, including a focus on ancient biomolecules for intepreting past disease, the limitations of study, and some past and current 'big' projects on past health. It then focuses on three "case studies" to explore environmental impacts on health in more detail. It finishes with some thoughts for the future of bioarchaeology.

Introduction

Palaeopathology

Today disease affects everybody globally, and it is without doubt that this was the case in the past, not least because disease (or trauma) caused people's death, even if they had not suffered poor health during their lives. Disease also affects how we function within our social milieu, and by extension affects society at large. If we are ill then our lives are compromised. Therefore, and thinking about the past, by exploring the health challenges our ancestors faced, we can begin to consider the success or otherwise of past societies. Current health problems that affect large sections of society or regions of the world may lead to considerable 'damage' to normal daily life. For example, the widespread socioeconomic impact of the Ebola virus disease during 2014 is clear (World Bank 2015), and ethical issues associated with its management were debated (Venkat et al. 2015). Unfortunately, it is usually the poorer sections of society who are burdened by health problems in general, but major epidemics in particular (see Wilkinson and Pickett

2009). They are also the ones who are the first to be affected by major catastrophic 'events', such as famines. Similarly, in the past the plague claimed a large proportion of the English population in the 14th century AD, led to particular management methods, and undermined the fabric of society (Park 1993). Therefore, understanding the long history of disease could be claimed to be essential for understanding the origin and evolution of society. Indeed, there is evidence of disease in remains that stretches back to our earliest ancestors (e.g. Trinkaus 2005). Disease has been with us as long as the human species has been in existence.

It is worth reviewing how our health has changed over the thousands of years the human species has been in existence, but more specifically the epidemiological transitions that have faced the human population over the last 10,000 years (Armelagos et al. 2005). These transitions affected the very "fabric" of society and changed the way people lived and died. The *first transition* occurred about 10,000 years ago when people started to farm animals and plants, from a previous life as hunter-gatherers (Roberts 2015a). Diet became less varied, leading to deficiency diseases, harvests could fail, with inevitable starvation and malnutrition, permanent settlements were essential, which could lead to challenges for controlling food and water contamination, population density increased because a larger population could be supported (and were needed to farm the land), leading to density dependent diseases such as infections. Zoonoses became a problem for humans because of their closer association with domesticated animals, and there was more trade, mobility and contact between groups, allowing diseases such as infections to be more readily transmitted (see Cohen 1989 for an overview). Palaeopathological work has widely documented a decline in health with this transition (e.g. Cohen and Crane-Kramer 2007; chapters in Pinhasi and Stock 2011; Cohen and Armelagos 2014, and many published papers), although the picture is not consistent. For example, dental caries in three Thai populations did not increase with increasing reliance on rice agriculture in Southeast Asia, unlike in other parts of the world where rice was not a staple (Tayles et al. 2000). However, the picture is complex, as this paper points out. In a similar study, a decline in caries with this transition was also seen at a site in India (Inamgaon, 3700–2700 BP; Lukacs 2007). The *second transition* occurred with the onset of the Industrial Revolution in the 18th and 19th centuries. There was dramatic population growth, much migration, intensified urbanization and industry, and commercialisation of agriculture. Developments in transport affected markets and commerce and the distribution of foodstuffs, the mobility of people, and the consequent introduction of new pathogens, leading to exposure of immigrants to new diseases (Roberts and Cox 2003: 293–358). There is evidence that although there was economic growth during this period, inequalities in wealth increased, there was much poverty, and living conditions were often poor. Specific occupations, the impact of the Little Ice Age, poor quality housing, low standards of hygiene, exposure to extremes of air and water pollution, under-, mal- and over nutrition all took their toll on health. In recent years palaeopathology has provided a window on the life experiences of people living at that time, especially as increasing numbers of post-medieval cemeteries have been excavated in advance of modern developments. It is clear that health was frequently compromised (e.g. see Molleson and Cox 1993; Brickley and Buteux 2006 for England). The *third transition* is where the world's population now 'sits'. This is characterized by an increase in degenerative conditions such as cancer and heart disease, and re-emergence of 'old' infectious diseases and emergence of new ones. The rise in infections, often now resistant to antibiotics, is accelerated by more frequent and rapid travel across the globe by more people. The human population has been regularly subjected to change in their environment that has compromised their health. Having an understanding particularly of the impact of these transitions, i.e. from a 'long view', can help us to appreciate who we are today and what might be in store for us in the future. As such, palaeopathology complements the increasingly fast emerging discipline of evolutionary medicine (Nesse and Williams 1994; Stearns 2012).

