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Creating communities of care: Sex estimation and mobility histories of adolescents buried in the cemetery of St. Mary Magdalen leprosarium (Winchester, England)

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Abstract

Objectives: This study examines the biological sex and geographical origins of adolescents buried at the St Mary Magdalen leprosarium (Winchester, UK). The data are combined with archaeological and palaeopathological evidence to broaden the understanding of mobility and its relationship to leprosy and leprosaria in Medieval England.

Materials and Methods: Nineteen individuals (~10–25 at death) with skeletal lesions diagnostic of leprosy were analyzed using standard osteological methods. Amelogenin peptides were extracted from five individuals whose biological sex could not be assessed from macroscopic methods. Enamel samples were analyzed to produce $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values to explore mobility histories.

Results: Amelogenin peptides revealed three males and two females. Tooth enamel samples provided an $^{87}Sr/^{86}Sr$ ratio range from 0.7084 to 0.7103 (mean 0.7090, ±0.0012, 2σ). $\delta^{18}O_P$ values show a wide range of 15.6‰–19.3‰ (mean 17.8 ± 1.6‰ 2σ), with corresponding $\delta^{18}O_{DW}$ values ranging from −9.7‰ to −4.1‰ (mean −6.3 ± 2.4‰ 2σ).

Discussion: Amelogenin peptide data reveal the presence of adolescent females with bone changes of leprosy, making them the youngest confirmed females with leprosy in the archaeological record. Results also show at least 12 adolescents were local, and seven were from further afield, including outside Britain. Since St. Mary Magdalen was a leprosarium, it is possible that these people traveled there specifically for care. Archaeological and palaeopathological data support the notion that care was provided at this facility and that leprosy stigma, as we understand it today, may not have existed in this time and place.

KEYWORDS
amelogenin peptides, infectious disease, isotope analyses, medieval, palaeopathology

1 | INTRODUCTION

1.1 | Leprosy in the present and past

Leprosy, also known as Hansen's Disease, is a bacterial infection caused by *Mycobacterium leprae* or *Mycobacterium lepromatosis*. Clinically, leprosy is a disease of the peripheral nervous system that possesses the capacity to affect the skin, extremities, vocal and respiratory tracts, mucous membranes, eyes, kidneys, endocrine system, and bone (Davey & Schenck, 1964; Walker & Lockwood, 2006). Leprosy is considered a spectral disease meaning the "type" of leprosy a person can develop presents along a broad immune spectrum, ranging from the high immune-resistant tuberculoid form (paucibacillary) to the low immune-resistant lepromatous form (multibacillary) (Lastória & Abreu, 2014; Walker & Lockwood, 2006). Lepromatous leprosy elicits pathognomonic or diagnostic patterning of lesions that allow it to be identified in archaeological skeletons (Møller-Christensen, 1961). These skeletal lesions include destruction and damage to the facial bones (resorption of the anterior nasal spine, remodeling of the nasal margins, abnormally porous/new bone formation on the oral and nasal surfaces of the palatal bones, destruction of the inferior nasal conchae, and vomer, abnormal porosity and resorption of the alveolar process), and characteristic destruction and remodeling of the hand and foot bones (acro-osteolysis and concentric atrophy of the metacarpals, metatarsals, and the phalanges (see Andersen et al., 1992; Andersen et al., 1994; Andersen & Manchester, 1987; Andersen & Manchester, 1988; Andersen & Manchester, 1992; Møller-Christensen, 1961; Ortner, 2008).

Leprosy has a complex biological and social history, and today may be linked with stigma and community expulsion in endemic areas. Although leprosy is commonly associated with medieval Europe, approximately 200,000 people are currently diagnosed with the infection annually (World Health Organization, 2019). Once infected, leprosy-causing mycobacteria multiply slowly, and the infection has a prolonged incubation period that can last upwards of 30 years (Bhat & Prakash, 2012; World Health Organization, 2015). Leprosy can affect people of all ages, but is considered rare in younger individuals, likely due to its lengthy incubation period (Bhat & Prakash, 2012; World Health Organization, 2015). However, when compared to adults, non-adults who do develop leprosy are at an increased risk of developing the more severe lepromatous form potentially with subsequent permanent disabilities, complicated by issues of delayed diagnosis, inadequate nutrition, immunodeficiencies, and pubertal endocrine system disruption (Butlin & Withington, 2018; Davey & Schenck, 1964; John et al., 2005). In situations where leprosy affects people who have not reached adulthood, medical treatment and community education related to de-stigmatization are of equal importance for familial, community, and hospital care networks (Butlin & Withington, 2018). Unsurprisingly, leprosy rates in children are higher in those who have familial contacts with leprosy (Fine, 1982; Goulart & Goulart, 2008; Jain et al., 2002; Jopling & McDougall, 1988; Lydyard et al., 2010; Melsom et al., 1980).

Although the effects of leprosy and courses of treatment for young people are well documented today through the World Health Organization and its affiliated charities (e.g., Lepra), archaeological evidence of leprosy in children, including how they were treated and attitudes of society to those affected, is notably absent in the published literature. Many historical sources repeatedly cite that people with leprosy in the past were expelled from their communities and treated poorly, but recent evidence suggests that this interpretation is a more contemporary view tied to colonialist narratives and medical racism (Edmond, 2006 pp. 61–109; Rawcliffe, 2006, pp. 13–43). This calls into question whether the historical and archaeological evidence of leprosy-related stigma and community expulsion in the Medieval Period can be supported (Filipek, Roberts, Gowland, & Tucker, 2021; Demaitre, 2007, pp. 99–102; Rawcliffe, 2006, pp. 67–78; Roberts, 2020, p. 280; Touati, 2000). In reviews of archaeological contexts that include skeletons with evidence of leprosy from Prehistory through the Medieval Periods in Asia, Africa, and Europe, there is usually no differentiation in the burial treatment of those with leprosy for the time and place (Baker & Bolhofner, 2014; Matczak & Kozłowski, 2017; Roberts, 2020: overview, 191–280; Filipek, Roberts, Gowland, & Tucker, 2021). In addition to treatment after death, pathological lesions present on the skeletons of people with leprosy can be interpreted within the "Index of Care" framework (Tilley, 2017; Tilley & Cameron, 2014) to assess whether individuals were provided with care (clinical and communal) during life. Although previous studies supported hints of a "community of care" (Filipek, Roberts, Gowland, & Tucker, 2021; Matczak & Kozłowski, 2017; Roberts, 2017), the "Index of Care" framework is limited by the incomplete nature of osteological data and the variable manifestation of skeletal pathologies, thereby meriting more nuanced studies to enrich these concepts of care in the past. More recently, analyses of mobility isotope data ($^{87}Sr/^{86}Sr$ and $\delta^{18}O$) derived from adolescents with leprosy buried at the Late Saxon (10th–11th centuries AD) parish cemetery of St. John at the Castle Gate/Timberhill (Norwich, England) revealed isotope values consistent with their burial location (Filipek, Roberts, Gowland, Montgomery, & Evans, 2021). This study indicated that not only were young people with leprosy included within their community parish cemeteries, but also their burial contexts demonstrated a level of care in their construction suggesting that the oft-cited narrative of leprosy stigma and expulsion may not have been present in this time and place (Filipek, Roberts, Gowland, Montgomery, & Evans, 2021). To interrogate these concepts of potential stigma or care further, biomolecular analyses of unique leprosy contexts, such as dedicated leprosy hospitals (also known as leprosaria), is warranted to observe if any differences in mobility histories exist when compared to non-leprosaria contexts (e.g., parish cemeteries).

The aim of this paper is to explore social reactions towards young people with leprosy buried at the St. Mary Magdalen leprosarium (9th–12th centuries AD; Winchester, Hampshire, England). In doing so, it examines amelogenin peptides and strontium and oxygen isotope ratios derived from the enamel of late forming teeth of adolescent individuals (~10–25) with leprosy. The objective was to explore the mobility histories of individuals with leprosy and question who, if anyone, was moving during their lives. These data are combined with archaeological and palaeopathological evidence to provide a broader

understanding of mobility and the experiences of leprosarium residents in Winchester.

1.2 | Archaeological context

The Magdalen Hill Archaeological Research Project (MHARP) began in 2007 with the aim of investigating the archaeological development of the St. Mary Magdalen leprosarium, Winchester (Figure 1) and its later transformation into other facilities (e.g., 16th century AD almshouse, English Civil War military camp, and a 17th century AD prison for Dutch prisoners of war). The first documentary reference to the site as a dedicated leprosarium can be traced to 1148 from the Winton Domesday, with a later re-foundation ~1180; however, archaeological evidence suggests the original foundation precedes this date (Barlow et al., 1976:90;Roffey, 2012; Roffey & Tucker, 2012). Archaeological evidence for these earlier phases includes a range of timber buildings with linear features, small

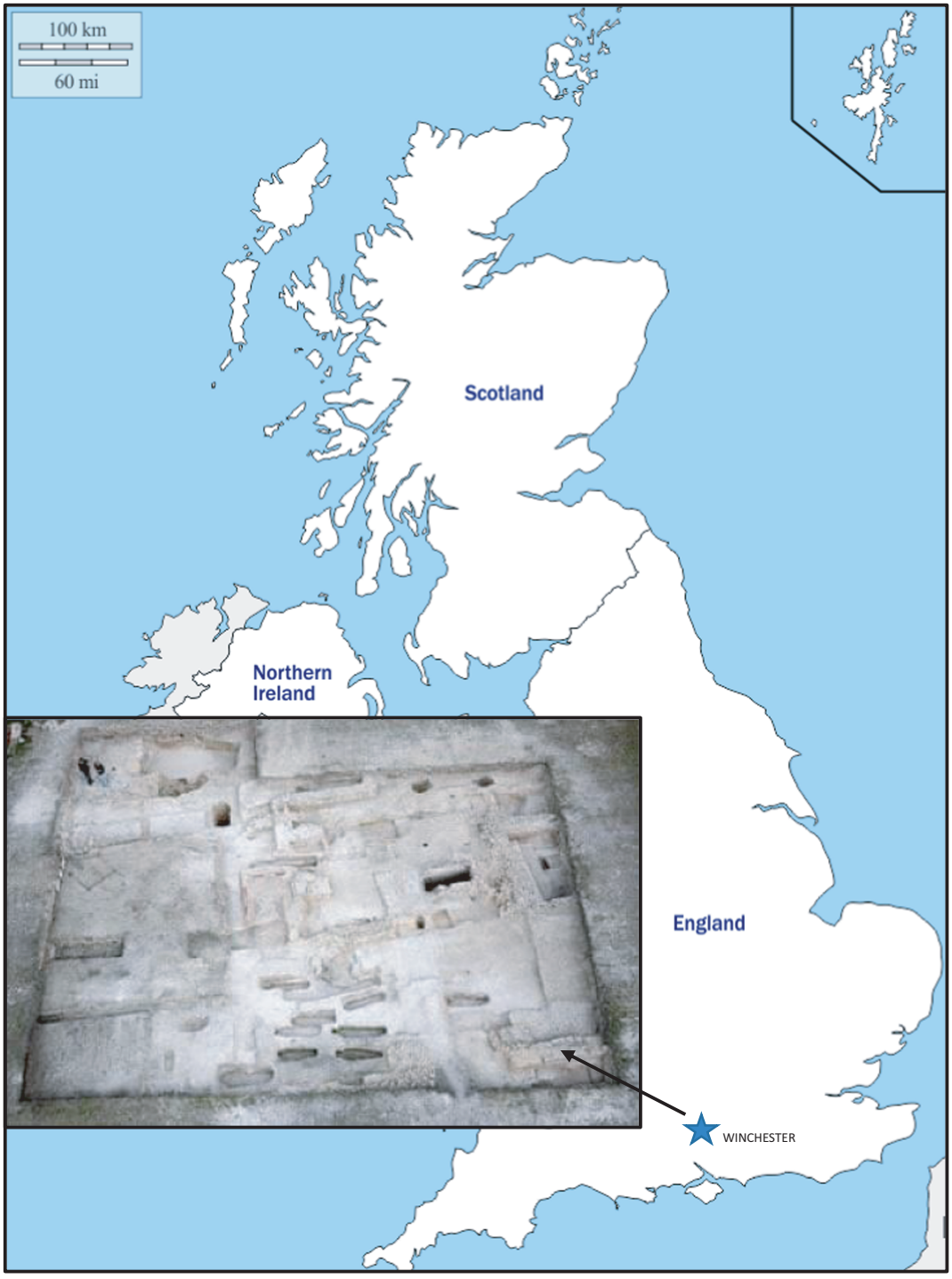

FIGURE 1 Location of Winchester with aerial view of excavations of St. Mary Magdalen leprosarium (inset)

