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Youth Mobility, Migration and Health before and after the Black Death.

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ABSTRACT

Migration is driven by the young but despite this, few isotope studies focus on adolescent migrants or the intricate nature of their movement. Using a multi-analytical approach we explore this mobility, and the impact of urban living on the diet and health of adolescents from the pre- and post-Black Death periods of Northern England.

Isotope analysis (carbon, nitrogen, oxygen, and strontium) and lead concentrations were measured in 63 adolescents (10-25 years) from three sites in medieval York, and from the nearby small town of Barton-on-Humber. York was an important centre in medieval England, acting as a magnet for adolescents seeking a new life and independence, Barton was seen as less attractive and harder to reach.

In the pre-Black Death sample, 33% of adolescents (n=8/24) were identified as possible migrants by their oxygen and strontium values (5 males and 2 females). Following the Black Death only 5% (n=2/39) of adolescents, both from Barton, appeared to be migrants from elsewhere in Britain, indicating the pattern changed from individuals traveling long distances, to more local isotopically 'invisible' movement. The non-locals appear to have

been well integrated, sharing the same diet to the locals, but there was some evidence for different burial practices. Working in medieval York posed significant health risks for all of the young inhabitants, with lead concentrations at pathological levels, and possibly linked to anaemia and vitamin D deficiency.

This research highlights the importance of combining historical, archaeological, palaeopathological and chemical data to understand complex life histories of adolescents in the past.

KEYWORDS: diet, medieval, lead exposure, York, Barton-on-Humber

Previous bioarchaeological studies of non-adults skeletons from medieval England have hinted at a change in youth mobility following the plague pandemic (AD1348-50), commonly known as the Black Death. Adolescents from rural areas appeared to move less and at an older age than those before the pandemic (Lewis, 2016). This contradicts historical accounts where short distance mobility in England was thought to be common, as labour shortages due to plague deaths provided new opportunities for employment away from rural areas. The important northern centre of York attracted over 40% of its migrants from a 20-mile radius (McClure 1979), while towns such as Barton-on-Humber are argued to have been more isolated, being smaller and harder to reach (Rodwell 2007a). There is still little direct archaeological evidence for the nature and diversity of population movement in medieval England, or how this may have been affected by the pandemic and the Labour Laws of AD1349 and 1388 that followed it (Bennett 2010). Such laws restricted transfer away from rural areas, and had the greatest impact on the young, the most likely cohort to engage in long- and short-distance movement. While mortality patterns based on osteological analysis can suggest changes in behaviour, direct evidence for mobility provided by isotope analysis gives a more detailed and accurate assessment. Previous research into the nature and extent of medieval migration using isotopes has mainly focussed on adult skeletons, with information on their age at death, rather than their age of migration being reported. New approaches using multiple teeth to trace the patterns of migration from birth to 14 years have improved our level of understanding about the age at which people moved (Hamre et al. 2017; Hemer and Evans 2018; Hrnčíř and Laffoon 2019; Petersone-Gordina et al. 2020), but a large-scale analysis of the nature of youth movement in the past has been lacking. In addition, the physical status of these adolescents is rarely considered. Here, we employ a multi-analytical and osteobiographical approach to explore the nature of medieval youth migration in adolescents from the North of England. Information on diet, health, puberty status, burial and exposure to the urban environment provide new information on the life of adolescents, and population diversity in northern areas before and after the Black Death. Social theories regarding the health, integration and visibility of these young migrants are tested using dietary, palaeopathological and burial evidence. Information from northern England contributes to an international understanding of the impact of the Black Death on migration, that has yet to be fully explored, and can provide a model for understanding diversity and mobility in other contexts.

Today, the movement of 15–24-year-olds is driven by economic migration. Youth migration is an important factor in maintaining urban population levels leading to increased fertility rates in the receiving population (Robards and Berrington 2016). The scale of this movement often raises concerns about the sustainability of the rural or coastal areas from which they originate (Argent and Walmsley 2008; Kaczmarczyk and Okólski 2008). Something that also appears to have been a factor following the Black Death. Today, youth movement is both small-scale and temporary (referred to here as mobility), or involves relocation, perhaps permanently, over long distances and across real or perceived political or cultural boundaries ('migration' see Gregoricka 2021). Theories of migration were first explored by Ravenstein in 1885, who set out five principles that resonate today: (1) most individuals move over short distances; (2) those who move long distances migrate to larger cities; (3) females migrate more than males, unless there is a strong female labour market in their home county, or the city in question is geared towards the male labour market (i.e. mining); (4) there is more rural to urban migration than urban emigration; (5) young adults migrate. Migration is also seen in the light of 'push and pull' factors, where the destination country has more favourable circumstances (pull) for that individual or family than their current location (push) (Holobinko 2012). Migration can involve complex patterns of movement. For example, people may move in stages, travelling ever further until they settle in one area, or people will migrate for a short time before returning home (Ravenstein 1885). Studies of modern rural to urban migration indicate rural migrants adapt well to their new urban situation, with individuals from the same village often settling in the same area, or keeping in contact through social networks (Smith 2014). Once they have moved to the town, these rural migrants may practice inter-urban migration as they strive to find work or get married within or between urban centres (Smith 2014). McSparron and colleagues (2019) argue that the size of the migrant group influences their visibility within the archaeological record. A small number of migrants are likely to make external efforts to integrate with the community and de-emphasise any differences, while privately maintaining their own cultural habits (low group agency). This is compared to migration on a large scale where the immigrant group dominate and make little effort to integrate or hide their cultural differences with the receiving population (McSparron et al. 2019). On this theme of visibility, Hemer (2014) suggests that some multiple burials in early medieval contexts may point to groups of travellers who arrived and died together, their multiple grave symbolising both their difference and identity as a migrant group. Such practices are alluded to in documentary sources (Hadley and Hemer 2011). Without the support of a diasporic community, a single young migrant may be invisible in the archaeological record with regards to cultural items and burial rites, but the impact of their movement will be embodied within their skeletons and teeth and can be read through isotope analysis and potentially, their physical health.

Palaeopathology has the potential to explore issues that are usually only attempted in modern populations. For example, the 'healthy migrant hypothesis' posits that migrant individuals are normally the healthiest members of their home community, leaving behind the chronically ill and disabled (Agyemang 2019). Although, inequalities in social status, poor living conditions and genetic factors may cause an initial migrant health advantage to decline rapidly (Agyemang 2019; La Parra-Casado et al. 2017). By focussing on adolescents, bioarchaeologists have the opportunity to examine the health of these individuals around the time they migrate, and potentially before any health advantage has dissipated. Humphries and Leunig (2009) showed that in post-medieval England, merchant sailors who migrated to London were taller than merchant sailors who did not migrate to the city. But assessing the health of migrants on a broad scale is complex. Despite a perceived health advantage, a lower mortality rate for first generation migrants may instead reflect the fact that immigrants who become sick often return to their country of origin, while the healthiest migrants remain (Agyemang 2019). In the past, entrance into a new environment may have increased risks of morbidity and mortality, due to a lack of adaptation or previous exposure to the stimuli they encounter in that environment (Little and Baker 1988). Children within migrating families can act as important mediators for cultural integration, picking up languages and making new friends more quickly than their parents (Hadley and Hemer 2011). However, they could also struggle with any dramatic changes in their social circumstances (Myers 1999). Psychological stress of migrant adolescents in post-medieval London upon leaving their natal home may explain the frequent accounts of melancholy and bedwetting in apprentices (Pelling 1994).

Observations of modern adolescents in the United States has shown a decrease in the age of puberty in those coming in from both developing and equally advantaged countries. This suggests a health advantage with more favourable conditions improving growth and development, however, it may also be related to less advantageous exposure to endocrine disrupting chemicals in the urban environment (Parent et al. 2003). Rural children who travelled to urban areas in the medieval period would also have been exposed to new environmental hazards such as lead and air pollutants. An analysis of 200 samples from individuals dating from the Neolithic to late medieval periods in Britain and Rome demonstrated a dramatic increase in childhood exposure to anthropogenic lead in the early and late medieval periods (Montgomery et al. 2010). These levels were highest in lead mining areas, such as medieval Yorkshire, Derbyshire, Durham and Devon (Homer 1991).

Patterns of medieval migration

Following the Black Death historical records indicate short distance mobility from rural to urban areas in medieval England was common, especially among women and adolescents seeking to improve their family income (Goldberg 1986). Penn and Dyer (1990) suggest the average distance moved was about 7 miles. Reasons for relocation were varied, finding work was probably the greatest motivator and records after the Black Death indicate councils tried to stem the follow of mass migration out of villages into towns (Dunlop 1912). In the early 14th century, York was an important ecclesiastical centre and second only in wealth to London but started to experience economic decline before the Black Death (Nightingale 2010). Analysis of poll tax and surname records from AD 1312-27 showed that while most migrants in York came from 1 to 40 miles away, 4.1% had travelled up to 100 miles. By 1360, this long-distance migration had reduced to 2.1% (McClure 1979). At the end of the 14th century many migrants who were once attracted to York as a major trade centre were lost to the draw of London (Nightingale 2010).

Just as today, economic migration was driven by the young and the fit. Most of the rural women who migrated to urban areas were adolescents (Bitel 2002). Prior to the Black Death apprenticeships for boys began between the ages of 14-16 years, with girls entering service earlier, sometimes by the age of 10 (Pelling 1994). After the pandemic, Goldberg (2004) calculated that domestic servants in York were aged between 11 and 23 years and that the average age of migration was 18 years for males and 19 years for females. Much of the documentary evidence for the lives of children in the medieval period is related to those of wealthier families who could afford to pay the required fees to secure work for their charges (i.e. wards or apprentices). Children from poorer families would have travelled to urban centres to seek employment in less secure circumstances, and perhaps at a younger age, as menial workers and domestic servants. We know little about the age of most economic migrants or where they may have originated (Lewis 2016). Younger children may also have moved across the country or from a rural or urban setting with their kin group, or as foster children (Hadley and Hemer 2011).

Archaeological evidence for adolescent migration patterns

Without the use of large-scale isotopic studies, youth migration has been inferred based on an imbalance of mortality patterns in urban and rural cemeteries. Gilchrist (2012) refers to a low number of 14–17-year-olds in rural Wharram Percy, Yorkshire compared to a peak in individuals dying at this age at Barton-on-Humber, Lincolnshire. In the pre-Black Death cemetery at St Mary Spital, London, over half the individuals were younger than 25 years old and the majority were male (Gilchrist 2012; Thomas et al. 1997). Lewis (2016) carried out the first large scale assessment of 4940 child and adolescent skeletons (6 to 25 years) from 151 sites in medieval England before and after the Black Death. The demographic data suggests a shift in urban migration after the pandemic, with increased numbers of females in urban centres. The average age of adolescent males in urban sites before the plague was 12 years compared to 14 years after it. If these patterns are reflecting migration, this suggests that after the Black Death, more females were moving to urban centres, but that younger males were less likely to move, despite greater opportunities in the labour market.