Palaeopathology as a discipline and its limitations

Palaeopathology concerns documenting the primary evidence for the origin, evolution and history of disease and trauma; that is: evidence for health and well-being as seen in human remains (bones, teeth and other preserved tissues of the body), and as preserved parasite eggs. It takes a biocultural approach and integrates data collected from the remains with the context from which the remains derive. Thus, to understand why people in the past suffered health problems, it is imperative to appreciate how they lived in the environment (including their housing and economy, and to what type of climate they were exposed), what they ate, what work they did, and who they interacted with (through trade, for example). These factors ('extrinsic' to the body) are notwithstanding the effect of biological sex, age, ethnicity, and genetic inheritance on disease occurrence. Indeed, many have said, "genes load the gun and the environment (or lifestyle) pulls the trigger". Palaeopathology also considers the funerary context, which can provide information that contributes to understanding of the place of a particular person in society at the time of their death.

Palaeopathology also has a long history, with various parts of the world seeing different rates of development of this discipline within bioarchaeology (see Buikstra and Roberts 2012 for an overview). It takes a multi-disciplinary, multi-method approach and is question and/or hypothesis driven. The research that has been produced incorporates detailed studies of individual skeletons or mummies (osteobiography), population based approaches considering larger numbers of human remains, and studies of specific diseases. Most research conducted uses a macroscopic approach where bone formation and destruction, and dental and alveolar bone destruction are recorded, their distribution pattern documented, and differential diagnostic options produced (Grauer 2008; Ortner 2012), based on a clinical understanding (Mays 2012). There is guidance for standards relating to data recording (Buikstra and Ubelaker 1994; Brickley and McKinley 2004), an essential consideration if data are to be reliably compared. Histological (Turner-Walker and Mays 2008), imaging (Mays 2008) and biomolecular (Brown and Brown 2011) methods are also used to aid diagnosis of disease, the latter – DNA analysis – particularly developing in their use at a rapid pace (e.g. see Preus et al. 2011).

The first report of ancient DNA survival was reported in 1985 in a mummy, DNA in bones in 1989, and the first 1st pathogen aDNA in 1993 (tuberculosis). This area of study has seen quite incredible developments, supplemented by sequencing of ancient and modern genomes, the latter enabling comparison with the former. The subject matter includes confirming disease diagnosis, helping with differential diagnosis, diagnosing disease in skeletons without bone changes, exploring species or strains of an organism, detecting carriers of disease (not necessarily suffering at the time of death), documenting soft tissue diseases in skeletons, looking at susceptibility and resistance genes, and attempting to look at real frequency rates of disease in populations. This method is, however, not without its challenges (e.g. see Cooper and Poinar 2000; Roberts and Ingham 2008); these include lack of preservation of the DNA, contamination with 'foreign' DNA, the fact that it is a destructive, costly and time consuming method needing specialised facilities, that not everybody uses the same methodology and processes for extracting DNA and interpreting it, and finally that there appears to be many curiosity rather than question driven studies that raise ethical issues regarding the destructive nature of this method using human remains. Nevertheless, this method is providing more nuanced data that could never be accessed using macroscopic analysis.

Alongside all this primary evidence collected using different methods, and analysed and interpreted within 'context', for some human remains there may be contemporary documentary and iconographic evidence that can be used in tandem (Rawcliffe 2006; Barnett 2014). This evidence that supplement and enhance our understanding of the health and well being of our ancestors, but may also provide us with data that is simply not present via human remains (e.g. soft tissue diseases such as the plague).

While the progress of palaeopathology as a discipline is impressive, it must not be forgotten that there are limitations to the study of disease, as seen in human remains and historical documentation (Mitchell 2011). Problems with the former have been well documented in Wood et al (1992) and will not be fully articulated here. However, some key points include: is the 'population' health as seen in skeletons representative of the original living population's health, postmortem damage of skeletons can affect effective recording, there are problems in adult age and sex estimation (relevant to interpretation of the impact of sex and age on disease), there will be unidentifiable subgroups within a population, there is an inability to assess 'frailty' (susceptibility to disease), the bone changes for disease are limited (bone formation/destruction) and many potential diagnoses can be made, people could die before bone, affected and, very importantly, skeletons with chronic (healed) evidence of disease are, essentially, the healthy ones is representing people who survived the acute stages of a disease and lived long enough for the disease to manifest itself on the skeleton. We must be cognizant of these limitations or our interpretations could be very flawed.

'Big' projects on past health

The different types of palaeopathological studies have already been considered above. In this section, some of the 'big' projects on health in the past are considered. Attempting the synthesis of large amounts of data on health is challenging but very rewarding, and technological advancements, such as for searching published and grey literature and database construction, is allowing some ambitious projects to be carried out. We are now moving from a predominance of studying the individual body or skeleton, through to more population studies at particular archaeological sites, and regional studies of health (e.g. in one country), and finally to much larger 'area' studies, such as in Europe or the Americas.