masonry structures, and a cemetery, all of which underlay the re-foundation of the documented hospital in the 12th century (Roffey, 2012; Roffey & Tucker, 2012). The area of the cemetery associated with this earlier context (North Cemetery) is archaeologically distinct from the area (South Cemetery) that is associated with the site's 12th century AD re-foundation (Roffey & Tucker, 2012; Roffey, 2012). Skeletal analyses of people who were buried within the North Cemetery show over half were children and adolescents (<25 years), and the entire burial population showed a high prevalence (~86%) of skeletal lesions diagnostic of lepromatous leprosy (Filipek, Roberts, Gowland, & Tucker, 2021; Roffey & Tucker, 2012). Radiocarbon dates from the North Cemetery (Table 1) suggest these earlier burials likely began sometime in the 10th century AD, and excavations reveal that individuals were interred in discrete, anthropomorphic graves with westward-facing head niches/earthen pillows, demonstrating a considerable degree of care in their construction (Gilchrist & Sloane, 2005, pp. 132–133; Roffey & Tucker, 2012). Burial goods were also found, which is a relatively rare phenomenon in medieval Christian cemeteries within the United Kingdom (Roffey, 2020; Roffey & Tucker, 2012). For example, Sk. 27 was found with a pilgrim badge from the shrine of St James at the Santiago de Compostela Monastery in Spain (Roffey et al., 2017), and Sk. 19 was found with artifacts adapted for another use (e.g., modified feeding bowls) associated with difficulties this individual may have experienced with eating as a consequence of leprosy (e.g., impaired hand function, as inferred from bilateral bone changes of the hand bones) (Filipek, Roberts, Gowland, & Tucker, 2021; Lastória & Abreu, 2014; Roffey & Tucker, 2012). The use of personalized assistive devices has also recently been documented in people with leprosy with "Grade 2 disabilities" (i.e., visible deformity or damage to the extremities, and/or severe visual impairment) in Brazil (Ferreira et al., 2018). These have enabled a number of individuals to regain independence in oral hygiene, although a reluctance to use the devices was noted in some, whether through frustration, lack of interest in learning how to use them, shame, or a denial of disability (Ferreira et al., 2018). Sk. 19 also had evidence of a well-healed amputation of his left foot, still a common treatment option for people with leprosy (da Costa Silva et al., 2014), suggesting some level of individualized medical and palliative care at St. Mary Magdalen (Filipek, Roberts, Gowland, & Tucker, 2021; Roffey & Tucker, 2012).

In contrast to the North Cemetery, all burials in the South Cemetery (post-1150 AD) had notably different alignments and revealed more haphazard burial treatments (e.g., multiple and truncated burials with no anthropomorphic grave cuts). This may indicate some degree of change over time in social perceptions of leprosy, evidenced by differences in burial practices at the site. The individuals in the South Cemetery also revealed a lower prevalence of lepromatous leprosy (<40%) (Roffey & Tucker, 2012), which is consistent with other post-12th-century leprosaria contexts in England (e.g., Chichester: Lee & Magilton, 2008, pp. 263–265). This perhaps signifies that the type of leprosy present during the Later Medieval Period was less severe (towards the tuberculoid or paucibacillary end of the immune spectrum) and therefore did not leave any skeletal lesions, and/or methods for diagnosing leprosy altered from the 13th century AD onwards (Demaitre, 1985, 2007, pp. 35–38; Touati, 2000).

It may also be a general reflection of a decline in the prevalence of leprosy in the Later Medieval Period (14th century onwards), possibly due to the rise of other infectious diseases, such as the Black Death and tuberculosis (Crespo et al., 2019; Manchester, 1984; Manchester & Roberts, 1989; Roberts, 2020, pp. 291–301; Roffey & Tucker, 2012). In common with leprosaria elsewhere in England, St. Mary Magdalen in Winchester had ceased to function exclusively as a leprosarium by the 14th century AD (Roberts, 1986; Roffey & Tucker, 2012). Linking together data for disease evident in individuals buried in these early care facilities with information on their origin, will help to contribute to a growing body of evidence on mobility histories and the potential care and treatment the sick received in the past.

1.3 | Evidence for leprosy in the young people buried at St. Mary Magdalen

An infectious pathological stimulus will only produce skeletal changes if the affected person had the disease for long enough before death (Wood et al., 1992). This is especially relevant when viewing the severe and potentially debilitating bone changes diagnostic of lepromatous leprosy in the adolescent cohorts at St. Mary Magdalen. The pathognomonic lesions present include rhinomaxillary changes (Figure 2), acro-osteolysis and concentric atrophy of the hands and feet, "knife-edge" or mediolateral remodeling of the metatarsal shafts, resorptive grooves on the palmar surfaces of the hand phalanges caused by flexion contractures of the fingers (termed volar grooving—Andersen & Manchester, 1987), tarsal fusion and dorsal exostoses

TABLE 1 Radiocarbon dates and SNP types for individuals buried at St. Mary Magdalen (Winchester, England)

Individual	Cemetery	Cal. ^{14}C date (95% CI)	SNP type	Reference
Sk. 8	North	AD 1010–1160	2F	Roffey and Tucker (2012)
Sk. 9	North	AD 890–1040	N/A	Roffey (2012)
Sk. 14	North	AD 995–1033	2F	Schuenemann et al. (2013)
Sk. 27	North	AD 1020–1162	2F	Roffey et al. (2017)
Sk. 2	South	AD 1268–1283	3I	Schuenemann et al. (2013)
Sk. 5	Chapel	AD 1290–1410	N/A	Roffey and Tucker (2012)

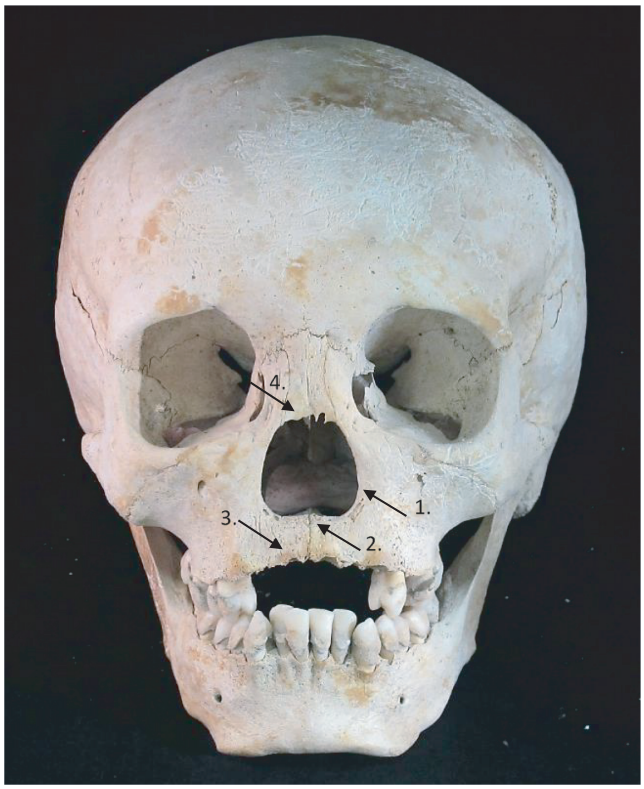

FIGURE 2 Skull of Sk. 28 (aged 12.5–13.5) from St. Mary Magdalen Leprosy Hospital (Winchester, England) displaying evidence of rhinomaxillary syndrome (black arrows) including (1) rounding of the nasal aperture, (2) resorption of the anterior nasal spine, (3) recession of the alveolar process, and (4) widening and flattening of the nasal bones

due to a drop foot (Andersen & Manchester, 1987, 1988), and subperiosteal new bone formation on the distal shafts of the tibiae and fibulae. Four individuals (SK. 8, SK. 28, SK. 52, SK. 56) also showed evidence for leprogenic odontodysplasia (Figure 3), or concentric constriction and dysplastic development of the anterior maxillary dentition caused by leprosy bacilli infiltration into the developing tooth in early childhood, via inhalation of the bacteria into the mouth and nose (Danielsen, 1970; Reichart, 1976). The development of leprogenic odontodysplasia and the pathological skeletal lesions associated with lepromatous leprosy are presumed to commence at approximately the same time (Ortner, 2008), revealing a more defined chronology for the onset of skeletal changes and the time elapsed before death.

Although St. Mary Magdalen leprosy hospital was referenced as a dedicated leprosarium in the mid-12th century AD (Roffey & Marter, 2012), it is important to note there were several other concomitant pathologies identified in these skeletons. All the young people from the hospital cemetery possessed at least one nonspecific indicator of childhood stress (linear enamel hypoplasia and/or cribra orbitalia), and eight yielded a higher dental development age in comparison to their skeletal age (long bone lengths shorter for their age, as estimated by dental development and eruption). Both these observations potentially indicate some form of arrested development as a consequence of leprosy but other aetiologies likely factor, for example, early childhood

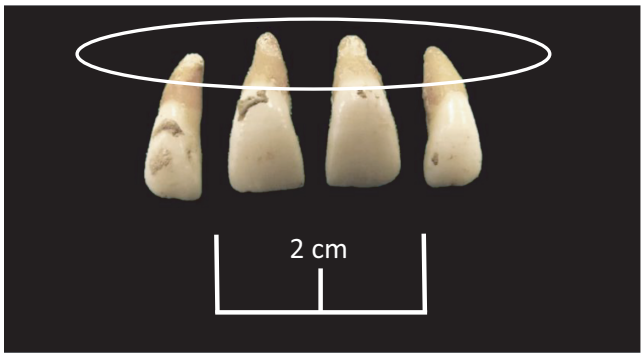

FIGURE 3 Leprogenic odontodysplasia (arrested development of the tooth roots) in the maxillary incisors of Sk. 56 due to infiltration of *Mycobacterium leprae* (encircled). Based on dental development (AlQahtani et al., 2010; Moorrees et al., 1963), this arrested growth would have occurred between 6.5–7.5 years of age

nutritional stresses. Other comorbidities within this young cohort included: pathologically induced fractures, possible tuberculosis or mycotic infections, and residual rickets. Individuals also displayed high levels of dental calculus formation (i.e., mineralized plaque), which is commonly found amongst patients with lepromatous leprosy today and may be an indicator of poor oral hygiene resulting from inflammation of the oral cavity, mouth-breathing due to facial paralysis, and/or chronic inflammation/congestion of the nasal passages, a softer pulpy diet, or a combination of the above (Ogden & Lee, 2008; Rawlani et al., 2011; Reichart, 1976; Roffey et al., 2017; Souza et al., 2009).

