North and South: a comprehensive analysis of non-adult growth and health in the Industrial Revolution (AD 18th-19th C), England.

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Abbreviated title: Child health in the North and South of England (18th-19th C)

ABSTRACT

Objective: Stark health inequalities exist in the present day between the North and South of England, with people in the South, overall, experiencing better health across a range of parameters (e.g. life expectancy and number of years spent in good health). Bioarchaeological studies of skeletal remains from cemeteries across this geographical divide have the ability to provide a temporal perspective on the etiology, longevity and nature of this disparity.

Methods: In total 574 non-adults (0-17 yrs) from six urban sites (c. AD 1711-1856) were analysed from the North and South of England. Measurements of long bone length, cortical thickness, and vertebral dimensions were analysed alongside both skeletal and dental palaeopathological data to assess patterns of disease and growth disruption between skeletal samples.

Results: There were few significant differences in growth parameters between the six sites in relation to geographical location. However, the northern-based sample Coach Lane (North Shields) demonstrated some of the highest rates of pathology, with metabolic disease being particularly prevalent.

Discussion: Northern and southern populations suffered alike from the detrimental environmental conditions associated with urban centres of the 18^{th}-19^{th} centuries. However, the elevated prevalence of vitamin D deficiency seen within the Coach Lane sample is indicative of a regionally specific risk that may be related to latitude, and/or the influence of particular industries operating in the North-East.

Key words: Vitamin D deficiency; post-medieval; vertebral growth; palaeopathology; stature

Industrialisation in Britain was a major economic transition during the 18th to 19th centuries. The seismic shift from a rural, domestic, workforce to one that was primarily urban and factory/mining-oriented resulted in increased population density, inadequate housing and sanitation, air pollution, usually poor work conditions, and long working hours (Kay, 1832; Engels, 1950; Report of the Commissioners, 1845a; Hudson, 1992; O'Brien & Quinault, 1993; Gowland & Newman**,** 2018). London in particular became a nucleus for industry, attracting increasing numbers of people in search of new employment opportunities (Porter, 1994; Floud & Harris, 1997). The detrimental living conditions of the industrial environment inevitably led to increased morbidity and mortality and was said to be "peculiarly severe on infant life" (Report of the Commissioners, 1845a: p5). Social and economic historians have written extensively on the impact of industrialisation on the growth and health of children throughout England during this period (Floud, Wachter, & Gregory, 1990; Nicholas & Steckel, 1991; Voth & Leunig, 1996; Oxley, 2003; Humphries & Leunig, 2009; Sharpe, 2012; Kirby, 2013). Bioarchaeological studies of urban health in 18th and 19th century England, however, currently have a strong London-based bias (for some examples, see Lewis, 2002a,b; King, Humphrey, & Hillson, 2005; Pinhasi, Shaw, White, & Ogden, 2006; Henderson, Lee-Thorp, & Loe, 2014; Ives & Brickley, 2014, Hassett, 2015; Ives & Humphrey, 2017). Studies by Mays et al. (2008; 2009a,b) and Brickley et al. (2007) have indicated that similar trends in urban health also existed within Birmingham, located in the middle of the country. This present study adds to the growing corpus of bioarchaeological data on growth and skeletal indicators of disease in non-adults (those less than 17 years of age) through the analysis and comparison of sites from both the North and South of England.

In England today, marked health inequalities exist across a range of physiological parameters between the North and the South of the country (Hacking, Muller, & Buchan, 2011; Whitehead, 2014). Research undertaken by Public Health England, and the Office of National Statistics has highlighted that those living in North-East England are likely to not only have shorter lives, but also spend a greater proportion of their lives enduring poor health (Office of National Statistics, 2016). Previous studies have explored the impact of social inequality on population health in the 18th-19th centuries, revealing heightened health risks for those living in poverty (DeWitte, Hughes-Morey, Bekvalac, & Karsten, 2015; Hughes-Morey, 2016; Newman & Gowland, 2016; Ives & Humphrey, 2017). This research aims to explore

whether similar health inequalities are also identifiable among contemporaneous skeletal samples from across the North/South geographical divide in the past.

The 'North' in focus

As the developing industries of the 18th and 19th centuries became increasingly reliant on steam power, the supply of coal from the northern regions became a vital commodity (Langton, 2004; Butler, 2012). This led to a rapid increase in population size within Newcastle ("Britain's metropolis of the North"), which approximately tripled in number between 1750-1850, particularly during the first half of the 19th century (Butler, 2012, p.21). Consequently, this region suffered from similar health issues to London, stemming from inadequate infrastructure brought about by rapid development and population density. By the middle of the 19th century Newcastle had "the third lowest levels of life-expectancy at birth of all provincial cities in England", after Manchester and Liverpool in the North-West (Barke, 2001; Butler, 2012, p.61).