In the early years of palaeopathology, the focus was on studies of disease in individual skeletons or preserved bodies, and much of the earliest work was on animal remains (see Buikstra and Roberts 2012; but also Thomas 2012 in particular). As time passed an increased emphasis was placed on hypothesis/question driven studies of larger populations, on tracing the history of specific diseases, and using methods beyond the 'macroscopic'. A focus was also on integrating the evidence for disease into its wider context to understand the patterns seen. Appreciating how people lived their lives through archaeological and (where available) historical evidence was key to determining why and when diseases appeared in the archaeological record.

Studies in recent years have become much more interdisciplinary and multi-method driven, making use of big datasets, statistical analyses, and advanced analytical methods, such as pathogen aDNA analysis. People tend to work in teams, each with a different expertise; this includes biologists, chemists, historians, archaeologists, clinicians, and biomolecular scientists. This has ensured that it has been possible to do synthetic regional and wider geographical studies of health over long time periods. In addition, the implementation of standards for recording has helped make datasets comparable (Buikstra and Ubelaker 1994; Brickley and McKinley 2004). For example, the Global History of Health Project (European Module): http://global.sbs.ohio-state.edu/european_module.htm) has collected a standardized health dataset from over 17,000 skeletons from European contexts of different time periods in order to chart the history of health on Europe. This is the first time this has been done for such a large sample size of skeletons, requiring each set of data to be entered onto a database where analyses are carried out to show trends in health. Other synthetic studies include Bennike's (1985) study of disease in Danish skeletons, Roberts and Cox (2003) who focused on Britain's health from prehistory to the post-medieval period, and Cohen and Crane-Kramer (2007) which brought together authors of chapters on health from different parts of the world. This was a follow-up on the well-cited book by Cohen and Armelagos (2013) looking at health at the transition to agriculture. Other studies have seen a focus on south-east Asia (Oxenham and Tayles (2006), the Near East (Perry 2012), and the Americas (Steckel and Rose 2002). Projects are now becoming much more ambitious and large, and we are learning much more nuanced information about health in the past through the human remains that are excavated and analysed. Palaeopathology is also contributing to evolutionary medicine.

Three "case studies" to explore environmental impacts on health in more detail

We now turn to exploring three specific examples of how palaeopathology has helped to show how the environment in which people resided had an impact on their health. Upper (sinuses) and lower (lungs) respiratory tract disease, vitamin D deficiency (rickets), and a specific occupationally related disease called 'phossy jaw' are discussed.

Respiratory tract disease (maxillary sinusitis and inflammation of the ribs)

Respiratory health can be affected by many factors in a person or population's environment, including disease, but indoor and outdoor 'pollution' leading to poor air quality has been shown to be a key driver for poor health (http://www.who.int/respiratory/en/). Indeed, Hippocrates in the 5th century BC talked about the importance of clean air in his "Airs, waters and places". The quality of air that we breathe can affect health in many ways. The body cells need energy and that energy is derived from chemical reactions for which oxygen is essential. The respiratory system provides a route for oxygen to enter the body and for carbon dioxide to be excreted (Wilson 1990:123). Particulates that can 'pollute' the respiratory system may be inert (carbon, diesel exhaust), allergens (house dust mite, pollen), or living organisms (bacteria, viruses), alongside gases that are organic (e.g. sulphur dioxide) or inorganic (e.g. tobacco smoke). Furthermore, 'pollution' may be naturally (e.g. volcanic eruptions) or human induced (e.g. car emissions). Detecting respiratory disease in skeletal remains relies on observing inflammatory new bone formation in the maxillary sinuses and on the visceral/internal surfaces of the ribs (Figs 1 and 2). Of note is the general inability for the (often) subtle bone changes in the sinuses and on the ribs to be recognised by a clinician; even a radiograph may not detect these bone changes.

Fig. 1. Maxillary sinusitis in a 12th–16th century person (135) from Fishergate House, York, England (circled).

Fig. 2. Rib lesions as seen in skeleton 187, Robert J Terry Collection, Department of Anthropology, National Museum of Natural History, Smithsonian Institution, Washington DC (lighter new bone formation).

Sinusitis is described as an infection of the paranasal sinuses, which causes headache, facial pain and tenderness (Holgate and Frew 2002:857). In palaeopathology sinusitis is classified as a non-specific reaction to poor air quality, which may be related to pathogens, exposure to smoke from biomass fuels or working in occupations producing "pollution", or even dental disease in the upper molar teeth spreading to the sinus. A limited number of studies have focused on sinusitis in palaeopathology but the general consensus seems to be that sinusitis levels are at their highest in urban populations when compared to rural and hunter-gatherer groups (see Roberts 2007; Sundman et al 2013). This perhaps reflects the fact that as societies become more complex and live in settled communities with high population density, the risk factors for sinusitis increase (e.g. occupations exposing people to poor air quality such as metalworking, and living conditions involving open fires or exposure to animals inhabiting the same space). However, as discussed above, the causes of sinusitis are many, and focusing on one cause for the changes seen in the sinuses of skeletons would be a dangerous palaeopathological interpretation.