Some of the first direct evidence for the pattern of medieval migration in England using isotope analysis were carried out at early medieval West Heslerton in Yorkshire (Montgomery 2002; Montgomery et al. 2005). The oxygen and strontium isotope compositions of four female migrants (three adults and one child) suggest they had travelled from Continental Europe or Scandinavia. Kendall et al. (2013) examine the pattern of migration in later medieval London during the plague years (AD 1348-1350) identifying 17% (n=5/30) of the individuals sampled as migrants from Devon, Cornwall, Wales or Scotland, consistent with documentary evidence for migration during this period. Curiously absent from medieval parish records in England is information about the presence of immigrants from beyond Europe, although in London those of 'alien birth' were inhibited from taking up an apprenticeship (Dunlop 1912) which in turn limited their ability to trade or become a citizen (Ben-Amos 1991; Spindler 2011). Osteological and isotopic evidence for first- and second-generation immigrants from across the Roman Empire, including North Africans in Roman York (Eckardt et al. 2014; Leach et al. 2010, 2009) and London (Shaw et al. 2016) have been reported for some time, but only recently have distant migrants been identified in medieval cemetery groups (Redfern and Hefner 2019; Roffey et al. 2017). For example, Redfern and Hefner (2019) identified two black African adults living and dying in London, around the time of the Black Death.

MATERIALS AND METHODS

The study sample

To understand the nature of medieval youth movement and urban health, 386 adolescents (10-25 years) were originally selected for osteological analysis from two urban sites in Northern England; Barton-on Humber (Barton) in Lincolnshire, and York (Figure 1). Isotopic and elemental analysis was carried out on 63 (16.3%) of these adolescents (Table 1), some who demonstrated work related pathologies (Lewis 2016). Barton was a relatively wealthy small town located on the Southern bank of the river Humber (Waldron 2007). Most residents are reported to have been born locally and were occupied in agriculture or the river trade (Clapson 2005), however Barton boasted a port and ferry that may have attracted young migrants from further afield. Documentary evidence indicates that the rich and middle-class members of the population were buried in the cemetery of St. Peter's Church (Tyszka 2006) between AD 950 and 1700, with some burials dating to before the pandemic. Previous dietary analysis indicates that the Barton population were well-nourished, with diets consisting of meat, vegetables, and fish (Beavan et al. 2011).

Samples from York were selected from three sites, representing different socioeconomic groups and dating before and after the pandemic. Adolescents from St. Helen-on-the-Walls (St Helens) represent individuals who lived in the poorest areas of the urban centre (Dawes and Magilton 1980). St Helens was located next to the city walls near the industrial area of Bedern on Aldwark. Archaeological and documentary evidence suggests that living conditions here were crowded, with dwellings being used for both residential and industrial purposes (Palliser 1980). Fishergate House (Fishergate) belonged to the parish church, and later the Priory of St Andrew's Fishergate (Spall and Toop 2005). Individuals were buried in non-familial groups in a narrow strip of land and are considered to be of low social economic status (Burt 2013). St Stephen's, Dixon Lane (St Stephens) is slightly earlier in date to the rest of the York samples, pre-dating the Black Death (AD900-1348). It is located between these two later sites not far from the River Foss. There were 33 individuals aged 7-25 years in the sample analysed by Tucker (2015), 11 of whom were sampled for the current study. Included in this group was a 14-17-year-old identified as having black ancestry based on cranial morphology (Tucker 2015). As well as inhabiting a crowded environment conducive to the spread of disease, it is unlikely that the poorer residents were able to afford a nutritionally adequate diet or grow much produce of their own. Instead, they would have been reliant on meals purchased from the city's cook shops and markets, with bread, porridge, and ale being common medieval staples (Roberts and Cox 2003). Historical sources suggest that York was an attractive centre for migrants and in particular females, who normally travelled short distances and for one or two years (Goldberg 1986).

Table 1. The study sample

Site	Date (AD)	Number of adolescents	Number sampled for chemical analysis
St Peter's Church, Barton-on-Humber, Lincs	950-1300	76	13
	1300-1700	153	14
	All Barton	229	27
St Stephen's Church, York	900-1348	11	11
St Helen-on-the-Walls, York	950-1550	111	10
Fishergate House, York	950-1539	35	15
Total		**386**	**63**

Methods

Sex and age determinations for the St Stephen's adolescents were provided by Tucker (2015), who estimated non-adult ages using dental and skeletal development (Scheuer and Black, 2000). Age-at-death for individuals at the remaining sites was estimated using the development of the mandibular permanent dentition, excluding the canine. A mean dental age was calculated using the average of the ages for all observed teeth (Liversidge and

Marsden 2010; Moorrees et al. 1963). When dental development was complete, age was determined using skeletal maturation of the pelvis (excluding the iliac crest), sacrum, medial clavicle and vertebral annular rings (Albert et al. 2010; Schaefer et al. 2009; Scheuer and Black 2000). Following Lewis et al. (2016) those demonstrating complete fusion of the vertebral annular rings, ischial epiphysis and sacrum, and a fusing epiphysis at the medial clavicle (c. 21-25 years) were assigned to the 22-25-year category. Anyone with a fused junction between the first and second sacral vertebrae and fused medial clavicle epiphysis was considered over 25 years of age and were excluded from the study.

Skeletons aged 10.0-13.9 years were assigned a biological sex based on features of the pelvis and humerus, and male, female, probable male and probable female were assigned when observations in both areas agreed. Only traits that have been reported to achieve over 70% accuracy were selected for the ilium, humerus and mandible (Falys et al. 2005; Sutter 2003). After 15 years, standard methods for the pelvis and mandible were used (Buikstra and Ubelaker 1994). The cranium was not used due to the potential for a false “female” result in adolescent males (Walker et al. 1988).

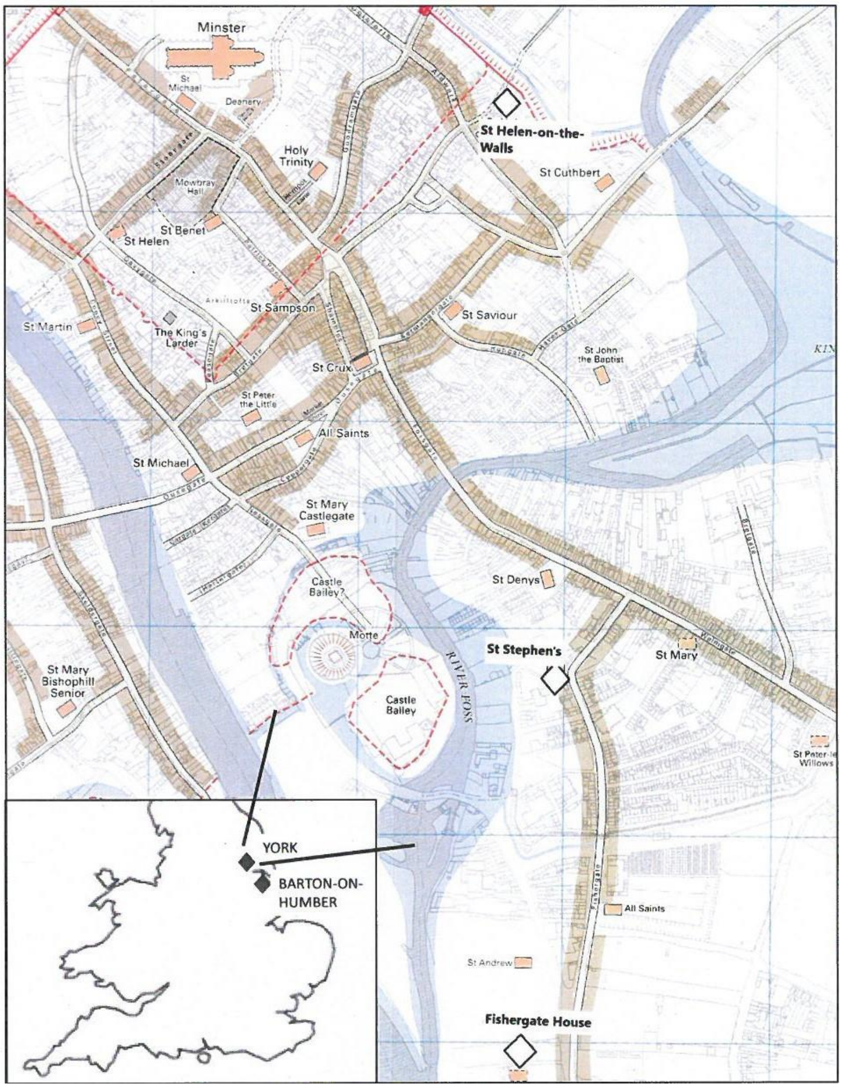

Figure 1. Location of the study sites, with a detailed map of York c. AD 1100. Study sites in York are marked with a white diamond (adapted from Addyman 2015: map 5, sheet J)

Palaeopathological information for each individual was recorded prior to the samples being taken (see Lewis, 2016 and Tucker 2015). Lesions were recorded following standard diagnostic criteria (Buikstra et al. 2020).

Puberty status

An assessment of pubertal stage was carried out using the osteological methods developed by Shapland and Lewis (2013, 2014) and Lewis et al. (2016). Assessment of the maturation stages of skeleton and mineralization of the canine, allow individuals to be placed within one of six stages around the adolescent growth spurt (pre-puberty, initiation, acceleration, peak height velocity, deceleration, maturation, post-puberty). A pubertal stage was assigned where three or more features could be observed and at least three stage features agreed. Peak height velocity (PHV) is a crucial period in adolescence and signals the external signs of sexual maturation including voice-breaking and increased musculature in males. Females normally achieve menarche during the deceleration phase towards the end of the growth spurt (Tanner 1962). Ossification of the superior iliac crest was taken as an indicator that PHV had been passed, and that menarche had occurred (Lewis et al. 2016). Puberty stage data was not available for the St Stephens individuals.

Isotope and elemental analysis

Enamel samples were taken from 63 permanent teeth (51 first premolars, 9 second premolars, 3 second molars) to provide dietary and migration information on the individuals when they were aged between 2 and 7 years of age. Of the 63 individuals sampled, 28 fell within the parameters for males or probable males and 19 were estimated to be female or probable female, for the remaining 16 sex was undetermined. The crowns of the second permanent premolar or second permanent molar typically mineralised between the ages of 3.0-6.5 and 4.0-7.0 years respectively (Moorrees et al. 1963), so any changes in the skeletal and dental signatures would indicate movement after 6.5-7.0 years. First premolars typically mineralise between 2-4 years giving an earlier age by which to identify any movement (Moorrees et al. 1963; Shackelford et al. 2012). The enamel was prepared following the methods described by Montgomery (2002). To avoid contamination issues, only caries-free, translucent core enamel was sampled and surface enamel and all adhering dentine was removed from each tooth using a tungsten carbide dental bur. A flexible diamond-edged rotary dental saw was used to take a slice of dental enamel longitudinally from the tooth wall avoiding the cusp and the cemento-enamel junction. Between samples, the tools were ultrasonicated in Decon® and rinsed three times. As dentine and bone have been demonstrated in numerous studies to be highly susceptible to postmortem uptake of strontium from the burial soil (Budd et al. 2000; Trickett et al. 2003), nine dentine samples were taken to characterise local bioavailable strontium for Barton and York following Montgomery et al. (2007).