These adverse environmental conditions were also experienced by the towns surrounding Newcastle, with Gateshead, North Shields, and South Shields described as "destitute of effective arrangements for drainage, sewerage, or cleansing" contributing to "the production of fever and other diseases" (Report of the Commissioners, 1845b, p.20). These industrial centers were also clustered within a valley, which meant that the atmospheric pollution was not easily dissipated (Report of the Commissioners, 1845b, p.44). This severe air pollution, combined with the reduced hours of sunlight between October to April (due to the northerly latitude), may have exposed the inhabitants of the industrial North to a heightened risk of developing deficiencies in vitamin D (Pearce & Cheetham, 2010; Macdonald et al., 2011). An investigation by the British Medical Association in AD 1889 identified a high prevalence of vitamin D deficiency in coal-mining and industrial districts, with the North-East representing a focal zone of elevated levels. (Owen, 1889). Vitamin D deficiency, however, was also reported to be commonplace in London and it is likely that air pollution, child labour, and industry more generally, were similarly contributing factors (Lewis, 2002a,b).

During the 18th and 19th centuries, different regions came to be associated with specific types of industry (e.g., the North-East with coal and shipping industries, the North-West with cotton mills, and London in the south with manufactories) (Hudson, 1992). It is possible that during this period northern and southern regions experienced

differentially expressed health inequalities aligned to latitude, occupation/industry, and social class.

To determine whether any differences in overall population health are identifiable between northern and southern urban centres of the 18th-19th centuries, a comprehensive study of the health of non-adults was undertaken utilising skeletal collections from the north and south of England. Children are regarded as particularly sensitive to adverse environmental stressors such as poor diet, exposure to disease, climatic change, and fluctuations in economic circumstance. Under such conditions they may succumb to poor health via infectious and deficiency diseases, and may demonstrate evidence of growth stunting as resources are directed towards survival rather than maintenance of growth processes (Bogin, 1999; Lewis, 2007). Evidence for growth disruption and disease within the non-adult samples from both of these regions can, therefore, act as a proxy for overall population health during the 18th and 19th centuries.

This study aims to combine the analysis of metrical parameters relating to growth with paleopathological evidence of deficiency disorders and non-specific indicators of disease. The sample includes non-adults (0-17 years) from the Tyneside region in the North-East, and London in the South-East. Today, these two regions represent the polarized extremes of health inequalities in England. We examine whether bioarchaeological analysis can contribute towards understanding the source of such health disparities by providing a longer-term perspective.

MATERIALS

The six skeletal collections analysed in this study primarily date to the 19th century, and are summarised in Table 1. Overall, 574 non-adult skeletons were assessed for evidence of pathological indicators of physiological stress relating to vitamin C and D deficiency, periosteal new bone formation, cribra orbitalia, and dental enamel hypoplasia. Measurements relating to tibial diaphyseal length, femoral cortical thickness, vertebral body height, and vertebral transverse diameter were also recorded when preservation allowed. Data collected from the London-based sites (with the exception of vertebral body height) have already been discussed in Newman and Gowland (2016) and served as a comparative data-set for the two northern sites. The overall sample sizes for pathological analysis, diaphyseal length, cortical thickness, and vertebral growth are presented in Table 2.

Insert Table 1 here

Insert Figure 1 here

Two skeletal collections were identified from the North of England (Fig. 1). Coach Lane was a former Society of Friends burial ground (c.1711-1857 AD) located in North Shields, a town east of Newcastle-upon-Tyne. North Shields in the early 19th century was a rapidly expanding shipping, fishing, and coal-mining community (Gould & Chappel, 2000; Proctor, Gaimster, & Langthorne, 2014). Due to simple Quaker burial practices, the establishment of social status within this group is problematic (Proctor et al., 2014). While there were plenty of prosperous Quakers within the region, those buried at this cemetery represent mostly low and middle status individuals (Watson, 1864; Boyce, 1889; Grybowska, 2011). Lower status families were often attracted to dissenter lifestyles, due to what was perceived to be the oppressive nature of the church and parish poor laws on those living in poverty (Cherryson, Crossland, & Tarlow, 2012; Henderson, Miles, Walker, Connell, & Wroe-Brown, 2013).

The skeletal collection of St Hilda's churchyard (known as Coronation Street hereafter) is from South Shields (c. AD 1816–1855), located south of the River Tyne. Local industries were similar to that seen in North Shields, centered on shipyards and collieries (Raynor, McCarthy, & Clough, 2011). The individuals of Coronation Street predominantly represent a working-class population.

The four skeletal collections identified from the South of England (London) include: Chelsea Old Church (c. AD 1712-1842), a relatively affluent population from the suburbs of the city; the St Benet Sherehog (c. AD <1853) and Bow Baptist (c. AD 1816-1856) collections, both from middling status populations; and the Cross Bones burial ground (c. AD 1800-1853), renowned for the pauper status of those interred there (Brickley & Miles, 1999; Cowie, Bekvalac, & Kausmally, 2008; Miles, White, & Tankard, 2008; Henderson et al., 2013).