Lower respiratory tract disease may be recognised by inflammatory new bone formation on the internal rib surfaces. While not described clinically, enlargement of ribs on a radiograph may suggest new bone formation as a result of lung disease (see Eyler et al. 1994). Again, the causes for these changes are many and may include not only exposure to poor air quality due to environmental "pollution", but also chronic bronchitis, pneumonia, lung cancer, emphysema, and disease caused by specific pathogens such as tuberculosis (TB). Much work on this bone change has emanated from the study of documented skeletal collections with known causes of death to try to establish causation (e.g. Roberts et al. 1994; Santos and Roberts 2001). There have been suggestions that TB more than any other disease is likely to be the cause for these lesions in palaeopathology (e.g. Nicklish et al. 2012), but the lesions are not pathognomonic (specific) for such a diagnosis. Perhaps the most likely explanation for their presence is the result of people living in close contact with each other at high population density in an urban environment, and transmitting their respiratory diseases more readily than they could in a hunter-gatherer society (e.g. see Lambert 2002).

However, TB as a respiratory disease has been a considerable focus of research in palaeopathology (e.g. see Roberts and Buikstra 2003). A bacterial infection (organisms of the *Mycobacterium tuberculosis* complex) that is contracted via the lungs (inhalation) or via the gastrointestinal tract (ingestion from infected meat and milk of animals), it has many risk factors. These include poverty, stress, high population density, lack of vitamin D, working with animals and their products, and migration. TB affects the skeleton particularly in the spine (Figure 3), hip and knee joints, but only in 3–5% of untreated people with TB will develop this (destructive) damage (Resnick and Niwayama 1995). TB has a long palaeopathological history (e.g. see Roberts and Buikstra 2003; also Roberts 2015b) stretching back several thousand years in the Old World, often outdating the historical texts.

This is a disease that has been re-emerging over the last 20 or so years (http://www.who.int/topics/tuberculosis/en/), and TB strains have become resistant to antibiotic treatment. Perhaps this is where palaeopathological research on this disease may help us understand this phenomenon. Since 1993 and the first study of the DNA of the tuberculous bacteria in an archaeo-

Fig. 3. Tuberculosis in the spine of skeleton 181, Robert J Terry Collection, Department of Anthropology, National Museum of Natural History, Smithsonian Institution, Washington DC (affected vertebrae circled – destruction of vertebral bodies).

logical skeleton (Spigelman and Lemma 1993), there has been much work on this disease using this method. As the method has developed and the questions posited about the history of TB have become more ambitious, we are beginning to unravel more about the interaction of people with environments that are conducive to TB development. Ancient DNA analysis has focused on identifying the species (human or animal) that has affected our ancestors, showing that, so far, the majority of research suggests it is the human form of the bacteria. However, it is in the last 10 years, or so, that technology has been able to show with which strains of TB people were affected. This has also been helped by the availability of modern genomic data on the bacteria with which to compare the ancient data (http://genome.tbdb.org/tbdb_sysbio/MultiHome.html). Indeed, modern strains have been isolated in Iron Age England (200BC – Taylor et al 2005) and in 18th/19th century Hungary (Fletcher et al. 2003). Most recently, Bos et al (2014) found 1000 year old Peruvians with TB strains closely related to strains adapted to seals and sea lions. In the Old World, a Natural Environmental Research Council funded project has focused on detecting strains of TB in skeletons mainly from English archaeological sites of different periods. It has become clear from this research that there were indeed different strains of TB in England at varying periods of time. For example, at one Roman site (2nd–3rd century AD) there were two different strains of TB, and at contemporary post-medieval sites (19th century AD), there were different strains (Müller et al. 2014a,b). At another post-medieval site a woman with TB had contracted a strain that was not common in England at that time but was found to be more common in North America (Bouwman et al. 2012). This does suggest that there was a considerable relationship between mobility and the transmission of TB. The differences in strains in people from any time period clearly will be affected by environmental factors, but this continues to be fascinating research in palaeopathology that provides a deep time perspective to the challenge of TB today.

Rickets and osteomalacia

Another environmental factor that can be detrimental to people's health is lack of exposure to ultraviolet light and a consequent deficiency in vitamin D. This vitamin is produced in the skin due to the action of UV light and its presence enables calcium and phosphorous to be absorbed into the bones to make them strong. Lack of vitamin D leads to rickets (or osteomalacia in adults) and 'soft' unmineralised bones (Figures 4 and 5). Rickets is becoming an increasing problem today for the world's children (Holick 2007; http://www.dailymail.co.uk/news/article-2543724/Rickets-soar-children-stay-indoors-Number-diagnosed-disease-quadruples-ten-years.html), and it is exposure to sunlight that is known to be the main source of vitamin D. Children staying indoors for long periods of time, or being protected excessively from the sun by sun cream, are risk factors. While some foods, such as oily fish, have high levels of this vitamin, they do not provide the amounts that are comparable to those derived via exposure to ultraviolet light. It has also been established that vitamin D treatments can decrease the risk of many diseases such as cancers and infectious diseases (Holick ibid). Other

Fig. 4. Model of a boy with rickets displayed at the Wellcome Trust Collections, London.