Cortical rib samples were taken from each individual, except from the Fishergate House group, for carbon and stable nitrogen isotope analysis. Collagen extraction was achieved using the standard laboratory protocol - a modified Longin (1971) method - at University of Bradford Stable Light Isotope Laboratory. In short, the rib surface was first cleaned using air-abrasion and *c*.300 mg samples were demineralized in 0.5 M hydrochloric acid at 4°C for several days, rinsed and gelatinised in deionised water acidified to pH 3 with HCl for 48 hours at 70°C. Insoluble residues were removed with the aid of a 5–8µm EzeeR filters and the remaining solution passed through AmiconR Ultra-4 filters in a centrifuge to purify the collagen prior to freezing and freeze drying.

Strontium ($^{87}Sr/^{86}Sr$) and oxygen ($\delta^{18}O$)

Strontium and oxygen isotopes are commonly used to explore residential mobility in archaeological humans (Evans et al. 2012). Strontium isotope ratios of tooth enamel were measured by Thermal Ionisation Mass Spectrometry (TIMS) using a Thermo Triton multi-collector mass spectrometer (MC-MS) following standard laboratory procedures at the

NERC National Environmental Isotope Facility at Keyworth, Nottingham. Briefly, strontium isotope composition and concentrations were determined by thermal ionization mass spectrometry (TIMS) using a Thermo Triton automated multi-collector. Samples were loaded onto outgassed rhenium filaments with TaF after the method of Birck (1986). $^{87}Sr/^{86}Sr$ was normalized to an accepted NBS 987 value of 0.710250. External reproducibility was ± 0.002% (2 σ, *n* = 15). Laboratory contamination, monitored by procedural blanks, was negligible (<100 pg). Oxygen isotopes ratios of powdered enamel samples were analysed at the University of Bradford Stable Light Isotope Laboratory. Samples were pre-treated following the standard laboratory method published in Towers et al. (2014). Freeze-dried samples were weighed into septa-capped vials (~1.3 mg for each sample), which were loaded into a Finnigan Gasbench II connected to a Thermo Delta V Advantage continuous flow isotope ratio mass spectrometer, reacted with phosphoric acid (103%) at 70°C to release CO_2, which was analysed by the mass spectrometer. $\delta^{18}OV_{SMOW}$ and $\delta^{13}C_{VPDB}$ measurements were normalized using a calibration equation derived from the measured and accepted values of one international (NBS19), and two internal standards (OES1 and Merck). Analytical precision was ± 0.2‰ for $\delta^{18}OV_{SMOW}$ (1σ) and ± 0.1‰ for $\delta^{13}C_{VPDB}$ (1σ), determined from repeated analyses of an internal enamel laboratory standard (*n* = 33 over 15 months). The $\delta^{18}O$ carbonate values were converted to the VSMOW scale following Coplen (1988) and $\delta^{18}O$ phosphate values were calculated using Chenery et al. (2012).

Evans et al. (2012) provided strontium and oxygen isotope ratios derived from enamel samples of 164 individuals from 74 different archaeological sites in the UK. They suggested $^{87}Sr/^{86}Sr$ values of between 0.7078 and 0.7165 for Britain, with maximum values for England and Wales of 0.7142, and for Scotland of 0.7165. For the current study, dentine samples provided $^{87}Sr/^{86}Sr$ values between 0.7084 and 0.7091 from the Cretaceous chalk at Barton (n=3 samples) and higher values of 0.7101 and 0.7104 for the Triassic Sandstones of York (n=7 samples). To support this evidence, 2SD ranges for Cretaceous chalk and Triassic sandstones were obtained from Evans et al. (2018). However, the BGS online biosphere map for the York area specifically, and previous studies of humans from York (Müldner et al. 2011; Martiniano et al. 2016), suggest *c.* 0.7105 is an appropriate upper limit for humans originating in the Vale of York. Hence individuals that fell outside of the strontium ranges provided were considered 'non-local' to Britain, while values between 0.7091-0.7101 may suggest individuals were non-local to Lincoln (Barton) or York.

The 2 SD range of oxygen enamel carbonate values measured in archaeological humans excavated from Britain is 25.2-27.9‰ although for eastern Britain only it has been determined to be 24.8-27.31‰ (Evans et al. 2012).This latter range has been used in this study as both study sites lie within the eastern Britain zone (Evans et al. 2018). However, the mean values of 17.7 ± 1.4‰ 2SD for Britain and 17.2 ± 1.3‰ 2SD are similar to other geographical regions including France, the northern Mediterranean and south-east Norway (Evans et al. 2012), so it would not be possible to differentiate people local to eastern Britain from individuals from these areas.

Carbon ($\delta^{13}C$ carbonate and collagen) and nitrogen ($\delta^{15}N$ collagen) isotopes

Carbon and nitrogen stable isotopes were employed to reconstruct the major components of the diet. Analysis was carried out at the University of Bradford Stable Light Isotope Laboratory and measured in duplicate by combustion in a Thermo Flash EA 1112. The samples were introduced to a Delta plus XL via a Conflo III interface. Analytical error, calculated from repeat measurements of international standards (IAEA CH3, IAEA600, N1) was ±0.2‰ (1σ) for both elements. All samples produced collagen yields of >1% and met the quality control parameters for C:N, %C and %N (van Klinken 1999). Marine (fish, marine mammals, shellfish seabirds, seabird eggs etc) and terrestrial diets (meat, freshwater fish and plants) have distinct $\delta^{13}C$, however, nitrogen stable isotope ratios can be elevated during periods of undernutrition due to the recycling of body proteins. This can occur with negligible change to stable carbon isotope ratios that are recycled from the body's fat stores (Beaumont et al. 2013).

Strontium (Sr) and lead (Pb) concentrations

Strontium and lead concentrations were analysed in dental enamel at the National Environmental Isotope Facility (NEIF) and prepared following the process and standards outlined in Shaw et al. (2016). Enamel samples were analysed for trace elements by ICP-MS (Thermo Scientific XSeries2) and the final enamel concentrations were determined using sample weights and total dilution volumes.

Lead concentrations were used to explore the level of lead exposure in the children from Barton and York to make inferences about their environmental conditions and health. WHO recommend a blood level limit of 10 μg L-15 in drinking water and just 0.5 μg/m3 in the air with symptoms associated with lead toxicity evident at 40 μg L-15 (World Health Organisation 2019). The level of lead in the bloodstream needs to reach 0.7 μg dL^{-1} to produce a lead concentration of 0.07ppm in the enamel (Montgomery et al., 2010). In their study of deciduous teeth in children from Philadelphia, Needleman and co-workers (1972) identified accumulated lead concentrations in suburban enamel at 11.1ppm compared to

51.1ppm urban children living in the 'lead belt' of the city, this was as high as 110ppm in a child being treated for lead poisoning.

RESULTS

Table 2 presents data for strontium ($^{87}Sr/^{86}Sr$), oxygen ($\delta^{18}O$), carbon ($\delta\ ^{13}C$) and nitrogen ($\delta^{15}N$) isotopes as well as lead and strontium concentrations (ppm). Stable carbon and nitrogen isotope ratios were not available for Fishergate House, except for that published for SK1055 (Burt 2013), so this site was not included in the dietary analysis.

Table 2. Isotopic and elemental data (strontium, oxygen, stable carbon, nitrogen isotopes, lead concentration)

Site	Individual	Enamel/dentine element	Age (years)	Sex	Date (AD)	Sr ppm	$^{87}Sr/^{86}Sr$	$\delta^{18}O$ (VSMOW)‰	$\delta\ ^{13}C$ ‰	$\delta\ ^{15}N$ ‰	Pb ppm
Barton	1018	$PM^2_{+dentine}$	22-25	F	AD 950-1150	94.6	0.70854	25.2	-	-	16.13
Barton	1913	PM_2	10-13	M?	AD 950-1150	61.5	0.71085	26.4	-20.5	9.5	25.48
Barton	2427	PM_2	22-25	F	AD 950-1150	94.1	0.70904	25.4	-20.5	11.3	27.39
Barton	731	PM_2	22-25	F	AD 950-1300	183.0	0.70917	24.8	-19.4	12.4	2.79
Barton	1023	PM^2	14-17	M	AD 950-1300	88.8	0.70906	24.6	-19.8	11.6	6.41
Barton	1158	PM^2	18-21	F	AD 950-1300	108.6	0.70948	25.5	-19.3	13.1	25.37
Barton	1259	$PM^2_{+dentine}$	14-17	F	AD 950-1300	95.0	0.70917	25.4	-20.4	12.2	9.79
Barton	1269	PM_2	22-25	M	AD 950-1300	173.6	0.70903	25.3	-18.6	14.3	11.25
Barton	2340	PM_2	18-21	M	AD 950-1300	79.9	0.70883	25.0	-19.3	12.3	2.31
Barton	2753	PM_2	10-13	M?	AD 950-1300	146.7	0.70908	24.7	-19.3	11.8	12.02
Barton	742	$PM_{2+dentine}$	18-21	M	AD 1150-1300	138.7	0.70923	24.8	-19.9	12.0	4.30
Barton	2474	PM_2	10-13	?	AD 1150-1300	174.5	0.70913	25.2	-20.1	11.5	3.73
Barton	2551	$PM^2_{+dentine}$	10-13	M?	AD 1150-1300	64.4	0.71257	25.4	-20.1	10.5	5.96
Barton	810	PM_2	10-13	M	AD 1150-1500	209.9	0.70876	26.0	-18.9	12.2	16.06
Barton	1592	PM^2	14-17	F	AD 1150-1500	100.0	0.70898	26.3	-19.1	10.8	18.44
Barton	1738	PM^2	18-21	M	AD 1150-1500	153.0	0.70971	26.1	-18.6	14.4	30.22
Barton	1855	PM^2	10-13	?	AD 1150-1500	160.0	0.70905	25.6	-19.8	10.4	4.07