METHODS

For the London sites, diaphyseal tibial lengths and palaeopathological data were obtained from previously recorded data available from the Wellcome Osteological Research Database (WORD) and provided by the Museum of London

Archaeology (MOLA). All additional data for the London sites was collected by the authors.

Assessment of dental age

Dental age was assessed using standards for the calcification of both the deciduous and permanent dentition (Moorrees, Fanning, & Hunt, 1963a,b; Smith, 1991). These standards were selected for comparability with previous growth studies (Pinhasi et al., 2006). Each dentition was examined radiographically, or macroscopically when loose teeth were present. Following Mays et al. (2008), these stages were used to assign a dental age to each individual, based on the mid-point of the age category into which they fell. For example, those between 0.5-1.49 years of age were classed as 1 year of age (Mays et al., 2008).

Measurement of diaphyseal length

Growth profiles were constructed by plotting measurements of tibial diaphyseal length for each individual against dental age. The tibia was selected for this measurement as distal limb segments are thought to be more sensitive to growth disruption (Holliday & Ruff, 2001; Bogin, Smith, Orden, Varela Silva, & Loucky, 2002; Pomeroy et al., 2012). The maximum diaphyseal length was measured for the left tibia using a standard osteometric board to 0.01mm (Buikstra & Ubelaker, 1994). When the left tibia was absent it was substituted with the right (Ives & Brickley, 2004). For the London-based skeletal collections, previously recorded tibial diaphyseal lengths obtained from WORD (WORD database, 2012a; WORD database, 2012b; WORD database, 2012c) had been measured according to these standards. MoLA provided data for the Bow Baptist collection. Tibial diaphyseal lengths were compared to existing modern comparative data for individuals aged 0-18 years (Maresh, 1955). This sample represents a healthy modern data-set from Colorado, US, and is based on a study of 175 individuals (Maresh, 1955).

Measurement of cortical thickness (CT)

The left femur was selected for radiographic analysis (substituted with the right side when necessary) following Mays et al. (2009a). Antero-posterior radiographs were taken at between 65-80kVp and 4-6mAs for the London based samples using a Kubtec Xtend 100HF x-ray source and Kubtec 3600 CR reader; for

the Coronation Street sample using a NOMAD Pro handheld x-ray system; and for the Coach Lane sample using a Portable GE Medical MPX X-ray unit and Kodak point of care CR System. Total bone width (T) and the medullary width (M) were taken from the mid-shaft of the femur, and cortical thickness determined as T-M (Mays et al., 2009a). Each measurement was plotted against the dental age for the six samples. Femoral CT measurements were compared to existing modern comparative data for individuals 0-18 years of age (Virtama and Helëla, 1969). This study was undertaken on a healthy modern Finnish population, and includes CT measurements for 164 femora (Virtama and Helëla, 1969).

Vertebral measurements

The mid-thoracic region of the vertebral column demonstrates the least inherent variation for transverse diameter (Newman & Gowland, 2015). Measurements of vertebral body height and vertebral neural canal size (VNC) were taken using sliding calipers from vertebrae T6-8 (see Newman & Gowland, 2015 for methodology). Measurements were taken to the nearest 0.01mm. Averages of the vertebral measurements from T6-8 for each individual were plotted against dental age. Measurements of body height were also taken from adults aged 18-35 years from each sample to provide comparative data. As there is currently no reliable macroscopic method for sex determination in non-adults, adult data was pooled for the sexes (Saunders, 2008).

There is no modern comparative data set for vertebral body height, but a study by Hinck et al. (1966) provides average transverse diameter measurements for 353 children up to 18 years of age (data averaged into ages 4, 7, 9, 12, 14, and 16), and also averages for measurements from 121 adults (aged 18 years and above).

Recording of pathological indicators of stress

All non-adult individuals were assessed for the presence/absence of five pathological conditions vitamin D deficiency, scurvy, periosteal new bone formation, cribra orbitalia, and dental enamel hypoplasia.

Scurvy and vitamin D deficiency have many skeletal changes in common, and also frequently co-occur, which can lead to diagnostic confusion (Ortner & Mays, 1998; Stark, 2014; Schattmann, Bertrand, Vatteoni, & Brickley, 2016). In addition, the diagnostic criteria for vitamin D deficiency and scurvy have continued to develop

over recent years. To account for any potential misidentification, all data for the southern cemeteries obtained from WORD and MoLA were re-categorised according to recent publications (Brickley & Ives, 2008; Armelagos et al., 2014; Klaus, 2014a; Stark, 2014). This recategorization was based on detailed description provided by the Museum of London and MoLA. Individuals were grouped into 'scurvy', 'possible scurvy', 'vitamin D deficiency', 'possible vitamin D deficiency', and 'metabolic disease'. The 'metabolic disease' category includes individuals demonstrating skeletal changes indicative of 'vitamin D deficiency', 'possible vitamin D deficiency', 'scurvy', 'possible scurvy', and those that could not be placed into either of the aforementioned categories reliably (Table 3).