Fig. 5. Rickets in the lower limb long bones of skeleton 75 (3–4 years old) from Coach Lane, North Shields, Tyne and Wear, England.

risk factors for this condition include the wearing of clothing that covers most of the skin, and staying indoors too much (for example, in hot countries or in work environments).

In the past polluted environments and working long hours in factories were the most likely risk factors. It is well known from historical evidence that rickets in particular increased as environments became more polluted and populations worked indoors, as seen in the industrial period in England, and skeletons from archaeological sites have been diagnosed with rickets (e.g. Mays et al. 2009). Particularly important, however, is where in the world a person resides and how much ultra violet light exposure is available. Of particular interest in this respect are data from the History of Health in Europe, discussed above (Brickley et al. 2009; Fig. 6). Archaeological sites with evidence of skeletons with rickets were most often from sites above 45 degrees latitude where sunlight availability is reduced.

However, one modern study has found that allelic frequencies of apolipoprotein E (ApoE4) vary substantially around the world (e.g. Hu et al. 2011). In Southern Europe they are 10–15% and in Northern Europe they are 40–50%. ApoE4 is linked to higher serum vitamin D levels, and carriers are less likely to develop D deficiency. Of course, UV light exposure is less in the north and consequently we would expect to find more D deficiency there. What would be interesting to find out is whether we can find the ApoE4 preserved in skeletons to prove this association.

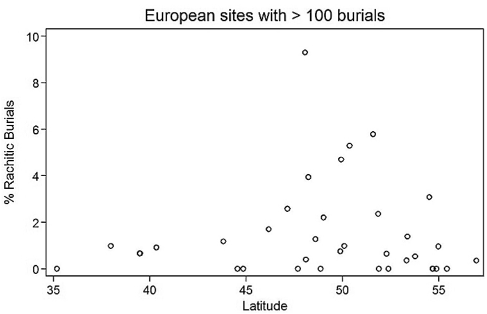


Fig. 6. Rickets in skeletons according to latitude; Global History of Health Project (courtesy of Rick Steckel, Ohio State University, USA).

‘Phossy jaw’

The person whose skeleton is described here may well have also had rickets and worked for long hours inside a factory, and lived in an environment that was polluted. This person was between 12 and 14 years old when they died and were buried in a Quaker cemetery in the north-east of England in North Shields, next to Newcastle-upon-Tyne in the 18th–19th centuries (Roberts et al. 2016). At this time the region was heavily industrialised and historical documentation tells us that there were a number of polluting industries operating. This child suffered from many health problems, likely including rickets, scurvy, and tuberculosis, but the most striking disease evident seen was damage to the lower jaw (Fig. 7). An inflammatory reaction had led to damage to the left side, and the rib surfaces and right elbow joint (Fig. 8) were also affected. Following a consideration of differential diagnoses, it was suggested that this person had been suffering from ‘phossy jaw’. This was an affliction common to those working in the white phosphorus-loaded match making industry at this time, and historical data show a number of said industries in the region. Inhalation of phosphorus occurred through this occupation. It was a painful disease that affected the person’s identi-

Fig. 7. Mandible showing bone formation and destruction from a 12–14 year old person buried in a post-medieval cemetery in North Shields, Tyne and Wear, England, likely illustrating 'phossy jaw'.

Fig. 8. Elbow joint showing bone formation and destruction from a 12–14 year old person buried in a post-medieval cemetery in North Shields, Tyne and Wear, England.

ty, attracted stigma (facial swelling, oral discharge), and could lead to septicaemia and even death. It is possible that phosphorus inhalation also caused the rib lesions evident in this skeleton. Clearly this is a very specific occupationally related disease but shows the environmental effects of the work environment.

These four examples of environment related conditions affecting people in the past illustrate how closely related to environmental risks populations have been in the past, and continue to be today. Bioarchaeology (and palaeopathology in particular) has the potential to show the long dureé of human-environment interaction. Finally we turn to some thoughts on how palaeopathology may develop in the future.

Some thoughts for the future of palaeopathology

Palaeopathology potentially has a huge contribution to make to understanding health today and planning for the future health of the world. Its synergies with evolutionary medicine are clear; evolutionary medicine is dealing with medical problems using evolutionary biology insights, and population health today illustrates that there are mismatches to modern living that are leading to disease (biology cannot keep up with cultural change) – Nesse and Williams 1994. Palaeopathology is relevant to understanding health today (for example, antibiotic resistance, re-merging/emerging disease, change in pathogen virulence). It is also clear that developments in methods will continue, and more research using ancient DNA and other biomolecules to detect the nuances of the past disease experience of our ancestors will become more frequent. It is hoped that more 'big picture' approaches will be taken where large datasets are synthesized, and ambitious questions will be asked of those data, allowing scholars to think more 'outside the box' of the norm for palaeopathology.