Previous aDNA analyses of individuals buried in the cemetery associated with St. Mary Magdalen revealed the presence of two different single nucleotide polymorphisms (SNP) types and subtypes of *M. leprae*: 3I and 2F (Table 1). Type 3I likely originated in Central Asia and, until recently, was thought to be the sole strain type responsible for all European leprosy (both archaeological and modern) (Economou et al., 2013; Mendum et al., 2014; Monot et al., 2009; Schuenemann et al., 2013; Schuenemann et al., 2018; Taylor et al., 2013). Type 2F is considered the precursor strain that migrated with humans from the Middle East to modern-day India and South-East Asia (Economou et al., 2013; Mendum et al., 2014; Monot et al., 2009; Schuenemann et al., 2013; Schuenemann et al., 2018; Taylor et al., 2013). The appearance of the 2F strain at St. Mary Magdalen is of particular relevance having only been previously identified in a skeleton from a seventh-century tomb in Italy (Belcastro et al., 2005; Donoghue et al., 2015) and concurrent Scandinavian and Irish contexts (Economou et al., 2013; Mendum et al., 2014; Schuenemann et al., 2018; Taylor et al., 2018). The presence of this strain is linked to extended Middle Eastern trade networks, suggesting extensive geographical connections that aided medieval dissemination of the disease (Donoghue et al., 2015; Economou et al., 2013; Mendum et al., 2014; Schuenemann et al., 2018). In order to view whether these younger cohorts with skeletal lesions diagnostic of lepromatous leprosy were from areas local to the leprosarium or from further afield, we applied strontium and oxygen isotope analysis of tooth enamel from late-forming teeth (e.g., second or third molars).

1.4 | Isotopic background

The analysis of the strontium ($^{87}Sr/^{86}Sr$) and oxygen ($\delta^{18}O$) isotope ratios of tooth enamel is a robust and well-established method for examining an individual's geographic origins in archaeology and forensic science (Bartelink & Chesson, 2019; Bentley, 2006; Chenery et al., 2010; Eckardt et al., 2009; Evans et al., 2010; Evans et al., 2012; Evans, Chenery, & Fitzpatrick, 2006; Evans, Stoodley, & Chenery, 2006; Montgomery, 2010; Moore et al., 2020). Tooth enamel is an avascular acellular tissue that is highly resistant to isotopic alterations both after mineralization and in the postmortem burial environment, making it highly suitable for multi-isotope analysis (Budd et al., 2000; Montgomery, 2010; Moore et al., 2020). The strontium ratios and oxygen isotope values of enamel are ultimately subsumed through the ingestion of food and water during the development of the enamel of the teeth, respectively, and are linked to the geological and climactic biospheres during the enamel's mineralization periods (Evans et al., 2010; Evans et al., 2012). Strontium weathers from the bedrock into soil and subsequently through the human food chain largely unfractionated. Therefore, strontium ratios within enamel can directly reflect the geological area from which an individual derived their food and water during childhood and adolescence (Bentley, 2006; Coelho et al., 2017; Montgomery, 2010). Oxygen isotope values derived from enamel reflect an individual's drinking water values and indirectly reflect the isotopic composition of a location's meteoric water, which varies by altitude, temperature, latitude, and other climatic factors (Darling et al., 2003; Darling & Talbot, 2003; Evans et al., 2012; Pederzani & Britton, 2019). Once consumed, oxygen undergoes a metabolic fractionation process, and therefore regression formulae (see Section 2.5 Isotope methods) must be applied to values in order to make comparisons with modern data (Chenery et al., 2010; Chenery et al., 2012; Daux et al., 2008). Interpretation of $\delta^{18}O$ results must also consider the potential influence of other biological and culturally mediated behaviors, such as the alteration of water temperature in the preparation of foodstuffs (e.g., stewing, brewing, and boiling: Brettell et al., 2012), pathophysiological influences (e.g., diabetes and anemia; Reitsema, 2013), or additional metabolic fractionations through other biological processes (e.g., ingestion of breast milk: Wright & Schwarcz, 1998; Tsutaya & Yoneda, 2015).

Based on these principles, both isotope systems can reveal whether strontium and oxygen isotope values from adolescents buried within this leprosarium context are consistent with their burial location when their tooth enamel was developing. Despite being a key factor in disease transmission and the subsequent social milieu surrounding disease status, few studies have examined the mobility histories of individuals with skeletal lesions diagnostic of specific infectious diseases (but see Kendall et al., 2013; Quinn, 2017; Roberts et al., 2013; Roffey et al., 2017). This is in part due to the difficulty in establishing whether a person was infected with the disease before, during, or after moving to the area where they were buried (Kendall et al., 2013; Quinn, 2017; Roberts et al., 2013; Roffey et al., 2017). By examining isotope ratios from younger individuals, the likelihood that their geographical origins during childhood overlap with the location where they were infected with leprosy increases, due to the longer incubation periods associated with the disease (Walker & Lockwood, 2006). Concurrently, the opportunity for movement during their lifetime is reduced, that is, being young, they had less time or ability to move before death (Evans, Chenery, & Fitzpatrick, 2006; Montgomery et al., 2000).

1.4.1 | Characterizing the strontium and oxygen isotope ranges for Winchester

The city of Winchester is located on the South Downs (chalk hills across the south-eastern coastal counties of England), and approximately 30 km north from the southern coast of England. The St. Mary Magdalen leprosy hospital site is situated approximately 1.6 km east of Winchester Cathedral, and the local geology is characterized by Cretaceous Chalk within a 10 km radius (British Geological Survey, 2007). Within a larger 30 km radius, the dominant bedrock geology remains Cretaceous Chalk, but deposits of Oligocene and Eocene sands, clays, silts, and gravel can be found to the south and, in a small area, to the north of the site, and Gault Clay and Upper Greensand formations can be found approximately 25 km to the east on the western margin of the Weald (British Geological Survey, 2007).

In order to establish the local range of an area, both isotope systems rely on isotopic baselines for comparison, and the geographic distributions of isotope compositions across Britain are well-evidenced (Darling et al., 2003; Darling & Talbot, 2003; Daux et al., 2008; Evans et al., 2010; Evans et al., 2012; Evans, Stoodley, & Chenery, 2006; Montgomery, 2010; Pellegrini et al., 2016). Data for $^{87}Sr/^{86}Sr$ values are compared against a dataset of bioavailable strontium isotope ratios for Britain provided by Evans et al. (2010, 2018). The expected $^{87}Sr/^{86}Sr$ values should lie between 0.7072 (value of the Cretaceous chalk) and 0.7092 (modern seawater) (Evans et al., 2010; Evans et al., 2012; Evans et al., 2018). Analyses of modern rodent teeth and a human dentine sample from the site revealed an $^{87}Sr/^{86}Sr$ value range of 0.7077–0.7082, which is consistent with predicted ranges (Taylor et al., 2013).

The $\delta^{18}O$ from groundwater within Britain is primarily influenced by precipitation (Darling et al., 2003; Darling & Talbot, 2003). The overall $\delta^{18}O_P$ range for archaeological humans excavated from Britain is 17.7‰ ± 1.4 (2σ), with western and southern areas having higher rainfall, including Winchester, producing a mean $\delta^{18}O_P$ value of 18.2‰ ± 1 (2σ, $n = 40$) (Evans et al., 2012). This is statistically different from easterly, lower rainfall areas that produce a mean of 17.2‰ ± 1.3 (2σ, $n = 83$) (Evans et al., 2012). On this basis, oxygen isotope ratios may be used to discriminate broad geographical origins. Individuals raised local to the Winchester area should fall within the southerly, higher rainfall range (>700 mm/year) with predicted $\delta^{18}O_P$ ranging from 17.2‰ to 19.2‰ (Eckardt et al., 2009; Evans et al., 2012; Evans, Stoodley, & Chenery, 2006). Additional conversions to drinking water values ($\delta^{18}O_{DW}$) help to provide comparisons with well-documented modern groundwater values, but these conversions are associated with larger errors (±1, 2σ) and therefore should be interpreted with caution (Chenery et al., 2012; Daux et al., 2008; Pollard et al., 2011). The modern $\delta^{18}O_{DW}$ for Winchester falls between −7.0 and −5.6‰ (Eckardt et al., 2009).

2 | OSTEOLOGICAL ANALYSES AND BIOMOLECULAR METHODS

In order to access and analyze the individuals from this site, and take tooth samples for subsequent isotopic analyses, permission to do so, with ethical justification, was sought from and approved by the curators of the human skeletal remains and the in-house ethics committee in the Department of Archaeology, Durham University. The Codes of Ethics (2010a) and Practice (2010b) of the British Association of Biological Anthropologists and Osteoarchaeologists (BABAO) (https://www.babao.org.uk/publications/ethics-and-standards) were strictly adhered to in sampling individuals selected for the study.

2.1 | Individuals analyzed

This study chose to focus on adolescent individuals, due to their liminal biological and social statuses, and general underrepresentation in previous archaeological enquiries (Lewis, 2016). Our study assigned individuals between the ages of 10–25 years at death as adolescents to first, align with 9th–12th century AD social definitions of life cycles (i.e., *pueritia* and *adolescentia* ~7–28; Cochelin, 2013, pp. 3–6; Gilchrist, 2012, pp. 34; Sharpe & Seville, 1964, pp. 49); secondly, to fit with the age of independent adulthood within the medieval lay population (i.e., >25 years; Cochelin, 2013; Lewis, 2016, pp. 139); and finally, to conform with modern biological classifications of growth and development that designate the period of adolescence as occurring between the ages of 10–25 years (Patton et al., 2016; Sawyer et al., 2018; World Health Organization, 1993, pp. 1). By looking at the adolescent experience, we can magnify the larger biological and social impacts of disease on a population, which make them a "pivotal conduit" for understanding the overall effects of environments and cultural reactions on how diseases were perceived and managed (Mays et al., 2017; Redfern & Gowland, 2011, pp. 111). Adolescents with previously recorded evidence of leprosy were selected from the unpublished recording forms and re-evaluated for further study in the Osteology Lab within the Department of Archaeology at the University of Winchester. Only individuals with bones or teeth showing lesions diagnostic of lepromatous leprosy (see Ortner, 2008) were chosen for further biomolecular analyses.

2.2 | Age and sex

Age at death of the individuals was reassessed based on tooth development, in accordance with the methods set out in Moorrees et al. (1963) and AlQahtani et al. (2010), and with the aim of identifying adolescents. Due to disparities between dental and skeletal ages (i.e., dental development yielding an older age than skeletal development), dental developmental was used as the primary age estimation method as it is largely buffered against environmental and biological stressors (Cardoso, 2007; Conceição & Cardoso, 2011; Smith, 1991).

Biological sex using standard osteological methods (Acsádi et al., 1970, pp. 113–135; Buikstra & Ubelaker, 1994, pp. 15–38; Phenice, 1969) was assigned to adolescents who showed evidence of sexual dimorphism and had achieved and/or surpassed the deceleration phase of puberty, in accordance with the methods recommended by Shapland and Lewis (2013) and Lewis et al. (2016). For the remainder of the prepubertal individuals, a previous study (Taylor et al., 2013) determined the biological sex of Sk. 8 (aged 8.5–9.5 at death) through aDNA analyses, and the sex of the remaining five individuals (Sk. 28, Sk. 41, Sk. 45, Sk. 52, Sk. 54) was determined using amelogenin peptide extraction methods described by Stewart et al. (2016, 2017). The genes that form the protein amelogenin are located on the sex-linked chromosomes and can easily be extracted with minimal destruction to the tooth by performing surface acid etching of the enamel surface (Stewart et al., 2016, 2017; see methods below).