Barton	2222	PM_2	18-21	F	AD 1150-1500	121.0	0.71016	25.1	-18.5	14.9	4.26
Barton	2541	PM_2	14-17	F	AD 1150-1500	346.4	0.70939	25.9	-19.4	13.7	17.39
Barton	198	PM_2	22-25	F	AD 1300-1500	187.6	0.70999	27.3	-19.0	14.8	25.07
Barton	205	PM_2	18-21	F	AD 1300-1500	63.9	0.71016	26.8	-	-	6.93
Barton	339	PM^2	14-17	?	AD 1300-1500	162.0	0.70887	25.9	-18.8	14.1	27.34
Barton	230	PM^2	10-13	?M	AD 1300-1700	187.2	0.70913	24.4	-19.3	12.8	21.07
Barton	496	PM_2	14-17	M	AD 1300-1700	190.7	0.70945	26.3	-19.3	12.6	12.29
Barton	913	M_1	14-17	?	AD 1300-1700	82.6	0.70894	24.8	-19.0	12.1	7.77
Barton	2121	PM_2	14-17	?	AD 1300-1700	118.7	0.70961	25.5	-19.7	10.6	1.40
Barton	2252	PM_2	18-21	M	AD 1300-1700	212.3	0.70890	26.0	-19.3	11.8	11.18
St Stephens	6	M_2	10-13	?	900-1348	113	0.70996	25.9	-19.3	12.7	69.6
St Stephens	14	PM_1	18-21	M	900-1348	47	0.70983	26.4	-19.8	11.8	19.9
St Stephens	18	PM^1	22-25	M	900-1348	91	0.70838	25.6	-20.3	10.5	36.6
St Stephens	25	PM_1	10-13	?	990-1160	134	0.70822	25.4	-19.9	9.8	35.6
St Stephens	39	$PM_{1+dentine}$	10-13	?	900-1348	67	0.71023	25.6	-19.7	9.7	56.1
St Stephens	45	PM_1	18-21	?	900-1348	58	0.71262	26.0	-20.5	9.0	1.5
St Stephens	64	PM^1	22-25	?	900-1348	111	0.71051	25.7	-20.4	11.0	16.6
St Stephens	84	PM_1	18-21	?	900-1348	-	-	26.8	-20.1	10.7	2.3
St Stephens	92	PM_1	10-13	?	900-1348	-	-	25.3	-19.3	11.4	7.5
St Stephens	94	PM_1	14-17	F?	900-1348	125	0.71127	26.5	-19.7	11.1	18.0
St Stephens	95	$PM_{1+dentine}$	22-25	M	900-1348	77	0.71035	25.5	-20.1	11.8	7.3
St Helens	5144	PM_2	22-25	M	1067-1539	-	-	26.3	-18.9	13.4	7.8
St Helens	5189a	PM_1	10-13	F?	1067-1539	112	0.70991	26.5	-19.6	12.7	23.2
St Helens	5224	$PM_{1+dentine}$	14-17	M?	1067-1539	109	0.70995	25.9	-19.0	12.6	22.3
St Helens	5409	PM_2	21-25	M	1067-1539	84	0.71025	25.5	-19.5	12.4	3.5
St Helens	5473	PM_1	21-25	F	1067-1539	94	0.70870	25.9	-18.8	12.4	9.8
St Helens	5518	PM^1	10-13	M?	1067-1539	104	0.70956	25.8	-19.4	12.8	12.1
St Helens	5592	$PM_{1+dentine}$	18-21	M	1067-1539	95	0.70933	25.8	-19.5	12.3	9.5
St Helens	5711	M_1	18-21	M?	1067-1539	159	0.71005	26.0	-19.4	12.5	15.2
St Helens	5887	PM_1	18-21	M	1067-1539	95	0.70906	25.7	-20.0	11.8	2.1
St Helens	6034	PM_1	10-13	M?	1067-1539	112	0.70984	25.9	-19.4	12.2	63.6
Fishergate	1039	PM^2	14-17	M	1420-1530	54	0.71047	26.4	-	-	2.2
Fishergate	1055	PM^2	18-21	F	1067-1539	124	0.70987	26.7	18.7	12.7	24.5
Fishergate	1067	PM_2	14-17	M?	1067-1539	101	0.70926	25.7	-	-	12.9
Fishergate	1083	PM_1	22-25	M	1067-1539	83	0.70893	26.3	-	-	9.9
Fishergate	1085	$PM_{1+dentine}$	14-17	F	1067-1539	105	0.71046	27.0	-	-	13.6
Fishergate	1132	PM_2	10-13	M	1195-1360	59.5	0.71037	26.8	-	-	15.4
Fishergate	1151	PM^2	14-17	?	1195-1360	128	0.71053	25.6	-	-	4.6
Fishergate	1165	PM^1	22-25	F	1067-1539	114	0.71004	26.9	-	-	19.0

Fishergate	1205	$PM_{1+dentine}$	10-13	M?	1067-1539	85	0.71039	26.3	-	-	8.5
Fishergate	1263	PM_2	10-13	?	1067-1539	103.5	0.71017	26.4	-	-	16.4
Fishergate	1322	PM^1	18-21	?	1067-1539	150	0.70938	25.7	-	-	7.9
Fishergate	1328	PM_2	18-21	F	1067-1539	96	0.71036	25.7	-	-	13.3
Fishergate	1330	PM_1	14-17	F?	1067-1539	134	0.71000	26.8	-	-	33.0
Fishergate	1410	$M^2_{+dentine}$	14-17	?	1067-1539	123	0.71030	25.5	-	-	5.6
Fishergate	1465	PM_2	14-17	F?	1067-1539	167.5	0.70976	25.6	-	-	18.8

M=male. F=female. M? = possible male. F? possible female; ? sex unknown; PM^1=maxillary first premolar. PM_1=mandibular first premolar. PM^2=maxillary second premolar. PM_2=mandibular second premolar. M^1=maxillary first molar. M^2=maxillary second molar. M_1=mandibular first molar; M_2=mandibular second molar. '-' =no data.

Mobility

Figure 2 plots the strontium and oxygen isotope ratios for the four sites. All of the individuals fell within the strontium range for England and Wales, and while most fell within the parameters set for York and Lincoln based on the dentine values, there were four individuals, two from Barton and two from St Stephens with higher strontium isotope ratios than the rest (Figure 2, Table 3).

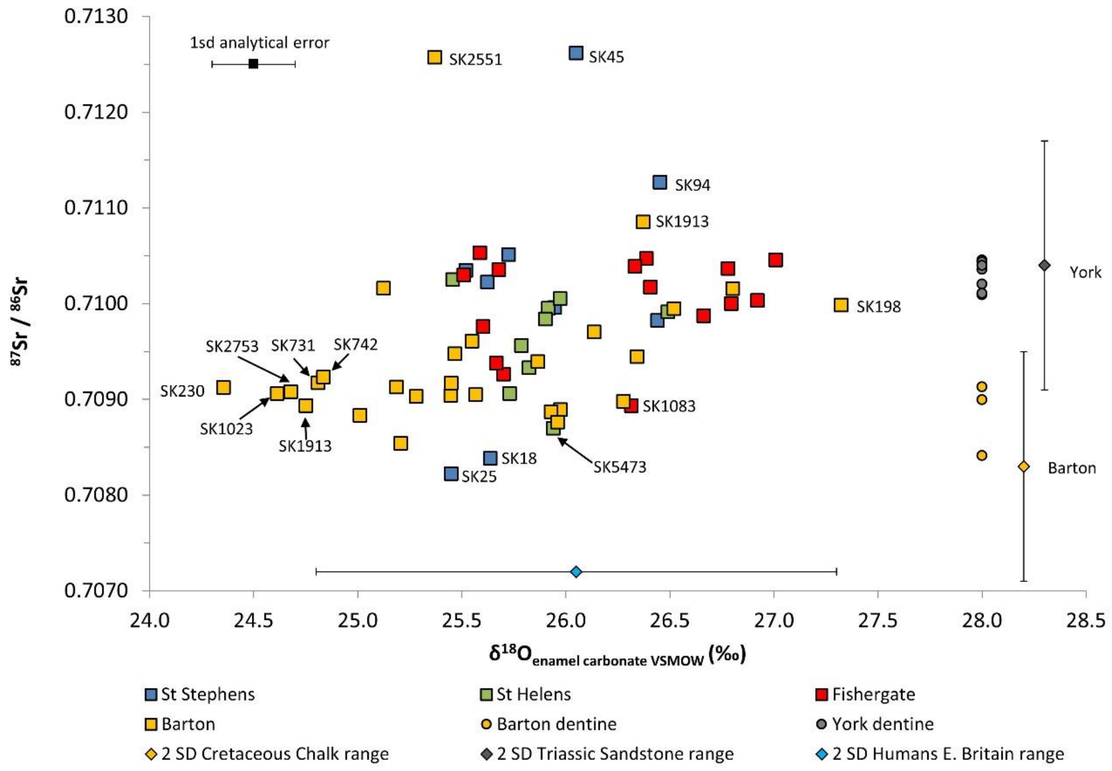

Figure 2. Plot of strontium and oxygen isotope ratios including $^{87}Sr/^{86}Sr$ isotope data from dentine as a proxy for values for the York and Barton burial soil. The range for human oxygen isotopes from Eastern Britain is from Evans et al. (2012) and the 2SD ranges for the York and Barton biospheres from Evans et al. (2018), See text for discussion of highlighted individuals.

All of these individuals dated to the pre-Black Death period. Barton SK2551, a 10–13-year-old possible male had values more consistent with the older rocks of western and northern Britain, for example, Hereford, Southwest England or Scotland. This child had an unusual healing blade injury to their shin. Barton SK1913 was also a 10–13-year-old (possible) male buried in a mass grave with four other individuals (Rodwell 2007a). He died just as he was beginning his puberty growth spurt. At St Stephens, SK45 was a 18-20-year-old of unknown sex among a group of burials with a south-east or north-west alignment, in contrast to the usual east west orientation at the site (McCormish 2006). Like Barton SK2551, this individual had values that were consistent with a more northern or western origin, such as Scotland. This potential migrant also had evidence of a chest infection and they had fractured their finger. St Stephens SK94 was a teenage girl of black African ancestry (Tucker 2015), who was living outside the Yorkshire area between the ages of 3 and 8 years when the enamel of her first premolar was forming. There is nothing in her isotope profile that suggests she moved to Lincolnshire from outside Britain, or any values that are fairly unique to Africa such as extremely high strontium isotope ratios, so she was likely born in in the UK, perhaps as a second generation migrant.

Table 3. Summary of individuals with 'non-local' strontium values.

Individual	Date (AD)	Biological sex	Age (years)	Details of burial	Puberty status	Skeletal pathology
Barton 1913	950-1150	?Male	10-13	Buried in a rectangular pit with two mature adult males and two non-adults aged 7 and 8 years	Died during acceleration phase	None observed
Barton 2551	1150-1300	?Male	10-13	Line of graves that follow Norman defensive ditch.	-	Healing cut mark on shin (tibia)
St Stephen 94	900-1348	?Female	14-17	Near boundary ditch	-	Schmorl's nodes, cortical defect on right femur
St Stephen 45	900-1348	?	18-21	With group buried in north-west body orientation	-	Chest infection, congenital anomaly of the spine, fractured MC4

All of the adolescents from York had oxygen isotope values considered consistent with the UK. At Barton there was a cluster of 6 individuals with lower oxygen isotope values than would be expected for Britain and eastern Britain in particular (i.e. below 24.8‰), although their strontium isotope ratios fell within the expected ranges for Barton (Figure 3, Table 4). Of the five individuals where the dominant sexual characteristics could be scored, all but one (SK731) were male. These individuals died at different times throughout the use of the cemetery, with four pre-dating the Black Death. One of the youngest males (SK230) suffered from septic arthritis of his elbow, perhaps indicative of tuberculosis, and died during his peak growth spurt, while another male died as his adolescent growth spurt was beginning (SK2753). One other individual, SK198, a 22–25-year-old high status post-puberty female, stood out as having had the highest oxygen values in the sample (27.3‰).

Table 4. The group of six Individuals at Barton-on-Humber with oxygen isotope values lower than expected for Britain.

Individual	Date (AD)	Biological sex	Age (years)	Details of burial	Puberty status	Skeletal pathology
Barton 731	950-1300	Female	22-25	Nothing to note	Post-puberty	None observed
Barton 1023	950-1300	Male	14-17	Not on burial plan	Died during PHV	None observed
Barton 2753	950-1300	?Male	10-13	Coffin with bronze stud	Died during acceleration phase	None observed
Barton 742	1150-1300	Male	18-21	Nothing to note	died during maturation phase	Healed fractured clavicle
Barton 230	1300-1700	?Male	10-13	Nothing to note	Died during PHV	Septic arthritis of right elbow

Barton 913	1300-1700	?	14-17	Possible double burial with SK937 (14-17 years)	-	Clay shoveler's fractures of spine

At York, 11% (n=4/36) of the individuals sampled had signatures not consistent with local values but suggesting short-distance mobility. One was from Fishergate House; a 22–25-year-old male from the Lincolnshire area (SK1083). He was buried with a local female (SK1085) aged 14-17 years, who probably died around the time of her first menarche. At St Helens, a 18-20-year-old female (SK5473), who was just coming to the end of her adolescent growth spurt when she died, fell just outside the York range. At the pre-Black Death site of St Stephens, two individuals (SK25 and SK18) had low strontium isotope values that placed them within the Barton (i.e. Cretaceous chalk) range. SK25 was one of the earliest burials in the cemetery dating from the Anglo-Scandinavian period, this 10–13-year-old has sustained a fracture to the left side of their skull. SK18 was an older adolescent male who was among a group of individuals buried in coffins with clench bolts in a cross-shaped pattern similar to those found at Barton (McCormish 2006).