However, it is pertinent at this point to highlight three areas of concern. One relates to *ethical issues* and the increasing amount of destructive analysis that is being done using archaeological human remains. In some respects this is inevitable as our methods advance and we have the wherewithal to answer complex questions about the past. However, destructive analyses should only ever be undertaken if the question that is being asked cannot be answered using a non-destructive method. Human remains are a finite resource, apart from the fact that they represent once living people, just like us. Having access to human remains for study is a privilege and not a right, and if we are to study our ancestors' remains we should provide a professional dedicated environment, be respectful of the remains we curate, and emphasise that long-term curation benefits science. The second concern relates to making our palaeopathological research more relevant to the 'here and now' so that our research impacts the living more. Related to this, and an area of specific interest to higher education institutions in the UK, is that increasingly our research is being scrutinized not only for its quality, but for its direct relevance to the needs of commerce, industry, and to the public and voluntary sectors (see http://www.ref.ac.uk). Palaeopathological research has the potential to create "impact" in the UK research assessment sense, and we should promote this opportunity. Finally, we should try not to call skeletons or preserved bodies samples, materials, cases, subjects or specimens. We should respect that they are the remains of people whose identity varied through time and space. We owe that respect to our ancestors.

Corresponding author

Charlotte Ann Roberts, Department of Archaeology, Durham University, South Road, Durham DH1 3LE Great Britain
e-mail address:
c.a.roberts@durham.ac.uk

References

Armelagos GJ, Brown PJ, Turner B. 2005. Evolutionary, historical and political economic perspectives on health and disease. Soc Sci Med 61:755–65.

Barnett R. 2014. The sick rose. Disease and the art of medical illustration. London: Thames and Hudson.

Bennike P. 1985. Paleopathology of Danish skeletons. Copenhagen, Denmark: Akademisk Forlag.

Bos KI. et al. 2014. Pre-Columbian mycobacterial genomes reveal seals as a source of New World human tuberculosis. Nature 514:4–497.

Bouwman AS, Kennedy SL, Muller R, Stephens RH, Holst M, Caffell AC, Roberts CA, Brown TA. 2012. Genotype of a historic strain of Mycobacterium tuberculosis. Proceedings of the National Academy of Sciences of the United States of America 109(45):18511–6.

Brickley M, Buteux S. 2006. St Martin's Uncovered: Investigations in the Churchyard of St. Martin's-in-the-Bull Ring, Birmingham, 2001. Oxford: Oxbow Books.

Brickley M, McKinley J editors. 2004. Guidelines to the standards for recording human remains. Reading: Institute of Field Archaeologists Paper Number 7.

Brickley M et al. 2009 Socio-culturally mediated disease: rickets and scurvy. Poster presented in the symposium Reconstructing health and disease in Europe. The early Middle Ages through the Industrial Period. American Association of Physical Anthropologists Annual Meeting, Chicago, USA.

Brown TA, Brown K 2011. Biomolecular archaeology. An introduction. Oxford: Wiley-Blackwell.

Buikstra JE, Roberts CA. (eds) 2012. The global history of palaeopathology. Pioneers and prospects. Oxford: University Press.

Buikstra J, Ubelaker D. (eds) 1994. Standards for data collection from human skeletal remains. Arkansas: Archeological Survey Research Seminar Series 44.

Cohen M. 1989. Health and the rise of civilisation. Yale, Yale University Press.

Cohen M, Armelagos G. (eds) 2013. Palaeopathology at the origins of agriculture. Reprint of 1984 publication). Gainesville, Florida: University Press of Florida.

Cohen MN, Crane-Kramer GMM. (eds) 2007. Ancient Health: Skeletal Indicators of Agricultural and Economic Intensification. Gainesville, Florida: Florida University Press.

Connell B, Gray Jones A, Redfern R, Walker D. 2012. A bioarchaeological study of the medieval burials on the site of St Mary Spital. Excavations at Spitalfields Market, London E1, 1991–2007.London: Museum of London Archaeology Monograph 60.

Cooper A, Poinar H. 2000. Ancient DNA. Do it right or not at all. Science 289:1139.

Eyler WR, Monsein LH, Beute GH, Tilley B, Schultz LR, Schmitt WGH. 1996. Rib enlargement in patients with chronic pleural disease. Am J Radiol 167:921–6.

Fletcher HA, Donoghue HD, Holton J, Pap I, Spigelman M. 2003. Widespread occurrence of Mycobacterium tuberculosis DNA from 18th–19th century Hungarians. Am J Phys Anthropol 120:144–52.

Gowland R, Knüsel C editors. 2006. Social archaeology of funerary remains. Oxford: Oxbow Books.