Vitamin D deficiency was diagnosed when an individual demonstrated several of the following criteria: bowing of the long bones, flaring/swelling of the metaphyses, cupping deformities of the metaphyses, coxa vara, porosity of the growth plate, thickening of the diaphysis, and flaring of the sternal rib ends (Ortner & Mays, 1998; Mays, Brickley, & Ives, 2006; Pinhasi et al., 2006; Brickley & Ives, 2008; Brickley, Mays, George, & Prowse, 2018). Other indicators such as new bone formation and porosity of the cranial bones were recorded, but as these can result from a range of other conditions, these were considered only tentatively (Brickley et al., 2018) (Table 3). Individuals demonstrating multiple non-diagnostic skeletal indicators associated with vitamin D deficiency were placed in the category 'possible vitamin D deficiency' (Table 3). Prevalence rates of healed and active instances of vitamin D deficiency were also considered, and were distinguished by the presence of flaring and porosity at the metaphyseal surfaces of the long bones, which is indicative of active vitamin D deficiency at the time of death (Ives, 2017: p5). Those demonstrating other skeletal changes (such as bowing of the long bones) in the absence of flaring and porosity at the metaphyseal surfaces were categorized as healed cases of vitamin D deficiency.

Scurvy was recorded as present when an individual demonstrated a multitude of skeletal changes including porosity/new bone formation on the sphenoid, maxillae, mandible, orbits, and on the infra- and supra-spinous regions of the scapulae (Ortner & Erickson, 1997; Brickley & Ives, 2006; Brickley & Ives, 2008; Armelagos, Sirak, Werkema, & Turner, 2014; Stark, 2014). Other indicators included new bone formation on the long bones, porosity/new bone formation on the bones of the cranial vault, and flaring/swelling of the rib ends (Ortner & Erickson, 1997; Brickley & Ives,

2006; Armelagos et al., 2014). This category encompasses all individuals with skeletal changes diagnostic of scurvy (Table 3). Those demonstrating multiple non-diagnostic skeletal indicators of scurvy were placed in the category 'possible scurvy' (Table 3).

Periosteal new bone formation cannot be attributed to a specific cause, but may indicate inflammatory processes associated with infection, trauma, or metabolic disease (Ribot & Roberts, 1996; Weston, 2008; Klaus, 2014b). It was recorded as present when evidence of periosteal reaction on the cranial bones and long bones was identified (excluding endocranial lesions).

Cribra orbitalia, referring to marrow hypertrophy seen in the orbits, can arise from a multitude of aetiologies relating to iron deficiency anaemia or megaloblastic anaemia and can indicate disease, unhygienic environment, and dietary deficiencies in past populations (Stuart-Macadam, 1991; Lewis, 2002a; Walker et al., 2009; Oxenham & Cavill, 2010). It was recorded using the five-stage scoring system of Stuart-Macadam (1991).

Dental enamel hypoplasia (DEH) is a defect that arises due to the disturbance of enamel formation in the developing teeth (Ribot & Roberts, 1996; King, Humphrey, & Hillson, 2005). Malnutrition and episodes of disease have been identified as major influences on the formation of DEH (Ogden, Pinhasi & White, 2007; Hillson, 2008). It was recorded as present when an individual demonstrated pit or furrow defects on one or more of the anterior teeth and molars.

Insert Table 2 here

Insert Table 3 here

Statistical analysis

Crude prevalence rates (CPR) for each of the pathological conditions were calculated as a percentage of individuals with the necessary skeletal elements present for diagnosis. Crude prevalence rates for some pathological indicators for Coach Lane may vary from the Gowland et al. (2018) publication due to differences in the categorisation of the metabolic disease data required for the purposes of this study, and also differences in the age categories used between the two studies. A Chi-square test was performed for each of the pathological conditions, and standard residuals calculated, to identify any potential significant differences between the sites.

The frequency of co-occurrence of metabolic disease, DEH, and cribra orbitalia was also explored within the pathological sample to examine differences in the patterns of pathology between the sites. This was calculated as a percentage of the number of individuals demonstrating at least one of the three stress indicators.

Analysis of covariance (ANCOVA) was used to detect any potential differences in tibial diaphyseal lengths, femoral CT, vertebral body height, and transverse diameter between the six archaeological data-sets and additionally compared to modern data, where possible (see above). This method accounts for the influence of dental age (the covariate) (Pinhasi et al., 2006; Field, 2013). The homogeneity of the regression slopes of the growth data was determined via the construction of scatterplots (Field, 2013) to ensure all assumptions had been met prior to statistical analysis. To avoid potential complications of the sex-differentiated pubertal growth spurt (Shapland & Lewis, 2013; Lewis, Shapland, & Watts, 2015), individuals of more than 12 years of age were excluded from statistical analysis.