Diet

The dietary signatures for the York and Barton adolescents are presented in Figure 3, along with stable carbon and nitrogen isotope ratio data for marine and freshwater fish, herbivores, pigs and fowl from medieval York (Müldner 2005). At Barton, those eating a C_3 terrestrial diet compared to those eating a mix of terrestrial and marine foods was almost equal. There was no pattern with regards to the period in which these individuals lived, with both early and later dated burials occurring in both diet groups. All individuals with oxygen and strontium isotope ratios lower than expected for Britain (i.e. non-locals) had terrestrial diets. Interestingly, at York there is a distinct trend over time from a completely terrestrial diet prior to the Black Death (St Stephens) to a mix of marine and terrestrial foods in the later medieval period (St Helens), with the exception of St Stephens SK6, a 10-12-year-old local whose values fell within the St Helen's values, suggesting they had some fish in their diet.

The highest nitrogen and carbon isotope values were at Barton, with four individuals having values above 14.4‰ for nitrogen and 18.5‰ for carbon(SK198, SK2222, SK1269 and SK1738), suggesting they were consuming more fish than their peers. Those with the highest nitrogen values were SK198, a non-local, high-status female from the cloth of gold burial, and SK2222 was also a post-puberty female, slightly younger at 18-21 years.

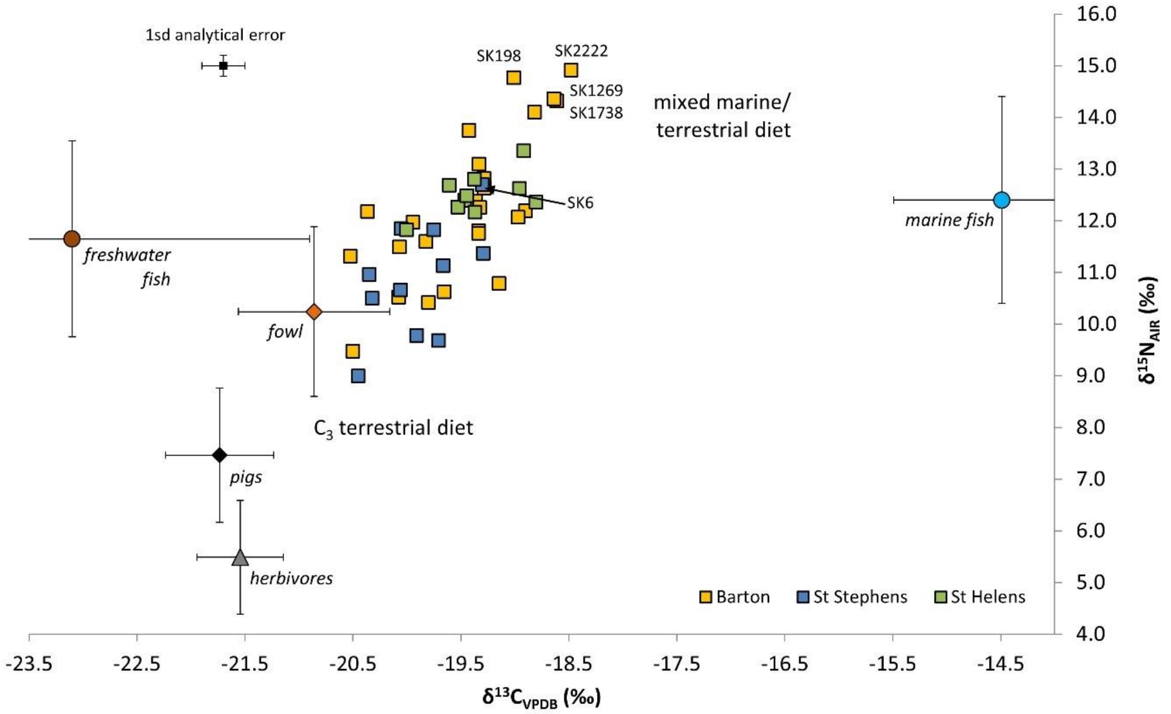

Figure 3. Plot of stable carbon and nitrogen isotope ratios for Barton and the York sites. York faunal data kindly provided by Müldner (pers. comm.).

Lead exposure

The mean lead concentration at Barton was 13.2ppm compared to 17.9ppm in the combined York samples (Figure 4). Of the York samples, St Stephens had the highest average lead concentration levels at 24.6ppm. These averages fall below the modern concentrations of inner city Philadelphia (51.1ppm), but are higher than modern suburban values (11.1ppm). The York combined sample contains three outliers (St Stephens SK39 and SK6, and St Helen SK6034) with high lead concentrations of 56.1, 69.6 and 63.6ppm respectively. All of these individuals are aged 10-13 years suggesting exposure from an early age to allow for lead accumulation in the enamel; exposure to high levels of lead over a shorter period, or greater lead absorption than their peers.

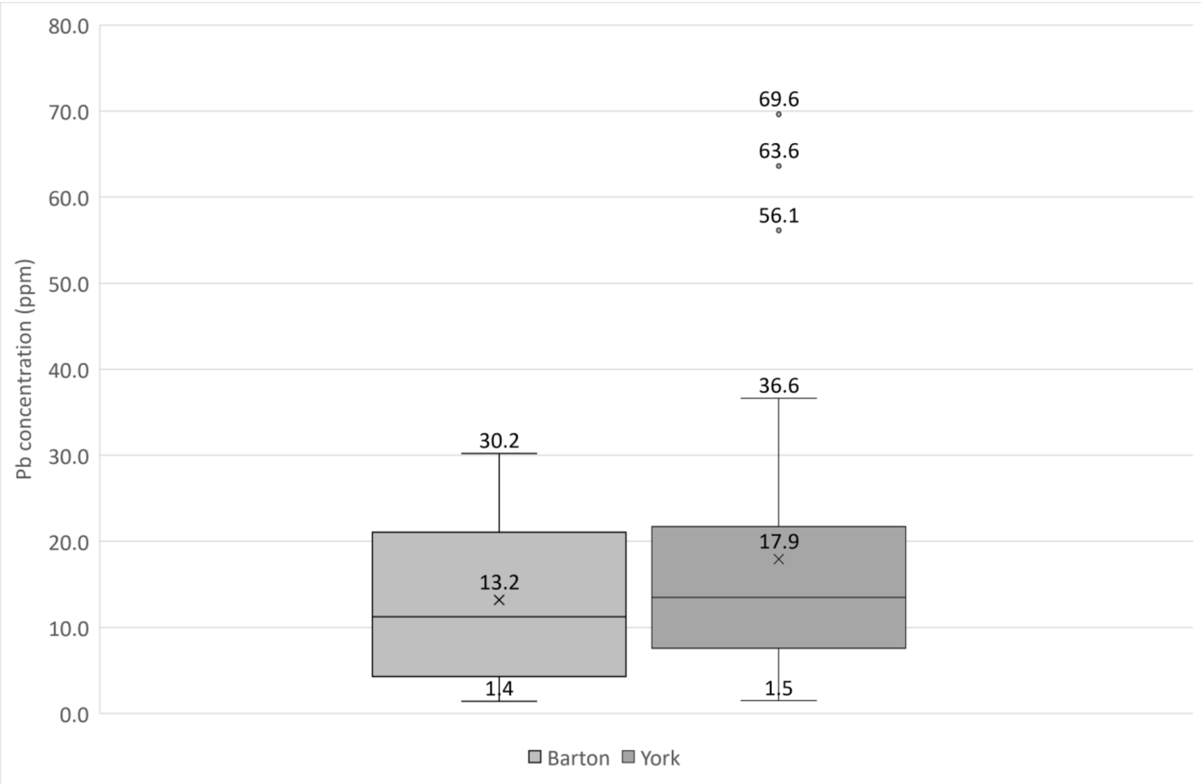

Figure 4. Lead concentrations at Barton and the combined York sites, showing means ('x') and the three York outliers.

Two other individuals showed pathological levels of lead (< 35ppm) in their enamel (Figure 5, Table 5). Both were from St Stephens, again SK25 was young, dying between 10-13 years of age, while SK18 was an older adolescent at 22-25 years. Overall 45% of individuals samples from St Stephens were exposed to hazardous levels of the toxic metal. By contrast, St Stephens SK45 and Barton SK2551 (from the pre-Black Death period) had the lowest levels of anthropogenic lead in their dental enamel. Read in conjunction with the strontium isotope data (Figure 5), this suggests that they migrated from less polluted rural areas, and may have travelled to York and Barton from Scotland after their premolar crowns had developed at 7 years of age.

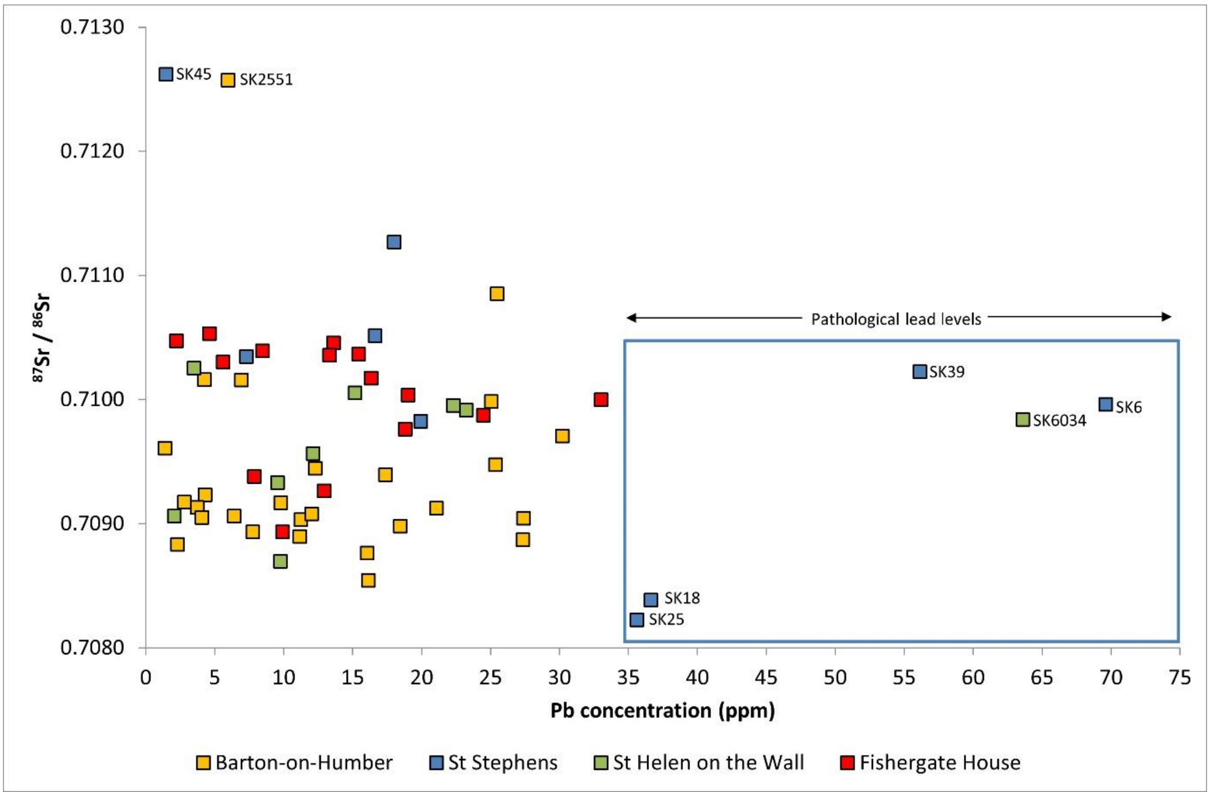

Figure 5. Lead concentration (Pb) by parts per mille (ppm) plotted against strontium isotope values

Table 5. Pathology and migratory status of individuals with high lead levels. St Stephen's pathological data taken from Tucker (2015).