2.3 | Sample preparation

A total of 19 tooth samples from 19 adolescent individuals were selected for radiogenic strontium and stable oxygen isotope analyses, and amelogenin peptide analyses (Table 2). Either second or third molars with no signs of pathology were selected for sampling to represent the most recently formed teeth (i.e., at the time of death) available for each individual and to lessen the influence of biologically mediated behaviors (e.g., breastfeeding). Teeth were removed from their alveolar sockets by hand and were photographed before sample preparation in their occlusal, buccal, lingual, and apical aspects. All remaining tooth sample material and archival photos are scheduled to be returned to Winchester.

Sections of core enamel were extracted in the Isotope Laboratory in the Department of Archaeology, Durham University for isotope analyses. Tooth sample preparation followed the guidelines of Montgomery (2002). Molar surfaces were first abraded using tungsten carbide burrs to remove any exogenous material and 15–25 mg of enamel was sectioned using diamond-edged dental saws. All surface enamel and any adhering dentine were mechanically removed from enamel sections. Processed chips of core enamel were sealed in Eppendorf microtubes and transferred to the (class 100, HEPA-filtered) laboratory facilities at the NERC Isotope Geosciences Laboratory (NIGL) at the British Geological Survey for further preparation (Keyworth, Nottinghamshire, England). The molar teeth of unsexed individuals were retained for enamel surface acid etching to extract amelogenin peptides.

2.4 | Amelogenin peptide extraction methods

Amelogenin peptide extraction was conducted on five individuals following the methods of Stewart et al. (2017). A wide area of molar enamel that avoided any previous sampling was selected for surface acid etching. The etched area of the enamel was washed with 3%

TABLE 2 Adolescents selected for study showing the resulting amelogenin peptide, strontium and oxygen isotope data

Burial	Sex	Age	Tooth	Sr ppm	$^{87}Sr/^{86}Sr$	$\delta^{13}C_{VPDB\ (‰)}$	$\delta^{18}O_{(C)VSMOW\ (‰)}$	$\delta^{18}O_{(p)VSMOW\ (‰)}$	$\delta^{18}O_{DW\ (Equation\ 6)\ (‰)}$
Sk. 8	M[a]	DD: 8.5–9.5; SA: 7–8	L. Max. M2	81	0.7089	−12.37	26.67	17.9	−6.2
Sk. 9	M	22.5–23.5	R. Max M2	102	0.7089	−12.65	26.25	17.4	−6.9
Sk. 14	M	16.5–17.5	L. Max. M3	57	0.7085	−13.04	26.63	17.8	−6.3
Sk. 15	M	20.5–22.5	L. Man. M3	96	0.7088	−12.88	26.77	18.0	−6.1
Sk. 16	M	20.5–21.5	R. Max. M3	91	0.7086	−12.65	26.95	18.1	−5.8
Sk. 18	M	DD: 18.5–19.5; SA: <14	R. Man. M3	111	0.7093	−13.66	26.68	17.9	−6.2
Sk. 21	M	DD: 21.5–22.5; SA: 16–19	L. Max. M3	82	0.7084	−13.2	26.42	17.6	−6.6
Sk. 25	M	DD: 18.5–20.5; SA: 17–19	R. Man. M3	56	0.7091	−13.21	27.27	18.5	−5.3
Sk. 26	M	22.5–23.5	L. Man. M3	99	0.7087	−12.58	27.59	18.8	−4.8
Sk. 27	M	22.5–23.5	R. Man. M3	70	0.7103	−12.79	26.09	17.2	−7.2
Sk. 28	M[b]	12.5–13.5	L. Max. M2	73	0.7094	−12.89	27.88	19.1	−4.3
Sk. 29	M	18.5–19.5	R. Max. M3	41	0.7095	−13.85	26.83	18.0	−6.0
Sk. 39	M	16.5–17.5	R. Max. M3	107	0.7102	−13.44	26.7	17.9	−6.2
Sk. 41	M[b]	13.5–15.5	R. Max M3	89	0.7086	−12.57	26.5	17.7	−6.5
Sk. 45	F[b]	DD: 15.5–16.5; SA: 10–12	L. Man. M2	111	0.7086	−12.83	26.32	17.5	−6.8
Sk. 46	M	16.5–17.5	R. Max. M3	120	0.7090	−13.12	26.18	17.3	−7.0
Sk. 52	F[b]	DD: 12.5–13.5; SA: 9–11	L. Man. M2	69	0.7099	−13.27	28.03	19.3	−4.1
Sk. 54	M[b]	DD: 14.5–15.5; SA: 9–11	R. Man. M2	78	0.7085	−12.21	26.09	17.3	−7.2
Sk. 56	M	16.5–17.5	R. Max. M2	94	0.7087	−12.55	24.49	15.6	−9.7

Note: $\delta^{18}O_P$ calculated from Chenery et al. (2012), and $\delta^{18}O_{DW}$ calculated from Daux et al. (2008) Equation 6, in accordance with Chenery et al. (2012).

Abbreviations: DD, dental development age; SA, skeletal age based on epiphyseal fusion.

[a]Biological sex determined via aDNA analysis (Taylor et al., 2013).

[b]Biological sex determined via amelogenin peptide extraction.

H_2O_2 for 30 seconds, and then rinsed with ultra-pure water. Enamel surface acid etching was carried out using 80 μl 10% HCl for 2-min on the chosen area. The first surface acid etch was discarded to remove any potential adhering surface contaminants, and a second 2-min etch was performed and subsequently retained. The peptides in the etch solution were bound to C18 resin ZipTips, and conditioned three times with 10 μl 100% acetonitrile and 0.1% formic acid. The peptides were eluted off the C18 resin using 4 μl of elution buffer (60% acetonitrile/0.1% formic acid). The peptide samples were then frozen at −18°C and lyophilized.

Freeze-dried samples were transferred to the School of Pharmacy and Biomolecular Sciences, University of Brighton, Sussex, England where they were dissolved in 12 μl 0.1% trifluoroacetic acid in water, and then centrifuged for 5 min to remove particulates, and transferred to 10 μl glass autosampler vials. Approximately 5 μl of the sample was analyzed by a reverse-phase nanoLC-MS with a liquid chromatograph (nanoRS U3000; Thermo Fisher Scientific) coupled to a hybrid quadrapole orbitrap mass spectrometer (Q Exactive; Thermo Fisher Scientific). The data were searched against the human proteome (UniportKB, 10/15) with MaxQuant v 1.5.1.2, using default search settings with methionine oxidation as a variable modification, unspecific digestion mode, and a minimum peptide length of six (Stewart et al., 2017).

2.5 | Isotope methods

For strontium isotope analyses, the sectioned core enamel was further prepared and measured according to Evans, Chenery, and Fitzpatrick (2006); Evans, Stoodley, and Chenery (2006). In a clean laboratory, the enamel sample was first cleaned ultrasonically in high purity water to remove dust, rinsed twice, dried down in high purity acetone, and then weighed into pre-cleaned Teflon beakers. A known amount of ^{84}Sr tracer solution was added to each sample, which was dissolved in Teflon distilled 8 M HNO_3. The sample was converted to chloride using Quartz distilled 6 M HCl and then taken up in 2.5 M HCl. The strontium was extracted using Eichrom Dowex AG50X8 resin and the samples were loaded onto Rhenium filaments (Birck, 1986). The isotope composition and concentrations were determined by thermal ionization mass spectroscopy using a Thermo Triton multi-collector mass spectrometer. The international standard for $^{87}Sr/^{86}Sr$, NBS-987, gave a value of 0.710251 ± 0.000005 ($n = 19$, 2SD) during the analysis of these samples. Procedural blank values were less than 100 pg.

For oxygen isotope analyses, approximately 3 mg of powdered enamel was loaded into a glass vial and sealed with septa. The vials were transferred to a hot block at 90°C on a GV Multiprep system. The vials were evacuated, and four drops of anhydrous phosphoric acid were added. The resultant CO_2 was collected cryogenically for 14 min and transferred to a GV IsoPrime dual inlet mass spectrometer. The resultant isotope values are reported as delta (δ) values, in parts per thousand (per mil; ‰) normalized to the VPDB scale using a within-run calcite laboratory standard (Keyworth Carerra Marble, KCM) calibrated against SRM19, NIST reference material. These ratios were normalized to the VSMOW scale using the published conversion equation of Coplen (1988): $VSMOW = (1.03091 \times \delta^{18}O_{VPDB}) + 30.91$. Analytical reproducibility for this run of laboratory standard calcite (KCM) is 0.09‰ (1σ, $n = 6$) for $^{18}O_{VSMOW}$ and ± 0.05‰ (1σ, $n = 6$) for $^{13}C_{VPDB}$. The reproducibility of the enamel was based on an average of 1σ of five duplicate pairs is ±0.07‰. The carbonate oxygen results ($\delta^{18}O_{(C)VSMOW}$) were converted to phosphate values ($\delta^{18}O_{(P)VSMOW}$) using the regression equation $\delta^{18}O_P = 1.0322 \times \delta^{18}O_C - 9.6849$, which produces an associated error of ±0.29‰, 1σ (Chenery et al., 2010; Chenery et al., 2012). The carbonate oxygen results ($\delta^{18}O_C$) were converted to drinking water values ($\delta^{18}O_{DW}$) using Daux et al.' (2008) equation 6 in accordance with Chenery et al.' (2012) calculation: $\delta^{18}O_{DW} = 1.590 \times \delta^{18}O_C - 48.634$. The calculation of drinking water values involves larger uncertainties (±1‰, 2σ) (Chenery, 2012; Pollard et al., 2011) and therefore these values are used only as general guidance.

3 | RESULTS

Biological sex based on amelogenin peptide extraction from the dental enamel of five individuals, and strontium and oxygen isotope data for all 19 individuals, are presented in Table 2 and Figure 4. Amelogenin peptide extraction revealed three males (Sk. 28, Sk. 41, Sk. 54) and two females (Sk. 45, Sk. 52). Strontium isotope ratios range from 0.7084 to 0.7103 (mean 0.7090, ±0.0012, 2σ). The $\delta^{18}O_{(P)VSMOW}$ values for the individuals show a wide range of 15.6‰–19.3‰ (mean 17.8 ± 1.6‰ 2σ), with corresponding $\delta^{18}O_{DW}$ values ranging from −9.7‰ to −4.1‰ (mean −6.3 ± 2.4‰ 2σ).

4 | DISCUSSION

The results presented here contribute to an evolving understanding of mobility and its relationship to infectious disease, and the treatment of adolescents with leprosy in England during the early-late medieval transition (9th–12th century AD). Details of early leprosaria and the people populating them are not well-documented (Rawcliffe, 2006, pp. 302–305), and this study helps to reveal further nuanced information that contributes to larger archaeological narratives about the disease in the past.