Grauer AL. 2008. Macroscopic analysis and data collection in palaeopathology. In: R Pinhasi, S Mays, editors. Advances in human palaeopathology. Chichester: Wiley. 57–76.

Groves SE, Roberts CA, Lucy S, Pearson G, Gröcke DR, Nowell G, Macpherson CG, Young G. 2013. Mobility histories of 7th–9th century AD people buried at Early Medieval Bamburgh, Northumberland, England. Am J Phys Anthropol 151:462–76.

Holgate ST, Frew A. 2002. Respiratory disease. In: P Kumar, M Clark editors. Kumar and Clark Clinical medicine. 5th edition. Edinburgh: WB Saunders. 833–955.

Holick MF. 2007 .Vitamin D Deficiency. New England J Medicine 357:266–81.

Hu P, Qin YH, Jing CX, Lu L, Hu B, Du PF. 2011. Does the geographical gradient of ApoE4 allele exist in China? A systemic comparison among multiple Chinese populations. Mol Biol Rep 38:489–94.

Kintigh KW, Altschul JH, Beaudry MC, Drennan RD, Kinzig AP, Kohler TA, Limp WF, Maschner HDG, Muchener WK, Pauketat TR, Peregrone P, Sabloff JA, Wilkinson TJ, Wright HT, Zeder MA. 2014a Grand challenges for archaeology. Proc National Academy of Sciences 111:879–80.

Kintigh KW, Altschul JH, Beaudry MC, Drennan RD, Kinzig AP, Kohler TA, Limp WF, Maschner HDG, Muchener WK, Pauketat TR, Peregrone P, Sabloff JA, Wilkinson TJ, Wright HT, Zeder MA. 2014a. Grand challenges for archaeology. 2014b Grand challenges for archaeology. American Antiquity 79:5–24.

Lambert P. 2002. Rib lesions in a prehistoric Puebloan sample from Southwestern Colorado. Am J Phys Anthropol 117:281–92.

Lukacs JR. 2007. Climate, subsistence and health in prehistoric India. The biological impact of a short-term subsistence shift. In: MN Cohen, GMM Crane-Kramer, editors. Ancient Health: Skeletal Indicators of Agricultural and Economic Intensification. Gainesville, Florida: University Press of Florida. 237–49.

Mays S. 2008. Radiography and allied techniques in the palaeopathology of skeletal remains. In R Pinhasi, S Mays, editors. Advances in human palaeopathology. Chichester: Wiley. 77–100.

Mays S. 2012. The relationship between palaeopathology and the clinical sciences. In: AL Grauer, editor. A companion to paleopathology. Cambridge: University Press. 285–309.

Mays M, Brickley M, Ives R. 2009. Growth and vitamin D deficiency in a population from 19th century Birmingham, England. Int J Osteoarchaeol 19:406–15.

Mitchell PD. 2011. Retrospective diagnosis and the use of historical texts for investigating disease in the past. Int J Paleopathol 1:81–8.

Molleson T, Cox M. 1993. The Spitalfields Project. Volume 2: The Anthropology: The Middling Sort. York: Council for British Archaeology Research Report 86.

Müller R, Roberts CA, Brown T. 2014a. Biomolecular identification of ancient Mycobacterium tuberculosis complex DNA in human remains from Britain and Continental Europe. Am J Phys Anthropol 153:178–89.

Müller R, Roberts CA, Brown T. 2014b. Genotyping of ancient Mycobacterium tuberculosis strains reveals historic genetic diversity. Proceedings of the Royal Society B: Biological Sciences 281(1781): 2013–3236.

Nesse RM, Williams GC. 1994. Why we get sick. The new science of Darwinian medicine. New York: Vintage Books.

Nicklish N, Maixner F, Ganslmeier R, Friederich S, Dresely V, Meller H, Zink A, Alt KW. 2012. Rib lesions in skeletons from early Neolithic sites in central Germany: on the trail of tuberculosis at the onset of agriculture. Am J Phys Anthropol 149:391–404.

Oxenham M, Tayles N editors. 2006. Bioarchaeology of Southeast Asia. Cambridge: University Press.

Park K. 1993. Black death. In: K Kiple, editor. The Cambridge world history of human disease. Cambridge: University Press. 612–15.

Perry MA. 2012. Bioarchaeology and Behavior: The People of the Ancient Near East (Bioarchaeological Interpretations of the Human Past: Local, Regional, and Global). Gainesville, Florida: University Press of Florida.

Pinhasi R, Stock JT editors. 2011. Human Bioarchaeology of the transition to agriculture. Chichester: Wiley-Blackwell.

Preus HR, Marvik OJ, Selvig KA, Bennike P. 2011. Ancient bacterial DNA (aDNA) in dental calculus from archaeological human remains. J Archaeol Sci 38:1827–31.

Ortner DJ. 2012. Differential diagnosis and issues in disease classification. In: AL Grauer, editor. A companion to paleopathology. Cambridge: University Press. 250–267.