RESULTS

Age-at-death distribution

The peak age-at-death for the Coach Lane, Chelsea Old Church, St Benet Sherehog, and Bow Baptist samples was 1-5 years of age (Fig.2). There is also a peak in this age category in the Cross Bones sample (30%), and a high percentage of non-adults between 1-11 months and 1-5 years in the Coronation Street sample (at 21% for both groups). At both Coronation Street (North) and Cross Bones (South), the foetal and perinatal age group predominates, making up nearly half of the non-adult samples (at 43% and 48% respectively). Coach Lane (North) and St Benet Sherehog (South) show an unusually high representation of individuals aged between 12-17 years.

Insert Figure 2 here

Diaphyseal length

All sites show similar growth patterns in tibial diaphyseal length to that seen in the modern data for the first two years of life but begin to drop below it from approximately 2-5 years of age (Fig.3a). All archaeological data were significantly lower than the modern data-set by 12 years of age (Table 4: p <0.001). For the

northern-based sites, Coach Lane displays some of the highest values throughout the remainder of the growth period, similar to St Benet Sherehog in the South. The only statistically significant differences in tibial lengths between the archaeological sites was seen in the significantly lower values for Coronation Street than the other northern-based site Coach Lane (p=0.026), and the London-based Bow Baptist site (Table 3: p=0.012). Statistically significant differences were not, therefore, linked to geographic location. More generally, Coronation Street (North and low status) and Chelsea Old Church (South and high status), exhibit some of the lowest values for tibial diaphyseal length until approximately 10 years of age. From 11-13 years of age, there is a marked deviation of the archaeological data away from the modern data, so that by 17 years of age, neither Coach Lane nor Coronation Street in the North, have reached the modern values for tibial diaphyseal length, similar to the pattern seen in the South. At 16 years of age, non-adults from Coach Lane have still only reached approximately 86% of the modern values respectively, and at 15 years of age, the Coronation Street group have only reached 81% of the modern values.

Cortical thickness

Femoral measurements for CT were plotted against dental age (Fig.3b). The majority of individuals from all of the archaeological populations fall below the modern data line, revealing statistically significant deficiencies (Table 4: p<0.001). This deviation commences from approximately 1-3 years. Individuals from the northern-based sites Coronation Street and Coach Lane demonstrated deficiencies in cortical thickness, particularly at four years of age, and between 9-12 years of age. However, the only statistically significant difference between sites was between Coach Lane and Cross Bones, with Cross Bones exhibiting significantly lower CT values in the first 5 years of the growth period (Table 3: p=0.047). All of the archaeological samples demonstrate increased cortical thickness from approximately 13 years of age. St Benet Sherehog and the Bow Baptists in the South appear to have similar CT values to modern population at 15 years of age (reaching approximately 100% and 94% of the modern data values), while the northern sites of Coach Lane and Coronation Street have only attained 88% and 77% respectively of the modern growth values by 16 years of age.

Insert Figure 3 here

Vertebral body height

Vertebral body height for each individual, based on averaged values for T6-8, was plotted against dental age (Fig.4a). Figure 4a also displays data for the average body heights of adult vertebrae from each site, as modern comparative data for vertebral body height is unfortunately not available.

Between 1-4 years of age the growth values for all skeletal samples are comparable. Coronation Street individuals demonstrate a lower range of growth values until 12 years of age, being significantly lower than Bow Baptist ($p<0.001$) and St Benet Sherehog ($p=0.023$) in the South, but also the other northern-based site of Coach Lane (Table 4: $p=0.008$). Beyond 12 years of age non-adults from Coronation Street demonstrate higher growth values, reaching 94% of the average adult measurement by 16 years of age. At birth, the individuals from the low status, southern site of Cross Bones have the lowest values for body height and continue to show some of the most deficient values until approximately three years of age, significantly lower than the Bow Baptist ($p=0.007$) site also in the South and the Coronation Street sample from the north (Table 4: $p=0.009$). Values for body height at birth are comparatively high for Chelsea Old Church (South); however, the data then begin to level off between 1-3 years of age and continue to demonstrate some of the lowest growth values until 10 years of age. By 14 years, this group appear to demonstrate higher growth values, reaching approximately 91% of the average adult measurements for this population. Coach Lane (North) and St Benet Sherehog (South) consistently demonstrate some of the highest growth values: by 15 years of age St Benet Sherehog non-adults have reached approximately 97% of the average adult measurement, and by 16 years of age the Coach Lane sample have achieved 90%. The Bow Baptist population appear to lag in growth beyond 12 years of age and are far from reaching their adult potential for vertebral body height by 17 years of age (at approximately 84% of the adult average).