Amelogenin peptide data reveal that adolescent females with lepromatous leprosy (Sk. 45, Sk. 52) were present in the North Cemetery population at St. Mary Magdalen. These individuals are also the youngest known females with lepromatous leprosy in the archaeological record. Previous to this study, only two older females had been identified in the North Cemetery, and therefore the presence of adolescent females broadens our knowledge of the demographic make-up of those in the leprosarium community. Prior to the 15th century AD, hospitals and leprosaria were purportedly sex-specific to avoid impropriety (Magilton, 2008, pp. 57–59; Rawcliffe, 2006, pp. 144–145), apart from the presence of older nurses to provide care in male

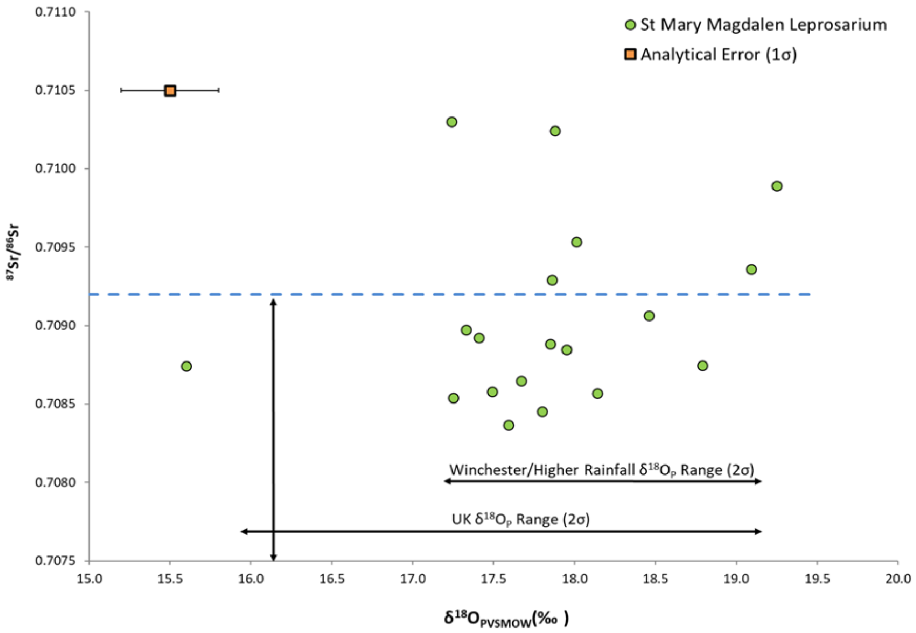

FIGURE 4 Strontium and oxygen isotope ratios showing mobility histories of 19 adolescents from the St. Mary Magdalen leprosy hospital, Winchester. The dashed line represents the strontium isotope ratio for modern seawater (0.7092) (Veizer, 1989), and therefore the upper limit for the predicted strontium isotope ratios for the Winchester area

institutions (Orme & Webster, 1995, pp. 82–83; Rawcliffe, 2006, pp. 148–149; 261–262). Given the advanced signs of lepromatous leprosy in these adolescent females, it is more likely they were there for care and treatment and not there to help provide it, as some have previously suggested (Magilton, 2008, pp. 59; Orme & Webster, 1995, pp. 22–23; 82–83). This new evidence warrants further investigation into the role and social identities of women in early leprosaria.

Individuals with $^{87}Sr/^{86}Sr$ and $\delta^{18}O_{(P)VSMOW}$ values are consistent with the study area (Winchester).

Twelve individuals have $^{87}Sr/^{86}Sr$ values between 0.7072 and 0.7092 and $\delta^{18}O_{(P)VSMOW}$ values between 17.3‰ and 18.8‰, compatible with residential origins on a terrain underlain by chalk with a higher rainfall area, such as Winchester (Evans et al., 2012), and comparable to locals identified in previous studies (Eckardt et al., 2009; Evans, Chenery, & Fitzpatrick, 2006; Evans, Stoodley, & Chenery, 2006). Equivalent $\delta^{18}O_{DW}$ values based on the conversion equations in Chenery et al. (2012) provide a drinking water range of −7.0‰ and −4.8‰, consistent with the modern precipitation values for Winchester given in Eckardt et al. (2009). Although there are alternative areas that produce a similar combination of strontium ratios and oxygen isotope values within the United Kingdom and further afield, the most parsimonious interpretation is that these individuals spent their childhoods near the St. Mary Magdalen leprosarium.

Individuals with nonlocal $^{87}Sr/^{86}Sr$ but $\delta^{18}O_{(P)VSMOW}$ values consistent with British ranges.

Six individuals (Sk. 18, Sk. 27, Sk. 28, Sk. 29, Sk. 39, Sk. 52) show higher than expected $^{87}Sr/^{86}Sr$ values (0.7093–0.7103) for an area underlain by marine carbonates such as in the Winchester area. These ranges are, however, common across silicate lithologies that can be found broadly throughout England (Evans et al., 2010; Evans et al., 2012).

All six individuals reveal oxygen ratios that are consistent with British ranges reported by Evans et al. (2012), but two individuals had higher $\delta^{18}O_{(P)VSMOW}$ values in comparison to others. Sk. 28 gave a $\delta^{18}O_{(P)VSMOW}$ value of 19.1‰ ($\delta^{18}O_{DW}$ -4.8‰), and Sk. 52 showed a $\delta^{18}O_{(P)VSMOW}$ value of 19.3‰ ($\delta^{18}O_{DW}$ -4.1‰), which hover at the 2σ range for Britain. Higher than expected $\delta^{18}O_{(P)VSMOW}$ values may be due to a variety of scenarios: they may indicate that these individuals come from the extreme western seaboard of Britain; or they may have spent their childhood further afield, for example in areas around the Mediterranean Sea (Chenery et al., 2010; Evans et al., 2012; Mitchell & Millard, 2009); their second molars may show an isotopic offset from an extended period of breastfeeding (Tsutaya & Yoneda, 2015; Wright & Schwarcz, 1998); or the majority of their childhood diet may have come from milk or heated/cooked food and drink (Brettell et al., 2012).

Individuals with $\delta^{18}O_{(P)VSMOW}$ values are inconsistent with British ranges.

One individual (Sk. 56) revealed an $^{87}Sr/^{86}Sr$ value (0.7087) consistent with an area underlain by chalk (limestone) but had an unusually low $\delta^{18}O_{(P)VSMOW}$ value. Sk. 56, a male aged 16.5–17.5, had a $\delta^{18}O_{(P)VSMOW}$ value of 15.6‰ ($\delta^{18}O_{DW}$ −9.7‰), which is more than 2σ compared to the other individuals buried at St. Mary Magdalen leprosy hospital, and at the 3σ threshold for British ranges reported by Evans et al. (2012). Oxygen isotope ratios fall with decreasing temperatures and increasing altitude and latitude (Darling et al., 2003; Evans et al., 2012; Figure 5), which indicates that Sk. 56's early childhood was spent in an area significantly cooler than Britain. Possible areas that may accommodate the combination of Sk. 56's strontium and oxygen isotope compositions include Iceland (Walser III et al., 2020), coastal areas of Denmark or possibly Norway (Price et al., 2014), Central/Eastern Europe (Eckardt et al., 2009; Hughes et al., 2014; Lecolle, 1985; Voerkelius et al., 2010), or regions underlain by basalts, chalks, or limestones that produce similar

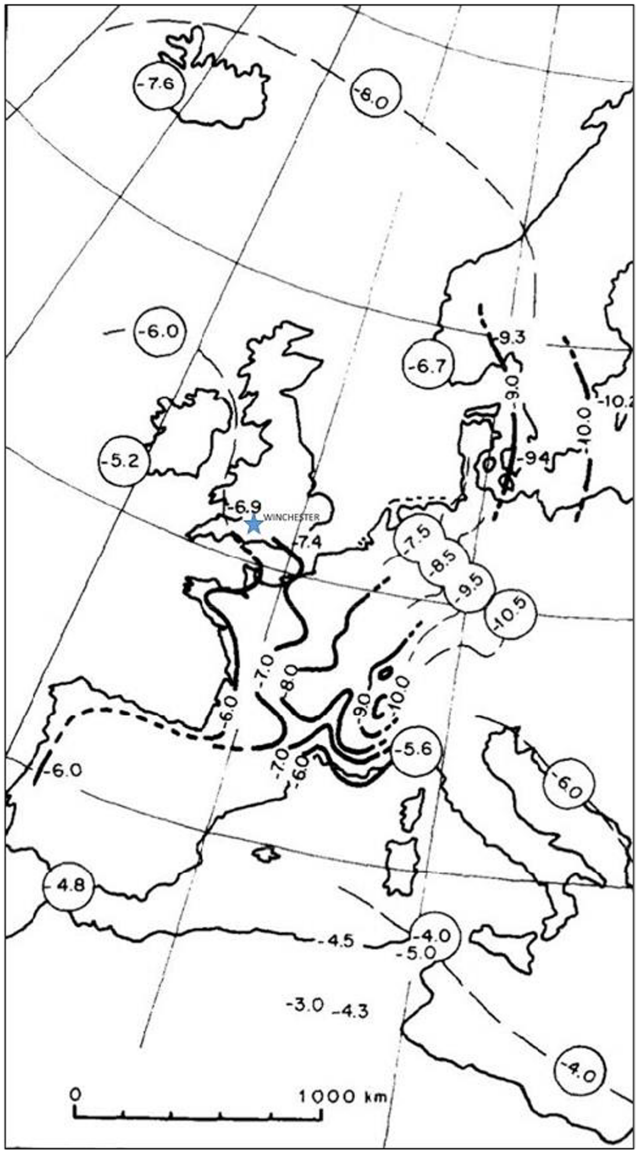

FIGURE 5 Oxygen isotope drinking water values from Western Europe with Winchester (starred) (modified from Lecolle, 1985)

oxygen isotope ratios. Another possibility is that Sk. 56 may have had a pathophysiological condition that altered their normal oxygen isotope composition (e.g., end-stage renal failure) (Kuo et al., 2012; Reitsema, 2013). Although leprosy does affect renal function (da Silva Junior et al., 2015), it is doubtful that end-stage renal failure would be the cause of the low isotope ratio seen here as life expectancy at that time would be unlikely to be long enough to reflect changes in the tooth enamel (da Silva Junior et al., 2015; Kuo et al., 2012). However, the accumulation of isotopically light metabolites within the kidneys cannot be wholly excluded and warrants future investigation.

The majority of individuals ($n = 12$, 11 males, 1 female) from the sample population were likely to have been raised local to the Winchester area. This combined with the high number of people with lepromatous leprosy suggests that, by this time, St. Mary Magdalen was functioning as a hospital for people with leprosy who resided both locally in Winchester, and nonlocally (see Section 4.1). This aligns with major Benedictine reforms in the 10th century AD that necessitated monastic institutions provide a dedicated facility for the infirm (Dainton, 1961, pp. 17–18; Huggon, 2018; Orme & Webster, 1995, pp. 15–18; Retief & Cilliers, 2006).

Seven individuals (six males, one female) fell outside the local ranges for strontium and oxygen isotope ratios. Four male individuals revealed relatively common strontium isotope ratios for central and southern England, but these were too high for Winchester, and two individuals (Sk. 28, Sk. 52) had oxygen isotope ratios that, if not a consequence of culturally mediated behaviors, place their origins in an extreme westerly point in Britain or further afield (e.g., the Mediterranean). One male individual (Sk. 56) had a significantly lower oxygen isotope ratio that, based on present data, is too low to for this person to have originated in Britain. These data suggest that the non-local individuals buried in the sample population did not all originate from the same geographic areas.

4.1 | Social reactions to leprosy

Previous researchers have refuted the long-held image of leprosaria as spaces for segregation. Life within the leprosarium likely offered security, medical and spiritual care, shelter and warmth, a place to sleep, food and ale, clothing, and transactional community contact (Filipek, Roberts, Gowland, & Tucker, 2021; Rawcliffe, 2006; Roberts, 2013, 2020). In order to receive these benefits within a leprosarium, a group agency model that culturally sanctioned and economically supported such an institution had to exist (Filipek, Roberts, Gowland, & Tucker, 2021). Further evidence with regard to burial construction (e.g., similar to those of high-status ecclesiastical burials), the unique and individual burial goods (e.g., pilgrim badges and modified artifacts for feeding), and an individual who underwent a foot amputation (suggesting the existence of some level of medical and palliative care) further demonstrates that at this time and place, the idea of medieval leprosy stigma and community expulsion was potentially not part of the broad social milieu (Roffey, 2012; Roffey, 2020; Roffey et al., 2017; Roffey & Tucker, 2012). The presence of both local and non-local adolescents buried within this early leprosarium context implies that this care was extended to the local community's adolescents with leprosy, as well as youth from the hinterland, and further afield.