Rawcliffe C. 2006. Leprosy in medieval England. Woodbridge: Boydell Press.

Resnick D, Niwayama G. 1995. Osteomyelitis, septic arthritis and soft tissue infection: orgnaisms. In: D Resnick, editor. Diagnosis of bone and joint disorders. 3rd edition. London: WB Saunders. 2448–558.

Roberts CA, Caffell A, Filipek KL, Gowland R, Jakob T. 2016. Til Poison Phosphorous Brought them Death': A potentially occupationally-related disease in a post-medieval skeleton from northeast England. Int J Paleopathol 13:39–48.

Roberts CA. 2007. A bioarcheological study of maxillary sinusitis. Am J Phys Anthropol 133:792–807.

Roberts CA. 2010. Adaptation of populations to changing environments: Bioarchaeological perspectives on health for the past, present and future. Bulletins et Mémoires de la Société d'Anthropologie de Paris 22:38–46.

Roberts CA. 2009. Human remains in archaeology: a handbook. York: Council for British Archaeology.

Roberts CA. 2015a. What did agriculture do for us? The bioarchaeology of health and diet. In: G Barker, C Goucher, editors. The Cambridge World History. Volume 2: A world with agriculture, 12,000 BCE–500 CE. Cambridge: University Press. 93–123.

Roberts CA. 2015b. Old World tuberculosis: evidence from human remains with a review of current research and future prospects. Tuberculosis 95: S117–21.

Roberts CA, Buikstra JE. 2003. The bioarcheology of tuberculosis: a global view on a re-emerging disease. Gainesville, Florida: University Press of Florida.

Roberts CA, Cox M. 2003. Health and disease in Britain: prehistory to the present day. Gloucester; Sutton Publishing.
Roberts C, Manchester K. 2005. The archaeology of disease. 3rd edition. Stroud: Sutton Publishing.
Roberts CA, Ingham S. 2008. Using ancient DNA analysis in palaeopathology: a critical analysis of published papers with recommendations for future work. Int J Osteoarchaeol 18:600–13.
Roberts C, Lucy D, Manchester K. 1994. Inflammatory lesions of ribs: an analysis of the Terry Collection. Am J Phys Anthropol 95:169–82.
Santos AL, Roberts CA. 2001. A picture of tuberculosis in young Portuguese people in the early 20th century. Am J Phys Anthropol 115:38–49.
Spigelman M, Lemma E. 1993. The use of the polymerase chain reaction (PCR) to detect Mycobacterium tuberculosis in ancient skeletons. Int J Osteoarchaeol 3:137–43.
Stearns S. 2012. Evolutionary medicine: its scope, interest and potential. Proceedings of the Royal Society B 279:4305–4321.
Steckel RH, Rose JC editors. 2002. The backbone of history. Health and nutrition in the Western Hemisphere. Cambridge: University Press.
Sundman EA, Kjellström A. 2013. Signs of Sinusitis in Times of Urbanization in Viking Age-Early Medieval Sweden. J Archaeol Sci 40:4457–65.
Tayles N, Domett K, Nelsen K. 2000. Agriculture and dental caries? The case of rice in prehistoric Southeast Asia. World Archaeolology 32:68–83.
Taylor GM, Young DB, Mays S. 2005. Genotypic analysis of the earliest known prehistoric case of tuberculosis in Britain. J Clin Microbiol 43:2236–40.
Thomas R. 2012. Nonhuman paleopathology. In: JE Buikstra, CA Roberts, editors. The global history of palaeopathology. Pioneers and prospects. Oxford: University Press. 652–64.
Trinkaus E. 2005. Pathology and the posture of the La Chapelle-aux-Saints Neandertal. American J Physical Anthropology 67:19–41.
Turner-Walker G, Mays S. 2008. Histological studies of ancient bone. In: R Pinhasi, S Mays, editors. Advances in human palaeopathology. Chichester: Wiley. 121–46.
Venkat A, Asher SL, Wolf L, Geiderman JM et al. 2015. Ethical Issues in the Response to Ebola Virus Disease in United States Emergency Departments: A Position Paper of the American College of Emergency Physicians, the Emergency Nurses Association, and the Society for Academic Emergency Medicine. Academic Emergency Medicine 22:605–615.
Wilkinson R, Pickett K. 2009. The spirit level. Why equality is better for everyone. London: Penguin Books.
Wilson KJW. 1990. Ross and Wilson Anatomy and Physiology in health and illness. Edinburgh: Churchill Livingstone.
Wood JW, Milner GR, Harpending HC, Weiss KM. 1992. The osteological paradox. Problems of inferring health from skeletal samples. Curr Anthropol 33:343–70.
World Bank. 2015. The Socio-Economic Impacts of Ebola in Liberia. Results from a High Frequency Cell Phone Survey Round 5. April 15, 2015. World Bank Group.