Individual	Date (AD)	Pb ppm	Age (years)	Biological sex	Local or non-local	Pathology
St Stephens 6	900-1348	69.6	10-13	?	Local	Bowed tibiae and fibulae suggest healed vitamin D deficiency; active infection on both legs
St Helens 6034	1067-1539	63.3	10-13	?Male	Local	Active cribra orbitalia
St Stephens 39	900-1348	56.1	10-13	?	Local	Healed depressed fracture on left frontal bone
St Stephens 18	900-1348	36.6	22-25	Male	Non-local	Os acromiale of left scapula
St Stephens 25	900-1348	35.6	10-13	?	Non-local	Healed depressed fracture of right parietal

DISCUSSION

This study explored that nature of medieval youth migration before and after the Black Death in England, using a rich multi-faceted dataset to fully contextualise the osteological, archaeological, and historical evidence. Historical sources suggest that shorter distance mobility replaced migration into York after the pandemic as the result of labour laws and a decline in York's fortunes. It was anticipated that many of these migrants would settle in the poorest districts of the town, such as St Helens and St Stephens, both located by the city walls. Historical sources suggest the proportion of longer distance migrants declined after the Black Death in line with the economic decline of York (Nightingale 2010). A reduction in the number and diversity of adolescents coming to York may also have been the result of Labour Laws introduced in 1349. This law stated that all able-bodied men and women had to accept work on the land if offered. In 1388 apprentices were ordered to rural areas to help with the harvest, and 12-year-olds living in rural areas were required to remain and work the land. No worker, once hired, could leave their job before their contract had ended (Clark 1983). It is possible that the demand for males to work the land outweighed that of females, limiting male mobility. These labour laws persisted until 1563 (Bennett 2010).

The strontium isotopic evidence identified two adolescents who migrated to York prior to the Black Death. St Stephens SK45, an 18–21-year-old, originated from an older geological terrain than the north or west of York, with oxygen isotopes indicating they may have come from Scotland. This individual had the lowest lead levels of all the adolescents in this study and an exclusively terrestrial diet, indicating they migrated from a rural area with limited access to marine foods. They were one of several individuals buried in a group, with a north-west body orientation. The young female identified as being of black African descent (SK94), moved to York from another part of England between 7 and 14 years of age. Although she may have been a second generation migrant, her presence, in addition to two black Africans identified in London (Redfern and Hefner 2019), hints at the diversity of medieval England before the pandemic. After the pandemic, the movement became more regional, with 93% of sampled adolescents from Fishergate House and 77% from St Helens showing an exclusively York signature, and the rest showing values within the Lincolnshire region. A search of immigration data derived from historical records for York between AD 1300-1540 (https://www.englandsimmigrants.com/) showed people moving into the areas from

Scotland and the Orkney Isles, as well as outside the UK, mainly in France and Scandinavia, but not outside Europe. In addition, tax records for Fishergate House show many immigrants had ‘moved away’ since the last tax collection indicating transitory relocation within the city.

Barton is considered a typical market town, but its importance in the medieval period was local, eclipsed in size and importance by nearby Hull and as a significant east coast port by Grimsby. Access to Barton, at least by the eighteenth century, was ‘an ill-favoured and dangerous passage’ by ferry, or rather an open boat transporting people and livestock across the Humber (Rodwell, 2007b:1). For these reasons it was expected that the population at Barton would have been ‘stable and predominantly indigenous’ (Rodwell, 2007b:1). However, the isotopic picture before the plague suggests it was attractive to people from outside the North of England. While 20 (74%) of the Barton adolescents sampled had oxygen signatures consistent with local origins, seven (26%) demonstrated much more diverse origins. This includes a group of six adolescents (including 4 males and 1 female) who all appear to have come from a similar northern location such as Scotland, all sharing a terrestrial diet. A further young migrant (SK2551) had strontium values and low lead levels consistent with migration from a rural location. Barton SK1913 was a 10–13-year-old possible male buried in a mass grave comprising a rectangular pit near the boundary hedge, his limbs intertwined with four other individuals. This was the only mass grave identified at Barton dated from AD 950-1150 (Rodwell 2007a). It is tempting to suggest that this is a group of single migrant males, with their multiple grave identifying them as travellers, a practice hinted at in the historical records of the time (Hadley and Hemer 2011). One female, Barton SK198, had the highest oxygen values in the sample (27.3‰). While just on the edge of expected values for England, she may have travelled from an area warmer than the UK. She died between AD1300-1500, and was the only Barton individual buried in the nave, with a cloth of gold and silk. The pattern of mobility at Barton and York indicate a change from migration from further afield to more regional, and perhaps invisible mobility after the Black Death. Historical sources and osteological data have indicated a change in the age at which adolescents migrated following the fourteenth century pandemic, from 14 to 18 years. Our small sample did not show any particular trend, with individuals as young as 10-13 years migrating in both periods. There was also no evidence for a majority of female movement to York following the Black Death, however biological sex estimations for younger adolescents are still a challenge, and future work should seek to include peptide analysis (Stewert et al. 2017) to explore this question further. There did, however, appear to be a pattern of male dominated migration into Barton. With its port, Barton would have had a strong male labour market, and the group of six non-locals may have included sailors or river workers.

The stable carbon and nitrogen isotope ratios indicated that both migrants and locals were consuming the same diet. The majority of individuals from Barton consumed either a terrestrial or mixed diet, but five individuals stood out with the highest nitrogen values in the sample, including the high-status female (SK198). While they may have been consuming more fish, living near the coast, two individuals died during PHV and these high values may be related to stress (Beaumont et al. 2013). The diachronic shift from a terrestrial to a mixed terrestrial and marine diet between St Stephens and St Helens is striking. Fish was an important dietary resource in medieval York, which acted as a major trading centre for marine foods into mainland England (Rycraft 2000). While freshwater fish would have been common in the early medieval period, it was expensive and scarce before 1348 (Barrett et al. 2004; Harland et al. 2016), perhaps explaining the almost exclusive terrestrial diet of the St Stephen's inhabitants. During the medieval period there was an increased reliance on marine fish and the mixed diet of the St Helens adolescents may also reflect the increase in fish eating throughout the general population with the increase in piety (Müldner and Richards 2007ab). Only St. Stephens SK6 showed a mixed diet similar to St Helens. They suffered from vitamin D deficiency earlier in their life and had an infected leg when they died. SK6 also had one of the highest lead concentrations at the site and the high nitrogen isotope values may suggest they were malnourished and stressed when they died, it is also possible they were being fed fish as part of their care.

Palaeopathological evidence revealed evidence for trauma in non-local adolescents. It was not possible to determine whether these fractures were sustained before or after they moved to Barton and York, but two males were suffering from active infections, one of the chest and the other the elbow that were possibly the result of exposure to their new environment. Lead was ubiquitous in medieval England, despite an acknowledgement that it was harmful. In the medieval period lead entered the atmosphere through mining, smelting, refining, recycling of the metal, as well as by being added to pottery glazes, glass, and water pipes (Homer 1991). Lead may also have been present in drinking water contaminated by lead in the dust and dirt. Brännvall and colleagues (1999) have argued that the metal industry in northern Europe was responsible for the dramatic rise in atmospheric lead pollution, previously attributed to the Industrial Revolution. Lead was mined as a by-product of silver mining, mainly from Yorkshire, Derbyshire, Durham and Devon (Homer 1991). Lead toxicity affects the nervous system and calcium metabolism, and has been linked to numerous conditions including encephalopathy and vitamin D deficiency in children. Clinical symptoms include anaemia, stomach aches, kidney damage, vomiting, gastrointestinal disorders, nerve disorders, infertility, memory loss and an inability to concentrate. Children are more susceptible to more severe neurological effects of lead toxicity as their blood-brain barrier is not fully developed (Byers and Lord 1943; World Health Organisation 2019). Levels above 40ppm have been attributed to mental disorders and neurobehavioral problems, and levels as low as 10ppm have been related to aggressive behaviour in children (Bellinger 2008; Needleman 2004). The high levels of lead exposure in some of the medieval adolescents from York raises questions about the effect on their social behaviour and historical accounts of the often violent and anti-social behaviour of urban youth (Lewis 2016), and the link between lead exposure and juvenile delinquency (Miller 2012).

Lead levels in all the sampled individuals exceeded the upper limit of 'natural' lead exposure seen in prehistoric samples (Montgomery 2010), and some adolescents had accumulated very high levels of lead in their enamel. While the average lead concentrations fell below the 51ppm seen in highly industrial areas of the 1970s (Neddleman et al. 1972), average levels in pre-Black Death St Stephens at 24.6ppm, were higher than in the 1970s suburbs. The two York adolescents with the highest lead levels also had skeletal changes that might be linked to high level of lead in their bloodstream – iron deficiency anaemia and vitamin D deficiency (Table 5). The association between rickets in children and lead exposure has long been recognised (Caffey 1938), and has also been identified in children from across the Roman Empire (Moore et al. 2021), but the relationship is complex. Both calcium and lead are divalent cations with similar metabolic characteristics, but as lead is a larger more active ion it is preferentially metabolised over calcium and 1, 25-dihydroxy-vitamin D, leading to vitamin D deficiency (Nwobi et al. 2019; Zhang et al. 2019). Lead absorbed in the gut through contaminated food can be as high as 45% in fasting conditions, and up to 53% in malnourished children (Gidlow, 2015). This may mean that low status, poorly nourished groups were likely to be more susceptible to lead poisoning in the past. St Helens SK6034 demonstrated the second highest levels of lead in their teeth and displayed severe active cribra orbitalia suggestive of iron deficiency anaemia or perhaps a respiratory disease (O'Donnell et al. 2020). Interestingly, St Stephens SK39 and SK25 were both previously identified by Tucker (2015) as having problems with their growth and maturation. It is possible that the high levels of lead absorbed by the St Stephen’s adolescents are a reflection of their lower calorie terrestrial diet.