We are not able to say, however, at what age these individuals moved to Winchester, whether they purposefully traveled there to seek medical care for leprosy, whether they were in familial groups or on their own, nor can we determine how long they would have been cared for prior to death. We are also not able to ascertain whether these individuals had leprosy when they went to Winchester, or if they developed leprosy after moving to the Winchester area. However, the long incubation period associated with lepromatous leprosy (~2–10 years, or more) (Bhat & Prakash, 2012; Smith et al., 2015), their young age at death, and their advanced lepromatous skeletal

lesions point towards the probability that the non-local individuals identified likely migrated with the disease.

In future, analyses of carbon and nitrogen isotope values from the incremental dentine of these individuals could reveal more nuanced aspects of mobility in relation to leprosy. This could go alongside considering subsequent care and treatment revealed by changes in their diet that may potentially be linked with their mobility histories, provision of food at the leprosarium, and pathophysiological stress. Further comparative studies of individuals with leprosy from the later contexts within the St. Mary Magdalen leprosarium cemetery (i.e., the South Cemetery) may also indicate whether any sociocultural related changes in the treatment of people with leprosy existed from the 12th century AD onwards. Lastly, further amelogenin peptide analyses would be highly beneficial in understanding demographic variation and social identities of children with leprosy in a medieval institutional setting, and access to medical care.

5 | CONCLUSIONS

The aim of this study was to explore social reactions towards young people with leprosy during a key historical and cultural event in England: the early-late medieval transition (9th–12th centuries AD). This was achieved by exploring biological sex as an aspect of identity alongside the mobility histories of adolescents buried in the North Cemetery at the St. Mary Magdalen leprosarium in Winchester. These data were combined with archaeological and palaeopathological evidence to view the extent of the journeys these people with leprosy made to the leprosarium. Amelogenin peptide extraction demonstrated that two adolescent females were amongst the burial population, currently the youngest known females with leprosy in the archaeological record. Strontium and oxygen isotope values revealed that 12 individuals showed isotope ratios and values consistent with their burial environment, whilst seven individuals had origins inconsistent with the local area, three of which from potentially beyond Britain. Combining these results with the contextual and palaeopathological data indicates that social reactions to young people with leprosy were not necessarily negative, as previous historians suggest, and underscores the relevance and importance of using multidisciplinary and holistic approaches to understanding social reactions to disease in the past.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

AUTHOR CONTRIBUTIONS

Kori Lea Filipek: Conceptualization (lead); data curation (lead); formal analysis (lead); investigation (lead); methodology (lead); project administration (lead); resources (lead); software (lead); validation (lead); visualization (lead); writing – review and editing (lead). **Charlotte A. Roberts:** Conceptualization (supporting); investigation (supporting); methodology (supporting); resources (supporting); supervision (lead); writing – review and editing (supporting). **Janet Montgomery:** Conceptualization (supporting); investigation (supporting); methodology (supporting); resources (equal); supervision (supporting); writing – review and editing (supporting). **Rebecca L. Gowland:** Conceptualization (supporting); methodology (supporting); supervision (supporting); writing – review and editing (supporting). **Joanna Moore:** Data curation (supporting); investigation (supporting); methodology (supporting); resources (supporting); writing – review and editing (supporting). **Katie Tucker:** Data curation (supporting); investigation (supporting); resources (supporting); visualization (supporting); writing – review and editing (supporting). **Jane A. Evans:** Data curation (supporting); investigation (supporting); resources (equal); supervision (supporting); validation (equal); writing – review and editing (supporting).

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available within the text of this article.

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REFERENCES

Acsádi, G., Nemeskéri, J., & Balás, K. (1970). *History of human life span and mortality*. Akadémiai Kiadó.

AlQahtani, S. J., Hector, M. P., & Liversidge, H. M. (2010). Brief communication: The London atlas of human tooth development and eruption. *American Journal of Physical Anthropology*, *142*(3), 481–490.

Andersen, J. G., & Manchester, K. (1987). Grooving of the proximal phalanx in leprosy: A palaeopathological and radiological study. *Journal of Archaeological Science*, *14*(1), 77–82.

Andersen, J. G., & Manchester, K. (1988). Dorsal tarsal exostoses in leprosy: A palaeopathological and radiological study. *Journal of Archaeological Science*, *15*(1), 51–56.

Andersen, J. G., & Manchester, K. (1992). The rhinomaxillary syndrome in leprosy: A clinical, radiological and palaeopathological study. *International Journal of Osteoarchaeology*, *2*(2), 121–129.

Andersen, J. G., Manchester, K., & Ali, R. S. (1992). Diaphyseal remodelling in leprosy: A radiological and palaeopathological study. *International Journal of Osteoarchaeology*, *2*(3), 211–219.

Andersen, J. G., Manchester, K., & Roberts, C. (1994). Septic bone changes in leprosy: A clinical, radiological and palaeopathological review. *International Journal of Osteoarchaeology*, *4*(1), 21–30.

Baker, B. J., & Bolhofner, K. L. (2014). Biological and social implications of a medieval burial from Cyprus for understanding leprosy in the past. *International Journal of Paleopathology*, *4*, 17–24.

Barlow, F., Biddle, M., von Feilitzen, O., & Keene, D. (1976). *Winchester in the early middle ages. An edition and discussion of the Winton Domesday*. Oxford University Press.

Bartelink, E. J., & Chesson, L. A. (2019). Recent applications of isotope analysis to forensic anthropology. *Forensic sciences research*, *4*(1), 29–44.

Belcastro, M. G., Mariotti, V., Facchini, F., & Dutour, O. (2005). Leprosy in a skeleton from the 7th century necropolis of Vicenne-Campochiaro (Molise, Italy). *International Journal of Osteoarchaeology*, *15*(6), 431–448.

Bentley, R. A. (2006). Strontium isotopes from the earth to the archaeological skeleton: A review. *Journal of Archaeological Method and Theory*, *13*(3), 135–187.

Bhat, R. M., & Prakash, C. (2012). Leprosy: An overview of pathophysiology. *Interdisciplinary Perspectives on Infectious Diseases*, *2012*, 181089.

Birck, J. L. (1986). Precision K-Rb-Sr isotopic analysis: Application to Rb-Sr chronology. *Chemical Geology*, *56*(1-2), 73–83.

Brettell, R., Montgomery, J., & Evans, J. (2012). Brewing and stewing: The effect of culturally mediated behaviour on the oxygen isotope composition of ingested fluids and the implications for human provenance studies. *Journal of Analytical Atomic Spectrometry*, *27*(5), 778–785.

British Association for Biological Anthropology and Osteoarchaeology (2010a). Code of ethics. https://www.babao.org.uk/assets/Uploads/BABAO-Code-of-Ethics-2019.pdf

British Association for Biological Anthropology and Osteoarchaeology (2010b). Code of practice. https://www.babao.org.uk/assets/Uploads/BABAO-Code-of-Practice-2019.pdf

British Geological Survey. (2007). *Bedrock geology UKsouth. 1:625,000* (5th ed.). British Geological Survey.

Budd, P., Montgomery, J., Barreiro, B., & Thomas, R. G. (2000). Differential diagenesis of strontium in archaeological human dental tissues. *Applied Geochemistry*, *15*(5), 687–694.

Buikstra, J., & Ubelaker, D. (Eds.). (1994). *Standards for data collection from human skeletal remains*. Arkansas Archaeological Survey.

Butlin, C. R., & Withington, S. (2018). Mothers and children with leprosy. In D. M. Scollard & T. P. Gillis (Eds.), *International textbook of leprosy* (Vol. 3.2, pp. 1–34). American Leprosy Mission.

Cardoso, H. F. (2007). Environmental effects on skeletal versus dental development: Using a documented subadult skeletal sample to test a basic assumption in human osteological research. *American Journal of Physical Anthropology*, *132*(2), 223–233.

Chenery, C., Mueldner, G., Evans, J., Eckardt, H., & Lewis, M. (2010). Strontium and stable isotope evidence for diet and mobility in Roman Gloucester, UK. *Journal of Archaeological Science*, *37*(1), 150–163.

Chenery, C. A., Pashley, V., Lamb, A. L., Sloane, H. J., & Evans, J. A. (2012). The oxygen isotope relationship between the phosphate and structural carbonate fractions of human bioapatite. *Rapid Communications in Mass Spectrometry*, *26*(3), 309–319.

Cochelin, I. (2013). Introduction: Pre-thirteenth-century definitions of the life cycle. In I. Cochelin & K. Smyth (Eds.), *Medieval life cycles: Continuity and change* (pp. 1–54). Brepols Publishing.

Coelho, I., Castanheira, I., Bordado, J. M., Donard, O., & Silva, J. A. L. (2017). Recent developments and trends in the application of strontium and its isotopes in biological related fields. *Trends in Analytical Chemistry*, *90*, 45–61.

Conceição, E. L. N., & Cardoso, H. F. V. (2011). Environmental effects on skeletal versus dental development II: Further testing of a basic assumption in human osteological research. *American Journal of Physical Anthropology*, *144*(3), 463–470.

Coplen, T. B. (1988). Normalization of oxygen and hydrogen isotope data. *Chemical Geology: Isotope Geoscience Section*, *72*(4), 293–297.

Crespo, F., White, J., & Roberts, C. (2019). Revisiting the tuberculosis and leprosy cross-immunity hypothesis: Expanding the dialogue between immunology and paleopathology. *International Journal of Paleopathology*, *26*, 37–47.

da Costa Silva, A., Ferreira, R. C., Ferreira, M. A. A., & de Freitas Ribeiro, M. T. (2014). Association between the degree of physical impairment from leprosy and dependence in activities of daily living among the elderly in a health unit in the state of Minas Gerais. *Revista da Sociedade Brasileira de Medicina Tropical*, *47*(2), 212–217.

da Silva Junior, G. B., Daher, E. D. F., Pires Neto, R. D. J., Pereira, E. D. B., Meneses, G. C., Araújo, S. M. H. A., & Barros, E. J. G. (2015). Leprosy nephropathy: A review of clinical and histopathological features. *Revista do Instituto de Medicina Tropical de São Paulo*, *57*(1), 15–20.

Dainton, C. (1961). *The story of England's hospitals*. Museum Press.

Danielsen, K. (1970). Odontodysplasia leprosa in Danish mediaeval skeletons. *Copenhagen: Tandlaegebladet*, *74*(6), 603.

Darling, W. G., Bath, A. H., & Talbot, J. C. (2003). The O and H stable isotope composition of freshwaters in the British Isles. 2. Surface waters and groundwater. *Hydrology and Earth System Sciences*, *7*, 183–195.

Darling, W. G., & Talbot, J. C. (2003). The O and H stable isotope composition of freshwaters in the British Isles. 1. Rainfall. *Hydrology and Earth System Sciences*, *7*(2), 163–181.

Daux, V., Lécuyer, C., Héran, M. A., Amiot, R., Simon, L., Fourel, F., Martineau, F., Lynnerup, N., Reychler, H., & Escarguel, G. (2008). Oxygen isotope fractionation between human phosphate and water revisited. *Journal of Human Evolution*, *55*(6), 1138–1147.

Davey, T. F., & Schenck, R. R. (1964). The endocrines in leprosy. In R. G. Cochrane & T. F. Davey (Eds.), *Leprosy theory and practice* (pp. 190–204). John Wright and Sons.

Demaitre, L. (1985). The description and diagnosis of leprosy by fourteenth-century physicians. *Bulletin of the History of Medicine*, *59*(3), 327–344.