Insert Figure 4 here

TR diameter

Measurements of TR diameter for each individual were plotted against dental age for T6-8 (Fig.4b). All of the archaeological individuals exhibit significantly

deficient growth in comparison to the modern data (Table 4: *p*=0.001). The Coronation Street and St Benet Sherehog samples demonstrate consistently higher growth values in comparison to the other archaeological samples, with Coronation Street having significantly higher TR diameters than Chelsea Old Church (Table 4: p=0.025). At 16 years of age non-adults from Coronation Street and St Benet Sherehog demonstrate TR diameters that are 89% and 91% of the modern adult average measurement, respectively. The Coach Lane individuals have particularly low TR diameters at 10 years of age, only reaching 80% of the average TR diameter for modern children of 9-10 years of age. However, the Coach Lane non-adults have some of the highest measurements for TR diameter in adolescence, reaching 93% of modern adult measurements at 16 years of age. Chelsea Old Church demonstrates significantly lower values than the Bow Baptist samples (Table 4: *p*=0.002), in addition to the significantly lower values than Coronation Street as already described. Other archaeological inter-site comparisons do not reveal any statistically significant differences (Table 4).

Insert Table 4 here

Pathological indicators of stress

For the northern sites Coach Lane had the highest rate of vitamin D deficiency at 25.9% (Fig.5). Examination of standardised residuals revealed that these rates were significantly higher than expected (z=3.5). However, Coronation Street had no diagnostic cases of this condition (Fig.5). The overall rate of 'metabolic disease' is also high in the southern Chelsea Old Church, St Benet Sherehog, and Bow Baptist samples, but is much higher at Coach Lane and Cross Bones, with approximately 66.7% and 44.2% of the non-adult sample affected respectively. Based on standardised residuals, rates of 'metabolic disease' at these two sites were significantly higher than expected (Coach Lane, z=6.1; Cross Bones, z=2.7). For Cross Bones this peak is due to the extremely high rate of scurvy (26%). However, in Coach Lane this high percentage is due to a large number of non-adults falling into the categories 'possible scurvy' (CPR 18.5%) and 'possible vitamin D deficiency' (CPR 17.3%). Coach Lane and Cross Bones were the only sites to have significantly high rates of scurvy (z=3.0 and z=5.4 respectively), and the Bow Baptists had a significantly lower rate of scurvy than expected (z=2.8). Overall prevalence of

metabolic disease is comparatively low for Coronation Street, and there were no diagnostic cases of scurvy within this sample. The CPR for DEH is high amongst the six groups, presenting a similar frequency between Coronation Street, Chelsea Old Church and the Bow Baptist group (Fig.5). However, it is more prevalent in St Benet Sherehog and Cross Bones in the South, and Coach Lane in the North (Fig.5). Only Coach Lane had a significantly higher rate of DEH than expected (z=4.7). Cross Bones had a significantly high rate of cribra orbitalia (80%, z=5.4). This was followed by the Bow Baptist group (39.2%), and Coach Lane (32.8%). Coronation Street and Chelsea Old Church have the lowest CPR for cribra orbitalia (at 16.1% and 18.2%).

Insert Figure 5 here

Co-occurrence of stress indicators

Of the entire non-adult sample for each site, Coach Lane (North) and Cross Bones (South) had the highest percentage of individuals demonstrating at least one or more metabolic disease, DEH, and cribra orbitalia (at 81.5% and 76.9% respectively). These were followed by the Bow Baptists (50.0%), St Benet Sherehog (45.3%), Chelsea Old Church (30.3%), and lastly Coronation Street (21.1%).

Metabolic disease was by far the most prevalent condition within Coach Lane (at 81.8% of the pathological sample), with the most common co-occurrence of stress indicators being between metabolic disease and DEH (39.4%) (Fig.6a). For the remaining samples, the proportions of pathology were not so heavily weighted towards metabolic disease, with sites generally demonstrating a more equal weighting of conditions, or being more frequently associated with cribra orbitalia (Fig.6b-f). It is likely that the small sample sizes of both Coronation Street and Chelsea Old Church have skewed the percentages at these sites (Fig.6b and Fig.6c).

DISCUSSION

"God help 'em! North an' South have each getten their own troubles." Nicholas Higgins – North and South, Elizabeth Gaskell (1855:118)

Historical evidence for this period attests to infancy being the most perilous stage of the life course. In AD 1850, approximately 41% and 39% of all deaths

recorded were in those under five years of age in London and Northumberland, respectively (Registrar-General, 1854). This is also reflected in the bioarchaeological data, with peak age-at-death generally occurring between 1-5 years. However, the peak age-at-death occurred much earlier, in the foetal and perinatal category, within Coronation Street in the North and Cross Bones in the South. Both of these samples represent populations of lower socio-economic status, and the early age-at-death is suggestive of poor maternal health and detrimental postnatal exogenous factors associated with being born into poverty (Lewis & Gowland, 2007; Gowland, 2015). The burial ground of Cross Bones was initially unconsecrated, as was a portion of the excavated area within Coronation Street (Brickley & Miles, 1999; Raynor et al., 2011); therefore the data may be skewed due to the use of these sites for the burial of un-baptised, or still-born infants.