CONCLUSIONS

Five hundred years before the Black Death, migrants in the north of England came from more distant areas of Britain, and potentially Europe, including a black African already living in Britain. After the Black Death, the archaeological evidence is consistent with that reported in parish records, with nearly all the migrants in the sample coming from regions close to York or Lincolnshire, indicating a change from long-term, long-distance migration, to regional mobility after the pandemic. With regards to visibility of migrants, more work needs to be carried out on multiple and marginal burials to test the hypothesis that migrants were buried in groups. There was at least one possible example of this practice at Barton, with other non-locals at Barton and York buried in a different orientation or on the periphery of the cemetery. There was no indication of diverse dietary practices in individuals identified as non-local however, and although the sample sizes are small, this suggests that individual migrants were integrating themselves with the local community. The difficulty of navigating the Humber in the medieval period had led to suggestions that this market town was isolated, despite being a port settlement (Rodwell 2007a). Our evidence revealed that before the Black Death, 32% of the individuals samples were from outside the town, indicating it was an attractive work prospect for young male migrants. The high levels of lead in all the adolescents sampled may provide an explanation for the historical accounts of anti-social behaviour often attributed to medieval youth in urban areas, with young individuals living in pre-Black Death St Stephens the most affected.

This study has highlighted the advantage of using a multi-analytical approach to explore the nature of medieval youth movement in medieval England, focusing on the bodies of the young migrants themselves. Combining detailed chemical and osteological analysis to elucidate the diversity and nature of migration before and after the Black Death, provides a model for such investigations in other urban centres of Europe.

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REFERENCES

Agyemang, C. 2019. Comfy zone hypotheses in migrant health research: time for a paradigm shift. *Public Health* 172: 108-115.

Albert, M., Mulhern, D., Torpey, M. A., and Boone, E. 2010. Age estimation using thoracic and first two lumbar vertebral ring epiphyseal union. *Journal of Forensic Sciences* 55(2): 287-294.

Argent, N., and Walmsley, J. 2008. Rural youth migration trends in Australia: An overview of recent trends and two inland case studies. *Geographical Research* 46(2):139-152.

Barrett, J. H., Locker, A. M., and Roberts, C. M. 2004. 'Dark Age Economics' revisited: the English fish bone evidence AD 600-1600. *Antiquity* 78(301):618-636.

Beaumont, J., Geber, J., Powers, N., Wilson, A., Lee-Thorp, J., and Montgomery, J. 2013. Victims and survivors: stable isotopes used to identify migrants from the Great Irish Famine to 19th century London. *American Journal of Physical Anthropology, 150*(1): 87-98.

Beaumont, J., Montgomery, J., Buckberry, J., and Jay, M. 2015. Infant mortality and isotopic complexity: new approaches to stress, maternal health. and weaning. *American Journal of Physical Anthropology* 157(3): 441-457

Beavan, N., Mays, S., Cook, G., and Ditchfield, D. 2011. Stable isotope analysis. In W. Rodwell and C. Atkins (Eds.), *St Peter's Barton-upon-Humber, Lincolnshire. A Parish Church and its Community, History, Archaeology and Architecture Part 2,* edited by W. Rodwell and C. Atkins. pp. 762-767. Oxford, Oxbow.

Bellinger, D. C. 2008. Very low lead exposures and children's neurodevelopment. *Current Opinion in Pediatrics* 20(2):172-177.

Ben-Amos, I. 1991. Failure to become freemen: urban apprentices in early modern England. *Social History* 16(2): 155-172.

Bennett, J. 2010. Compulsory service in late medieval England. *Past and Present* 209 (1): 7-51.

Bitel, L. 2002. *Women in Early Medieval Europe 400-1100*. Cambridge, Cambridge University Press.

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

Brännvall, M.-L., Bindler, R., Renberg, I., Emteryd, O., Bartnicki, J., and Billström, K. 1999. The medieval metal industry was the cradle of modern large-scale atmospheric lead pollution in northern Europe. *Environmental Science and Technology* 33(24): 4391-4395.

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

Buikstra, J. E., and Ubelaker, D. eds. 1994. *Standards for Data Collection from Human Skeletal Remains.* Fayetteville, Arkansas Archeological Survey.

Burt, N. M. 2013. Stable isotope ratio analysis of breastfeeding and weaning practices of children from medieval Fishergate House York, UK. *American Journal of Physical Anthropology* 152(3): 407-416.

Byers, R. K., and Lord, E. E. 1943. Late effects of lead poisoning on mental development. *American Journal of Diseases of Children* 66(5): 471-494.

Caffey, J. 1938. Lead poisioning associated with active rickets. *American Journal of Diseases of Children* 55(4): 798-806.

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.

Clapson, R. 2005. The later history of Barton-upon-Humber. In *Barton and the River Humber 1086-1900* edited by the Worker's Educational Association, pp. 123-157. Gainsborough, G.W. Belton Ltd.

Clark, E. 1983. Medieval labor law and English local courts. *American Journal of Legal History 27*, 330-353.

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

Daux, V., Lécuyer, C., Héran, M.-A., Amiot, R., Simon, L., Fourel, F., Martineau, F.,

Lynnerup, N., Reychler, H. and Escarguel, G. 2008. Oxygen isotope fractionation between human phosphate and water revisited. *Journal of Human Evolution*, 55(6): 1138-1147.

Dawes, J. D., and Magilton, J. R. 1980. *The Cemetery of St. Helen-on-the-Walls, Aldwark.* (Vol. 12/1). London, Council for British Archaeology.

Dunlop, O. 1912. *English Apprenticeship and Child Labour*. London, T. Fisher Unwin.

Eckardt, H., Müldner, G., and Lewis, M. 2014. People on the move in Roman Britain. *World Archaeology* 46(4): 534-550.

Evans, J. A., Chenery, C. A., and 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., and Marchant, A.P. 2018. User guide for the Biosphere Domains GB (Version 1) dataset and web portal. British Geological Survey Open Report, OR/18/005

Gidlow, D. A. 2015. Lead toxicity. *Occupational Medicine* 65(5): 348-356.

Falys, C., Schutkowski, H., and Weston, D. 2005. The distal humerus - a blind test of Rogers' sexing technique using a documented skeletal collection. *Journal of Forensic Science* 50(6): 1289-1294.

Gilchrist, R. 2012. *Medieval Life. Archaeology and the Life Course*. Woodbridge, Boydell Press.

Goldberg, P. 1986. Female labour, service and marriage in the late medieval urban north. *Northern History* 12: 18-38.

Goldberg, P. 2004. Migration, youth and gender in later medieval England. In *Youth in the Middle Ages*, edited by P. Goldberg and F. Riddy, pp. 85-99. Rochester, York Medical Press.

Gregoricka, L. A. 2021. Moving Forward: a bioarchaeology of mobility and migration. *Journal of Archaeological Research* 29: 581-635.

Hadley, D. M., and Hemer, K. A. 2011. Microcosms of migration: children and early medieval population movement. *Childhood in the Past* 4(1): 63-78.

Hamre, S. S., Ersland, G. A., Daux, V., Parson, W., and Wilkinson, C. 2017. Three individuals, three stories, three burials from medieval Trondheim, Norway. *PloS one* 12(7): e0180277.

Harland, J., Jones, A., Orton, D., and Barrett, J. 2016. Fishing and fish trade in medieval York: the zooarchaeological evidence. In *Cod and Herring: the archaeology and history of medieval sea fishing,* edited by J. H. Barrett and D. Orton, pp. 172-204. Oxford, OUP.

Hemer, K. 2014. Are we nearly there yet? Children and migration in early medieval western Britain. In *Medieval Childhood: Archaeological Approaches*, edited by D. Hadley and K. Hemer, pp. 131-144. Oxford, Oxbow Books, SSCIP.

Hemer, K. A., and Evans, J. A. 2018. The contribution of stable isotope analysis to the study of childhood movement and migration. In S. Crawford, D. Hadley, & G. Shepherd (Eds.), *The Oxford Handbook of the Archaeology of Childhood*. Oxford: Oxford University Press, pp 505-520.

Holobinko, A. 2012. Theoretical and methodological approaches to understanding human migration patterns and their utility in forensic human identification cases. *Societies* 2(2):42-62.

Homer, R. F. 1991. Tin, lead and pewter. In *English Medieval Industries* edited by J. Blair and N. Ramsay pp. 57-80. London, A&C Black.

Hrnčíř, V., and Laffoon, J. E. 2019. Childhood mobility revealed by strontium isotope analysis: a review of the multiple tooth sampling approach. *Archaeological and Anthropological Sciences* 11(10): 5301-5316.

Humphries, J., and Leunig, T. 2009. Was Dick Whittington taller than those he left behind? Anthropometric measures, migration and the quality of life in early nineteenth century London? *Explorations in Economic History* 46: 120-131.

Kaczmarczyk, P., and Okólski, M. 2008. Demographic and labour-market impacts of migration on Poland. *Oxford Review of Economic Policy* 24(3): 599-624.

Kendall, E., Montgomery, J., Evans, J., Stantis, C., and 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.

La Parra-Casado, D., Stornes, P., and Solheim, E. F. 2017. Self-rated health and wellbeing among the working-age immigrant population in Western Europe: findings from the European social survey (2014) special module on the social determinants of health. *European Journal of Public Health* 27(1): 40-46.

Leach, S., Eckardt, H., Chenery, C., Müldner, G., and Lewis, M. 2010. A lady of York: migration, ethnicity and identity in Roman Britain. *Antiquity* 84(323): 131-145.

Leach, S., Lewis, M., Chenery, C., Müldner, G., and Eckardt, H. 2009. Migration and Diversity in Roman Britain: A Multidisciplinary Approach to the Identification of Immigrants in Roman York, England. *American Journal of Physical Anthropology* 140(3): 546-561.

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

Lewis, M., Shapland, F., and Watts, R. 2016. On the threshold of adulthood: A new approach for the use of maturation indicators to assess puberty in adolescents from medieval England. *American Journal of Human Biology* 28(1): 48-56.

Little, M. A., and Baker, P. T. 1988. Migration and adaptation. In *Biological Aspects of Human Migration* edited by C. Mascie-Taylor and G. W. Lasker pp. 167-215. Cambridge, Cambridge University Press.

Liversidge, H. M., and Marsden, P. H. 2010. Estimating age and the likelihood of having attained 18 years of age using mandibular third molars. *British Dental Journal* 209(8), E13, https://doi.org/10.1038/sj.bdj.2010.976.

Longin, R. 1971. New method of collagen extraction for radiocarbon dating. *Nature* 230(5291): 241-242.

Martiniano, R., Caffell, A., Holst, M., Hunter-Mann, Kurt., Montgomery, J., Müldner, G., Mc-Laughlin, R. L., Teasdale, M. D., van Rheenen, W., Veldink, J. H., van der Berg, L. H., Hardiman, O., Carroll, M., Roskams, S., Oxley, J., Morgan, C., Thomas, M. G., Barnes, I., McDonnell, C., Collins, M.J. and Bradley, D.G. 2016. Genomic signals of migration and continuity in Britain before the Anglo-Saxons. *Nature Communications* 7(10326): 1–8. DOI: 101038ncomms10326.

McClure, P. 1979. Patterns of migration in the late middle ages: the evidence of English place-name surnames. *The Economic History Review* 32(2): 167-182.

McCormish, J. 2006. *Land at the Junction of Dixon Lane and George Street, York. Assessment report for an archaeological excavation.* York Archaeological Trust: York.