Demaitre, L. (2007). *Leprosy in Premodern medicine: A malady of the whole body*. Johns Hopkins University Press.

Donoghue, H. D., Taylor, G. M., Marcsik, A., Molnár, E., Pálfi, G., Pap, I., Teschler-Nicola, M., Pinhasi, R., Erdal, Y. S., Velemínsky, P., & Likovsky, J. (2015). A migration-driven model for the historical spread of leprosy in medieval Eastern and Central Europe. *Infection, Genetics and Evolution*, *31*, 250–256.

Eckardt, H., Chenery, C., Booth, P., Evans, J. A., Lamb, A., & Müldner, G. (2009). Oxygen and strontium isotope evidence for mobility in Roman Winchester. *Journal of Archaeological Science*, *36*(12), 2816–2825.

Economou, C., Kjellström, A., Lidén, K., & Panagopoulos, I. (2013). Ancient-DNA reveals an Asian type of *Mycobacterium leprae* in medieval Scandinavia. *Journal of Archaeological Science*, *40*(1), 465–470.

Edmond, R. (2006). *Leprosy and empire: a medical and cultural history* (Vol. 8), Cambridge: Cambridge University Press.

Evans, J., Stoodley, N., & Chenery, C. (2006). A strontium and oxygen isotope assessment of a possible fourth century immigrant population in a Hampshire cemetery, southern England. *Journal of Archaeological Science*, *33*(2), 265–272.

Evans, J. A., Chenery, C. A., & Fitzpatrick, A. P. (2006). Bronze age childhood migration of individuals near Stonehenge, revealed by strontium and oxygen isotope tooth enamel analysis. *Archaeometry*, *48*(2), 309–321.

Evans, J. A., Chenery, C. A., & Montgomery, J. (2012). A summary of strontium and oxygen isotope variation in archaeological human tooth enamel excavated from Britain. *Journal of Analytical Atomic Spectrometry*, *27*(5), 754–764.

Evans, J. A., Mee, K., Chenery, C. A., Cartwright, C. E., Lee, K. A., & Marchant, A. P. (2018). *User guide for the biosphere isotope domains GB (version 1) dataset and web portal*. British Geological Survey.

Evans, J. A., Montgomery, J., Wildman, G., & Boulton, N. (2010). Spatial variations in biosphere 87Sr/86Sr in Britain. *Journal of the Geological Society*, *167*(1), 1–4.

Ferreira, R. C., de Freitas Ribeiro, M. T., Vargas-Ferreira, F., Sampaio, A. A., Pereira, A. C. M., Vargas, A. M. D., de Jesus, R. M., & Ferreira e Ferreira, E. (2018). Assistive technologies for improving the oral hygiene of leprosy patients residing in a former leprosy colony in Betim, Minas Gerais, Brazil. *PLoS One*, *13*(7), e0200503.

Filipek, K., Roberts, C. A., Gowland, R., & Tucker, K. (2021). Alloparenting adolescents: Evaluating the biological and social impacts of leprosy on young people in early-late medieval England (9th – 12th centuries AD) through cross-disciplinary models of care. In E. J. Kendall & R. Kendall (Eds.), *The family in the past perspective* (pp. 37–50). Routledge.

Filipek, K. L., Roberts, C. A., Gowland, R. L., Montgomery, J., & Evans, J. A. (2021). Illness and inclusion: Mobility histories of adolescents with leprosy from Anglo-Scandinavian Norwich (eastern England). *International Journal of Osteoarchaeology, Early View*, *31*, 1180–1191.

Fine, P. E. (1982). Leprosy: The epidemiology of a slow bacterium. *Epidemiologic Reviews*, *4*(1), 161–188.

Gilchrist, R. (2012). *Medieval life: Archaeology and the life course*. Boydell Press.

Gilchrist, R., & Sloane, B. (2005). *Requiem: The medieval monastic cemetery in Britain*. Museum of London Archaeology Service.

Goulart, I. M. B., & Goulart, L. R. (2008). Leprosy: Diagnostic and control challenges for a worldwide disease. *Archives of Dermatological Research*, *300*(6), 269–290.

Huggon, M. (2018). Medieval medicine, public health, and the medieval hospital. In C. Gerrard & A. Gutiérrez (Eds.), *The Oxford handbook of later medieval archaeology in Britain* (pp. 836–855). Oxford University Press.

Hughes, S. S., Millard, A. R., Lucy, S. J., Chenery, C. A., Evans, J. A., Nowell, G., & Pearson, D. G. (2014). Anglo-Saxon origins investigated by isotopic analysis of burials from Berinsfield, Oxfordshire, UK. *Journal of Archaeological Science*, *42*, 81–92.

Jain, S., Reddy, R. G., Osmani, S. N., Lockwood, D. N. J., & Suneetha, S. (2002). Childhood leprosy in an urban clinic, Hyderabad, India: Clinical presentation and the role of household contacts. *Leprosy Review*, *73*(3), 248–253.

John, A. S., Rao, P. S., Kundu, R., & Raju, M. S. (2005). Leprosy amongst adolescents in Kolkata, India. *Leprosy Review*, *77*(2), 160–162.

Jopling, W. H., & McDougall, A. C. (1988). *Handbook of leprosy*. Heinemann Educational Books.

Kendall, E. J., Montgomery, J., Evans, J. A., Stantis, C., & Mueller, V. (2013). Mobility, mortality, and the middle ages: Identification of migrant individuals in a 14th century Black Death cemetery population. *American Journal of Physical Anthropology*, *150*(2), 210–222.

Kuo, T. C., Wang, C. H., Lin, H. C., Lin, Y. H., Lin, M., Lin, C. M., & Kuo, H. S. (2012). Assessment of renal function by the stable oxygen and hydrogen isotopes in human blood plasma. *PLoS One*, *7*(2), e32137.

Lastória, J. C., & Abreu, M. A. M. M. D. (2014). Leprosy: Review of the epidemiological, clinical, and etiopathogenic aspects-part 1. *Anais Brasileiros de Dermatologia*, *89*(2), 205–218.

Lecolle, P. (1985). The oxygen isotope composition of landsnail shells as a climatic indicator: Applications to hydrogeology and paleoclimatology. *Chemical Geology: Isotope Geoscience Section*, *58*(1–2), 157–181.

Lee, F., & Magilton, J. (2008). In J. R. Magilton, F. Lee, & A. Boylston (Eds.), *Discussion. In "Lepers Outside the Gate": Excavations at the cemetery of the Hospital of St James and St Mary Magdalene, Chichester, 1986–87 and 1993* (Vol. 158, pp. 263–269). Council for British Archaeology.

Lewis, M. (2016). Work and the adolescent in medieval England AD 900–1550: The osteological evidence. *Medieval Archaeology*, *60*(1), 138–171.

Lewis, M. E., Shapland, F., & Watts, R. (2016). The influence of chronic conditions and the environment on pubertal development. An example from medieval England. *International Journal of Paleopathology*, *12*, 1–10.

Lydyard, P., Cole, M., Holton, J., Irving, W., Porakishvili, N., Venkatesan, P., & Ward, K. (Eds.) (2010). Case 22: *Mycobacterium leprae*. In *Case studies in infectious diseases* (pp. 277–302). Taylor and Francis.

Magilton, J. (2008). In J. R. Magilton, F. Lee, & A. Boylston (Eds.), *A history of the hospital. In "Lepers Outside the Gate": Excavations at the cemetery of the hospital of St James and St Mary Magdalene, Chichester, 1986–87 and 1993* (Vol. 158, pp. 57–68). Council for British Archaeology.

Manchester, K. (1984). Tuberculosis and leprosy in antiquity: An interpretation. *Medical History*, *28*(2), 162–173.

Manchester, K., & Roberts, C. (1989). The palaeopathology of leprosy in Britain: A review. *World Archaeology*, *21*(2), 265–272.

Matczak, M. D., & Kozłowski, T. (2017). Dealing with difference: Using the osteobiographies of a woman with leprosy and a woman with gigantism from medieval Poland to identify practices of care. In L. Tilley & A. Schrenk (Eds.), *New developments in the bioarchaeology of care* (pp. 125–151). Springer.

Mays, S., Gowland, R., Halcrow, S., & Murphy, E. (2017). Child bioarchaeology: Perspectives on the past 10 years. *Childhood in the Past*, *10*(1), 38–56.

Melsom, R., Duncan, M. E., & Bjune, G. (1980). Immunoglobulin concentration in mothers with leprosy and in healthy controls and their babies at the time of birth. *Leprosy Review*, *51*(1), 19–28.

Mendum, T. A., Schuenemann, V. J., Roffey, S., Taylor, G. M., Wu, H., Singh, P., Tucker, K., Hinds, J., Cole, S. T., Kierzek, A. M., & Nieselt, K. (2014). *Mycobacterium leprae* genomes from a British medieval leprosy hospital: Towards understanding an ancient epidemic. *BMC Genomics*, *15*(1), 270.

Mitchell, P. D., & Millard, A. R. (2009). Migration to the medieval Middle East with the crusades. *American Journal of Physical Anthropology*, *140*(3), 518–525.

Møller-Christensen, V. (1961). Bone changes in leprosy. In *Bone changes in leprosy*. Munksgaard.

Monot, M., Honoré, N., Garnier, T., Zidane, N., Sherafi, D., Paniz-Mondolfi, A., Matsuoka, M., Taylor, G. M., Donoghue, H. D., Bouwman, A., & Mays, S. (2009). Comparative genomic and phylogeographic analysis of *Mycobacterium leprae*. *Nature Genetics*, *41*(12), 1282–1289.

Montgomery, J. (2002). *Lead and strontium isotope compositions of human dental tissues as an indicator of ancient exposure and population dynamics* [Unpublished doctoral dissertation]. University of Bradford.

Montgomery, J. (2010). Passports from the past: Investigating human dispersals using strontium isotope analysis of tooth enamel. *Annals of Human Biology*, *37*(3), 325–346.

Montgomery, J., Budd, P., & Evans, J. (2000). Reconstructing the lifetime movements of ancient people: A Neolithic case study from southern England. *European Journal of Archaeology*, *3*(3), 370–385.

Moore, J., Rose, A., Anderson, S., Evans, J., Nowell, G., Gröcke, D. R., Pashley, V., Kirby, M., & Montgomery, J. (2020). A multi-isotope (C, N, O, Sr, Pb) study of Iron Age and Roman period skeletons from East Edinburgh, Scotland exploring the relationship between decapitation burials and geographical origins. *Journal of Archaeological Science: Reports*, *29*, 102075.

Moorrees, C. F., Fanning, E. A., & Hunt, E. E., Jr. (1963). Age variation of formation stages for ten permanent teeth. *Journal of Dental Research*, *42*(6), 1490–1502.

Ogden, A. R., & Lee, F. (2008). In J. R. Magilton, F. Lee, & A. Boylston (Eds.), *Dental health and disease. In "Lepers outside the Gate": Excavations at the Cemetery of the Hospital of St James and St Mary Magdalene, Chichester, 1986-87 and 1993. Council for British Archaeology Research Report 158 and Chichester Excavations* (Vol. 10, pp. 188–197). Council for British Archaeology.

Orme, N., & Webster, M. (1995). *The English hospital, 1070–1570* (112138204). Yale University Press.

Ortner, D. J. (2008). In J. R. Magilton, F. Lee, & A. Boylston (Eds.), *Skeletal manifestations of leprosy. In "Lepers outside the Gate": Excavations at the Cemetery of the Hospital of St James and St Mary Magdalene, Chichester, 1986-87 and 1993. Council for British Archaeology Research Report 158 and Chichester Excavations* (Vol. 10, pp. 198–207). Council for British Archaeology.