All samples demonstrated significant deficiencies in TR diameter when compared to modern values. As this skeletal parameter completes the majority of its growth in the first two years of life (Jinkins, 2000; Scheuer & Black, 2000), this deficiency is indicative of episodes of growth disturbance in infancy. These data are indicative of sub-optimal maternal health and infant feeding due to detrimental urban conditions across both the North and the South.

For diaphyseal length and cortical thickness, the archaeological values diverge from the modern comparative data sets between 1-3 years of age. Evidence of stunting in this age range, alongside timings of peak prevalence of stress indicators, tend to be interpreted in terms of onset of weaning and deficiencies in weaning diet (Lewis, 2002a,b). One other possibility that tends not to be considered in bioarchaeological studies is the confluence of birth interval and cessation of weaning. In addition to stressors following reduced access to mother's milk, and exposure to harmful agents (e.g. physical hazards and pathogens) through greater mobility, the stretching of family resources following the addition of a subsequent infant within the family may result in a period of physiological and psycho-social disruption for the older child (Volling, 2012).

The late 18th and early 19th centuries saw a shift in the popularity of breastfeeding practices, a trend that spanned the social strata (see Newman & Gowland, 2016). Both northern and southern urban centres became increasingly reliant on the developing industries for employment, which often necessitated an early return of mothers to work following child-birth (Engels, 1950; Perkin, 1993). This not

only led to poor maternal health status, but also left infants exposed to risks of malnutrition from an early cessation of breastfeeding (Newman & Gowland, 2016). Relative wealth did not confer advantages in breastfeeding practices, with the similarities in growth patterns between high status Chelsea Old Church and low status Cross Bones being attributed to the influence of fashionable child care practices (Newman and Gowland, 2016). Previous isotopic research has revealed a range of infant feeding strategies in London-based skeletal collections of both middle to low status, with some infants breastfed until approximately 1.5 years of age, some weaned before or by six months of age, and some receiving little to no breast milk following birth (Nitsch, Humphrey, & Hedges, 2011; Henderson et al., 2014). Unfortunately, there is little comparative isotopic data from northern cemeteries to date. However, peak age ranges of those classed as having 'metabolic disease' also indicate a variety of detrimental breastfeeding and weaning practices within both northern and southern populations in this study, as well as being suggestive of deficiencies in maternal health amongst the poor in both regions (Table 5).

Insert Table 5 here

In theory, infants should not develop scurvy prior to six months of age, due to the provision of maternal vitamin C stores during pregnancy and via breastmilk after birth (Brickley & Ives, 2008; Buckley et al., 2014). Therefore, evidence of scurvy in infants, as observed here, is indicative of early cessation of breastfeeding, likely in conjunction with maternal vitamin C deficiency (Cheadle, 1889; Brickley & Ives, 2008). When rates for 'scurvy' and 'possible scurvy' are combined for each sample no distinct differences between northern and southern groups are evident, with Cross Bones and Coach Lane having the highest prevalence rates, at 37% and 38.3% respectively. This is compared to the relatively low prevalence within the Chelsea Old Church, St Benet Sherehog, Bow Baptist, and Coronation Street samples (at 9%, 5%, 10%, and 2%, respectively). The most frequent co-occurrent stress indicators seen in Cross Bones were cribra orbitalia and metabolic disease (Fig. 6). Porosity of the orbital roof can result from a multitude of pathological conditions, including scurvy and vitamin D deficiency (Klaus, 2017; Brickley et al., 2018); therefore this potential co-occurrence must be approached with caution. However, hemorrhaging and a reduced capacity for iron absorption associated with vitamin C deficiency may lead to

the development of anaemia, and in turn iron deficiency can impair absorption of nutrients such as calcium which therefore may propagate vitamin D deficiencies (Weinstein, Babyn, & Zlotkin, 2001; Wapler, Crubézy, & Schultz, 2004; Baker, Greer, & The Committee on Nutrition, 2010; Agarwal, Shaharyar, Kumar, Bhat, & Mishra, 2015; Ferrari, Possemato, Pipitone, Manger, & Salvarani, 2015; Brickley et al 2018, p.6). Cribra orbitalia is broadly related to unhygienic environments and dietary deficiencies, therefore its high prevalence within all of the samples and its potential association with metabolic disease is not surprising.