McSparron, C., Donnelly, C., Murphy, E., and Geber, J. 2019. Migration, group agency, and archaeology: a new theoretical model. *International Journal of Historical Archaeology* 24(2): 219-232.

Miller, S. M. 2012. Lead poisoning: the epidemic hitting the US juvenile justice system. *International Journal of Liability and Scientific Enquiry* 5(3-4): 213-220.

Montgomery, J. 2002. Lead and strontium isotope compositions of human dental tissues as an indicator of ancient exposure and population dynamics. PhD thesis, University of Bradford, UK.

Montgomery J., Evans J.A., and Cooper, R.E. 2007. Resolving archaeological populations with Sr-isotope mixing models. *Applied Geochemistry* 22: 1502–1514.

Montgomery, J., Evans, J., Chenery, S., Pashley, V., and Killgrove, K. 2010. "Gleaming, white and deadly":using lead to track human exposure and geographic origins in the Roman period in Britain. *Journal of Roman Archaeology, Supplementary Series 78*: 199-226.

Montgomery, J., J. Evans, D. Powlesland, and C. Roberts. 2005. Continuity or colonization in Anglo-Saxon England? Isotope evidence for mobility, subsistence practice, and status at West Heslerton, *American Journal of Physical Anthropology* 126(2): 123–138.

Moore, J., Filipek, K., Kalenderian, V., Gowland, R., Hamilton, E., Evans, J., and Montgomery, J. 2021. Death metal: Evidence for the impact of lead poisoning on childhood health within the Roman Empire. *International Journal of Osteoarchaeology, 31*(5): 846-856.

Moore, J., Rose, A., Anderson, S., Evans, J., Nowell, G., Gröcke, D., Pashley, V., Kirby, M. and 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. A., Fanning, E. A., and Hunt, E. E. 1963. Age variation of formation stages for ten permanent teeth. *Journal of Dental Research* 42: 1490-1502.

Müldner, G. (2005). *Eboracum - Jorvik - York: a diachronic study of human diet in York by stable isotope analysis.* (PhD), University of Bradford, Unpublished.

Müldner, G. 2009. Investigating medieval diet and society by stable isotope analysis of human bone. In *Reflections: 50 Years of Medieval Archaeology, 1957-2007*, edited by R. Gilchrist and A. Reynolds (pp. 327-346), Oxford, Routledge.

Müldner, G., and Richards, M. 2007a. Diet and diversity at later medieval Fishergate: the isotopic evidence. *American Journal of Physical Anthropology* 134(2):162-174.

Müldner, G., and Richards, M. P. 2007b. Stable isotopes evidence for 1500 years of human diet at the city of York, UK. *American Journal of Physical Anthropology*, 133: 682-697.

Müldner, G., Chenery, C., and Eckardt, H. 2011. The 'Headless Romans': multi-isotope investigations of an unusual burial ground from Roman Britain. *J. Archaeol. Sci.* **38,** 280–290.

Myers, S. M. 1999. Childhood migration and social integration in adulthood. *Journal of Marriage and the Family 1*: 774-789.

Needleman, H. L., Tuncay, O. C., and Shapiro, I. M. 1972. Lead levels in deciduous teeth of urban and suburban American children. *Nature* 235(5333): 111-112.

Needleman, H. 2004. Lead poisoning. *Annual Review of Medicine* 55: 209-222.

Nightingale, P. 2010. The rise and decline of medieval York: a reassessment. *Past and Present* 206(1): 3-42.

Nwobi, N., Adedapo, S. K., Oyinlade, O. A., Olukolade, O., Lagunju, I., Atulomah, N., Nwazuoke, I., Anetor, J. 2019. Urinary calcium: a promising predictive biomarker for early recognition of environmental lead exposure in children. *International Journal of Research in Medical Sciences* 7(6): 2265-2272.

O'Donnell, L., Hill, E. C., Anderson, A. S. A., and Edgar, H. J. 2020. Cribra orbitalia and porotic hyperostosis are associated with respiratory infections in a contemporary mortality sample from New Mexico. *American Journal of Physical Anthropology* 173(4): 721-733.

Palliser, D. M. 1980. Location and history. In *The Archaeology of York: The Medieval Walled City North-east of the Ouse* (Vol. 10/1), edited by J. Magilton pp. 2-14. London, Council for British Archaeology.

Parent, A.-S., Teilmann, G., Juul, A., Skakkebaek, N. E., Toppari, J., and Bourguignon, J.-P. 2003. The timing of normal puberty and the age limits of sexual precocity: variations around the world, secular trends, and changes after migration. *Endocrine Reviews* 24(5): 668-693.

Pearson, J. D., James, G. D., and Brown, D. E. 1993. Stress and changing lifestyles in the Pacific: physiological stress responses of Samoans in rural and urban settings. *American Journal of Human Biology* 5: 49-60.

Pelling, M. 1988. Child health as a social value in early modern England. *Social History of Medicine* 1(2): 135-164.

Pelling, M. 1994. Apprenticeship, health and social cohesion in early modern London. *History Workshop Journal 37*: 33-56.

Penn, S., and Dyer, C. 1990. Wages and earnings in late medieval England: evidence from enforcement of labour laws. *Economic History Review* 43(3): 356-376.

Petersone-Gordina, E., Montgomery, J., Millard, A., Roberts, C., Gröcke, D., and Gerhards, G. 2020. Investigating dietary life histories and mobility in children buried in St Gertrude Church Cemetery, Riga, Latvia (15^{th}-17^{th} centuries AD). *Archaeometry* 62*: 3-18*.

Ravenstein, E. G. 1885. The laws of migration. *Journal of the Statistical Society of London* 48(2):167-235.

Redfern, R., and Hefner, J. T. 2019. "Officially absent but actually present": bioarchaeological evidence for population diversity in London during the Black Death, AD 1348–50. In *Bioarchaeology of Marginalized People* edited by M. Mant and A. Holland, pp. 69-114. London, Academic Press.

Robards, J., and Berrington, A. 2016. The fertility of recent migrants to England and Wales. *Demographic Research* 34: 1037-1052.

Roberts, C., and Cox, M. 2003. *Health and Disease in Britain*. Gloucestershire, Sutton Publishing Ltd.

Roberts, C., Millard, A., Nowell, G., Gröcke, D., Macpherson, C., Pearson, D., and Evans, D. 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.

Rodwell, W. 2007a. Burial Archaeology. In *St Peter's, Barton-upon-Humber, Lincolnshire. A Parish Church and its Community* (Vol. 2) edited by T. Waldron, pp. 15-32. London, English Heritage.

Rodwell, W. 2007b. St Peter's Church: Its Setting and Community. In *St Peter's, Barton-upon-Humber, Lincolnshire. A Parish Church and its Community* (Vol. 2) edited by T. Waldron, pp. 1-32. London, English Heritage.

Roffey, S., Tucker, K., Filipek-Ogden, K., Montgomery, J., Cameron, J., O'Connell, T., Evans, J., Marter, P. and Taylor, G. 2017. Investigation of a medieval pilgrim burial excavated from the leprosarium of St Mary Magdalen Winchester, UK. *PLoS Neglected Tropical Diseases,* 11(1): https://doi.org/10.1371/journal.pntd.0005186.

Rycraft, A. 2000. Can we tell what people ate in late medieval York? *Food and Society* 10: 61-78.

Schaefer, M., Black, S., and Scheuer, J. L. 2009. *Juvenile Osteology*. London, Academic Press.

Scheuer, L., and Black, S. 2000. *Developmental Juvenile Osteology*. London, Academic Press.

Shackelford, L. L., Stinespring Harris, A. E., and Konigsberg, L. W. 2012. Estimating the distribution of probable age-at-death from dental remains of immature human fossils. *American Journal of Physical Anthropology* 147(2): 227-253.

Shapland, F., and 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.

Shapland, F., and Lewis, M. E. 2014. A proposed method for the assessment of pubertal stage in human skeletal remains using cervical vertebrae maturation. *American Journal of Physical Anthropology* 153(1): 144-153.

Shaw, H., Montgomery, J., Redfern, R., Gowland, R., and Evans, J. 2016. Identifying migrants in Roman London using lead and strontium stable isotopes. *Journal of Archaeological Science 66*: 57-68.

Smith, M. E. 2014. Peasant mobility, local migration and premodern urbanization. *World Archaeology* 46(4): 516-533.

Spall, C., and Toop, N. 2005. Blue Bridge Lane and Fishergate House, York. Report on Excavations: July 2000 to July 2002. York: Archaeological Planning Consultancy Ltd.

Spindler, E. 2011. Youth and old age in Late Medieval London. *The London Journal* 36(1): 1-22.

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.

Sutter, R. 2003. Nonmetric subadult skeletal sexing traits: I. A blind test of the accuracy of eight previously proposed methods using prehistoric known-sex mummies for Northern Chile. *Journal of Forensic Sciences* 48(5): 927-935.

Tanner, J. 1962. *Growth at Adolescence*. Oxford, Blackwell.

Thomas, C., Sloane, B., and Phillpotts, C. 1997. *Excavations at the Priory and Hospital of St Mary Spital, London*. London, Museum of London Archaeological Service.

Tillott, P. 1961. *A History of the County of York: the City of York.* http://www.british-history.ac.uk/vch/yorks/city-of-york [accessed 6 April 2021]. London, British History Online Towers, J., Gledhill, A., Bond, J. and Montgomery, J. 2014. Investigation of cattle birth seasonality using $\delta^{13}C$ and $\delta^{18}O$ profiles within first molar enamel. *Archaeometry* 56 (Suppl. 1): 208–236.

Trickett, M.A., Budd P., Montgomery J. and Evans J. 2003. An assessment of solubility profiling as a decontamination procedure for the $^{87}Sr/^{86}Sr$ analysis of archaeological human skeletal tissue. *Applied Geochemistry* 18: 653–658.

Tucker, K. 2015. The Human Bone. In *Roman, Anglian and Anglo-Scandianavian Activity and a Medieval Cemetery on Land at the Junction of Dixon Lane and George Street, York* edited by J. McCormish, pp. 154-233, York, York Archaeological Trust.

Tyszka, D. 2006. *The Later History of Barton-on-Humber. Part Six. Church and People in a Victorian Country Town. Barton Parish 1830–1900*. Gainsborough, Workers' Educational Association, GW Belton.

van Klinken, G.J. 1999. Bone Collagen Quality Indicators for Palaeodietary and Radiocarbon Measurements. *Journal of Archaeological Science* 26(6): 687-695.

Waldron, T. 2007. *St Peter's, Barton-upon-Humber, Lincolnshire, Vol 2. The Human Remains*. Oxford, Oxbow Books.

Walker, P., Johnson, J., and Lambert, P. 1988. Age and sex biases in the preservation of human skeletal remains. *American Journal of Physical Anthropology* 76: 183-188.

World Health Organisation. 2019. *Exposure to Lead: A Major Public Health Concern*. Chemical Safety and Health Unit, https://www.who.int/publications/i/item/9789240037632.

Zhang, Y.-f., Xu, J.-w., Yang, Y., Huang, X., and Yu, X.-q. 2019. The association between body lead levels and childhood rickets: A meta-analysis based on Chinese cohort. *Medicine (Baltimore),* 98(8) doi: 10.1097/MD.0000000000014680.