Patton, G. C., Sawyer, S. M., Santelli, J. S., Ross, D. A., Afifi, R., Allen, N. B., Arora, M., Azzopardi, P., Baldwin, W., Bonell, C., & Kakuma, R. (2016). Our future: A lancet commission on adolescent health and wellbeing. *The Lancet*, *387*(10036), 2423–2478.

Pederzani, S., & Britton, K. (2019). Oxygen isotopes in bioarchaeology: Principles and applications, challenges and opportunities. *Earth-Science Reviews*, *188*, 77–107.

Pellegrini, M., Pouncett, J., Jay, M., Pearson, M. P., & Richards, M. P. (2016). Tooth enamel oxygen "isoscapes" show a high degree of human mobility in prehistoric Britain. *Scientific Reports*, *6*(1), 1–9.

Phenice, T. W. (1969). A newly developed visual method of sexing the os pubis. *American Journal of Physical Anthropology*, *30*(2), 297–301.

Pollard, A. M., Pellegrini, M., & Lee-Thorp, J. A. (2011). Some observations on the conversion of dental enamel δ^{18}Op values to δ^{18}Ow to determine human mobility. *American Journal of Physical Anthropology*, *145*(3), 499–504.

Price, T. D., Frei, K. M., & Naumann, E. (2014). Isotopic baselines in the North Atlantic region. *Journal of the North Atlantic*, *2014*(sp7), 103–136.

Quinn, K. (2017). *A bioarchaeological study of the impact of mobility on the transmission of tuberculosis in Roman Britain* [Unpublished Doctoral dissertation], Durham University.

Rawcliffe, C. (2006). *Leprosy in medieval England*. Boydell and Brewer.

Rawlani, S. M., Rawlani, S., Degwekar, S., Bhowte, R. R., & Motwani, M. (2011). Oral health status and alveolar bone loss in treated leprosy patients of Central India. *Indian Journal of Leprosy*, *83*, 215–224.

Redfern, R. C., & Gowland, R. L. (2011). A bioarchaeological perspective on the pre-adult stages of the life course: Implications for the care and health of children in the Roman empire. In M. Harlow & L. L. Loven (Eds.), *Families in the Roman and late antique Roman world* (pp. 111–140). Continuum International Publishing Group.

Reichart, P. (1976). Facial and oral manifestations in leprosy: An evaluation of seventy cases. *Oral Surgery, Oral Medicine. Oral Pathology*, *41*(3), 385–399.

Reitsema, L. J. (2013). Beyond diet reconstruction: Stable isotope applications to human physiology, health, and nutrition. *American Journal of Human Biology*, *25*(4), 445–456.

Retief, F. P., & Cilliers, L. (2006). The evolution of hospitals from antiquity to the Renaissance. *Acta Theologica*, *26*(2), 213–232.

Roberts, C. A. (1986). Leprosy and leprosaria in medieval Britain. *Museum Applied Science Center for Archaeology Journal*, *4*(1), 15–21.

Roberts, C. A. (2013). Social aspects of the bioarchaeology of leprosy. In M. C. Lozada & B. O'Donnabhain (Eds.), *The dead tell tales: Essays in honor of Jane E. Buikstra* (pp. 136–144). Cotsen Institute of Archaeology Press at UCLA.

Roberts, C. A. (2017). Applying the 'Index of Care' to a person who experienced leprosy in late medieval Chichester, England. In L. Tilley & A. Schrenk (Eds.), *New developments in the bioarchaeology of care* (pp. 101–124). Springer.

Roberts, C. A. (2020). *Leprosy: Past and present*. University Press of Florida.

Roberts, C. A., Millard, A. R., Nowell, G. M., Gröcke, D. R., Macpherson, C. G., Pearson, D. G., & Evans, D. H. (2013). Isotopic tracing of the impact of mobility on infectious disease: The origin of people with treponematosis buried in hull, England, in the late medieval period. *American Journal of Physical Anthropology*, *150*(2), 273–285.

Roffey, S. (2012). Medieval leper hospitals in England: An archaeological perspective. *Medieval Archaeology*, *56*(1), 203–233.

Roffey, S. (2020). Sanctity and suffering: The sacred world of the medieval leprosarium. A Perspective from St Mary Magdalen, Winchester. In A. J. Langlands & R. Lavelle (Eds.), *The land of the English Kin* (pp. 538–554). Brill.

Roffey, S., & Marter, P. (2012). Treating leprosy: Inside the medieval hospital of St Mary Magdalen, Winchester. *Current Archaeology*, *267*, 12–19.

Roffey, S., & Tucker, K. (2012). A contextual study of the medieval hospital and cemetery of St Mary Magdalen, Winchester, England. *International Journal of Paleopathology*, *2*(4), 170–180.

Roffey, S., Tucker, K., Filipek-Ogden, K., Montgomery, J., Cameron, J., O'Connell, T., Evans, J., Marter, P., & Taylor, G. M. (2017). Investigation of a medieval pilgrim burial excavated from the leprosarium of St Mary Magdalen Winchester, UK. *PLoS Neglected Tropical Diseases*, *11*(1), e0005186.

Sawyer, S. M., Azzopardi, P. S., Wickremarathne, D., & Patton, G. C. (2018). The age of adolescence. *The Lancet Child & Adolescent Health*, *2*(3), 223–228.

Schuenemann, V. J., Avanzi, C., Krause-Kyora, B., Seitz, A., Herbig, A., Inskip, S., Bonazzi, M., Reiter, E., Urban, C., Dangvard Pedersen, D., & Taylor, G. M. (2018). Ancient genomes reveal a high diversity of *Mycobacterium leprae* in medieval Europe. *PLoS Pathogens*, *14*(5), e1006997.

Schuenemann, V. J., Singh, P., Mendum, T. A., Krause-Kyora, B., Jäger, G., Bos, K. I., Herbig, A., Economou, C., Benjak, A., Busso, P., & Nebel, A. (2013). Genome-wide comparison of medieval and modern *Mycobacterium leprae*. *Science*, *341*(6142), 179–183.

Shapland, F., & Lewis, M. E. (2013). Brief communication: A proposed osteological method for the estimation of pubertal stage in human skeletal remains. *American Journal of Physical Anthropology*, *151*(2), 302–310.

Sharpe, W. D., & Seville, I. O. (1964). Isidore of Seville: The medical writings. An English translation with an introduction and commentary. *Transactions of the American Philosophical Society*, *54*(2), 1–75.

Smith, B. H. (1991). Standards of human tooth formation and dental age assessment. In M. A. Kelley & C. S. Larsen (Eds.), *Advances in dental anthropology* (pp. 143–168). Wiley-Liss.

Smith, W. C., van Brakel, W., Gillis, T., Saunderson, P., & Richardus, J. H. (2015). The missing millions: A threat to the elimination of leprosy. *PLoS Neglected and Tropical Diseases*, *9*(4), e0003658.

Souza, V. A., Emmerich, A., Coutinho, E. M., Freitas, M. G., Silva, E. H., Mercon, F. G., Souza, A. C., Balla, V. A., Zandonadi, E., Peixoto, R. R., & Deps, P. D. (2009). Dental and oral condition in leprosy patients from Serra, Brazil. *Leprosy Review*, *80*(2), 156–163.

Stewart, N. A., Gerlach, R. F., Gowland, R. L., Gron, K. J., & Montgomery, J. (2017). Sex determination of human remains from peptides in tooth enamel. *Proceedings of the National Academy of Sciences*, *114*(52), 13649–13654.

Stewart, N. A., Molina, G. F., Issa, J. P. M., Yates, N. A., Sosovicka, M., Vieira, A. R., Line, S. R. P., Montgomery, J., & Gerlach, R. F. (2016). The identification of peptides by nanoLC-MS/MS from human surface tooth enamel following a simple acid etch extraction. *RSC Advances*, *6*(66), 61673–61679.

Taylor, G. M., Murphy, E. M., Mendum, T. A., Pike, A. W., Linscott, B., Wu, H., O'Grady, J., Richardson, H., O'Donovan, E., Troy, C., & Stewart, G. R. (2018). Leprosy at the edge of Europe—Biomolecular, isotopic and osteoarchaeological findings from medieval Ireland. *PLoS One*, *13*(12), e0209495.

Taylor, G. M., Tucker, K., Butler, R., Pike, A. W., Lewis, J., Roffey, S., Marter, P., Lee, O. Y., Wu, H. H., Minnikin, D. E., & Besra, G. S. (2013). Detection and strain typing of ancient *Mycobacterium leprae* from a medieval leprosy hospital. *PLoS One*, *8*(4), e62406.

Tilley, L. (2017). Showing that they cared: An introduction to thinking, theory and practice in the bioarchaeology of care. In L. Tilley & A. Schrenk (Eds.), *New developments in the bioarchaeology of care* (pp. 11–43). Springer.

Tilley, L., & Cameron, T. (2014). Introducing the index of care: A web-based application supporting archaeological research into health-related care. *International Journal of Paleopathology*, *6*, 5–9.

Touati, F. O. (2000). Contagion and leprosy: Myth, ideas and evolution in medieval minds and societies. In L. I. Conrad & D. Wujastyk (Eds.), *Contagion: Perspectives from pre-modern societies* (pp. 179–201). Ashgate.

Tsutaya, T., & Yoneda, M. (2015). Reconstruction of breastfeeding and weaning practices using stable isotope and trace element analyses: A review. *American Journal of Physical Anthropology*, *156*, 2–21.

Veizer, J. (1989). Strontium isotopes in seawater through time. *Annual Review of Earth and Planetary Sciences*, *17*(1), 141–167.

Voerkelius, S., Lorenz, G. D., Rummel, S., Quétel, C. R., Heiss, G., Baxter, M., Brach-Papa, C., Deters-Itzelsberger, P., Hoelzl, S., Hoogewerff, J., & Ponzevera, E. (2010). Strontium isotopic signatures of natural mineral waters, the reference to a simple geological map and its potential for authentication of food. *Food Chemistry*, *118*(4), 933–940.

Walker, S. L., & Lockwood, D. N. J. (2006). The clinical and immunological features of leprosy. *British Medical Bulletin*, *77*(1), 103–121.

Walser, J. W., III, Kristjánsdóttir, S., Gröcke, D. R., Gowland, R. L., Jakob, T., Nowell, G. M., Ottley, C. J., & Montgomery, J. (2020). At the world's edge: Reconstructing diet and geographic origins in medieval Iceland using isotope and trace element analyses. *American Journal of Physical Anthropology*, *171*(1), 142–163.

Wood, J. W., Milner, G. R., Harpending, H. C., Weiss, K. M., Cohen, M. N., Eisenberg, L. E., Hutchinson, D. L., Jankauskas, R., Cesnys, G., Česnys, G., & Katzenberg, M. A. (1992). The osteological paradox: Problems of inferring prehistoric health from skeletal samples. *Current Anthropology*, *33*(4), 343–370.

World Health Organization. (1993). *The health of young people: A challenge and a promise*. World Health Organization.

World Health Organization. (2015). Global leprosy update, 2014: Need for early case detection. *Weekly Epidemiological Record= Relevé épidémiologique hebdomadaire*, *90*(36), 461–474.

World Health Organization. (2019). Global leprosy strategy 2016–2020: Accelerating towards a leprosy-free world. New Delhi: World Health Organization, Regional Office for South-east Asia. 978-92-9022-509-6.

Wright, L. E., & Schwarcz, H. P. (1998). Stable carbon and oxygen isotopes in human tooth enamel: Identifying breastfeeding and weaning in prehistory. *American Journal of Physical Anthropology*, *106*(1), 1–18.

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