Only 5.9% and 5.2% of all deaths recorded in 1850 were those aged between 10-19 years of age in London and Northumberland, respectively (Registrar-General, 1854). It is an inherent feature of cemetery populations that adolescents are poorly represented, as these individuals have already survived the most hazardous stages of the growth period (Lewis, 2007). This pattern is evident in all of the samples with the exception of Coach Lane and St Benet Sherehog (Fig.2). Lewis and colleagues (2016) identify adolescence as a potential period of increased susceptibility to poor health and growth delay due to the interplay of the maturing immune system and increased agency exposing them to new diseases and potential for chronic infection. Entrance of children into the labour market from 12 years of age has also been identified by Cardoso and Garcia (2009) as a potential cause for growth delay seen in adolescence within skeletal samples from late medieval to early 20th century Portugal. An increase in energetic demands required for manual labour, combined with paucities in nutritional intake and exposure to infectious disease, may lead to an inability to meet the energetic demands of the pubertal growth spurt (Cardoso and Garcia, 2009; Duren et al., 2013). By 17 years of age, none of the Coach Lane, Bow Baptist, St Benet Sherehog, and Coronation Street samples reached the modern day values for tibial diaphyseal length, and it was noted that this deviation away from the modern data began from approximately 11-13 years of age, which is concurrent with the norm for age of entrance into the labour market for this time (Pike, 1966; Pinchbeck and Hewitt, 1973). The Bow Baptist sample also demonstrates lower growth values for vertebral body height in adolescence. A more in-depth study of vertebral growth within this site identified that this lag occurs between 9-16 years of age (Newman and Gowland, 2015). There is evidence that children within the Coach Lane community were employed in local industries (whether in the home, or in factories), with one non-adult aged 12-14 years suffering from phossy jaw, a necrotising condition

occurring from exposure to phosphorus, common in matchmaking (Roberts, Caffell, Filipek-Ogden, Gowland, & Jakob, 2016). However, deficiencies seen in growth are also likely to have their origins in the well-documented paucities in nutrition and environment experienced within the family home, so these data cannot be definitively attributed to child labour practices (Kirby, 2013).

It was hypothesised that the northern-based skeletal collections may demonstrate higher rates of vitamin D deficiency due to the reduced hours of sunlight during the winter months in northerly latitudes (Holick, 2004; Pearce & Cheetham, 2010). The Coach Lane skeletal sample does demonstrate a high rate of metabolic disease throughout the growth period (Table 5), particularly bowing deformities in older children and adolescents. A high rate of residual rickets was also recorded amongst the adults of this skeletal collection (Tschinkel, 2013). Overall there was a combined 43.2% CPR of 'vitamin D deficiency' and 'possible vitamin D deficiency' in the Coach Lane non-adult sample. This is much higher than that of the London samples (Bow Baptists = 17%, Cross Bones = 13%, St Benet Sherehog = 14%, Chelsea Old Church = 12%). Interestingly, the development of stress indicators within this site appeared to be strongly associated with the high rate of metabolic disease (Fig.6).

During winter, there is a reduction not only in day length, but also in the quantity of UVB photons that reach the Earth's surface (Holick, 2004). This is most notable in regions classed as "high latitude", above 37^{o} North, from October to March (Holick, 2004; Macdonald et al., 2011; NICE, 2014). While this region encompasses the majority of Europe, risk of vitamin D deficiency continues to increase with increasing northerly latitude. Recent surveys have revealed that one fifth of adults and 8-24% of children in the UK today suffer from deficiencies in vitamin D status (NICE, 2014). Postmenopausal women from Scotland (at latitude 57^{o} North) were shown to be particularly deficient when compared to those from the South of England (at 51^{o} North) (Macdonald et al., 2011). That the children within the northern Coach Lane collection demonstrate such a heightened prevalence of vitamin D deficiency compared to southern populations, despite similarities in industry and poor urban conditions, is therefore of great interest. The groups most at risk of developing vitamin D deficiencies today and likewise in the 18th/19th centuries are children under the age of five years, pregnant and breastfeeding women, individuals over 65 years of age, and those spending long hours indoors (NICE, 2014). Vitamin D status at birth is

reliant on maternal health in pregnancy (NICE, 2014); therefore, such deficiencies can be inherited. Approximately 23% of cases of 'vitamin D deficiency' and 'possible vitamin D deficiency' combined occurred in those under one year of age in the Coach Lane sample, indicating that maternal vitamin D status within this population was also compromised.

As with many childhood diseases of the 18th and 19th centuries, there was a degree of seasonality in vitamin D deficiency, with increases in its prevalence during the spring (Hardy, 1992). Infants were said to be "at their most vulnerable to rickets when the dietary imbalances of the weaning process were compounded by the sunlight deprivation of the winter months" (Hardy, 1992, p.398). As sunlight is responsible for 80-90% of vitamin D levels in the body, it must be assumed that there is a dependence on stores accumulated during the summer months (Macdonald et al., 2011). However, in regions such as the North-East, where air pollution was at such extreme levels in the 18th and 19th centuries, it is likely that such seasonal deficiencies could not be as easily abated and may have led to deficiencies that were more chronic in nature. The majority of cases of vitamin D deficiency seen in the Coach Lane non-adults were healed (Fig.7). According to Ives' (2017, 10) study of skeletons of similar date with documented causes of death from Bethnal Green in London, healed vitamin D deficiency occurring alongside other indicators of stress may be more indicative of multiple rather than concurrent episodes of illness. The high prevalence of healed vitamin D deficiency (Fig.7) and heightened co-occurrence of stress indicators with metabolic disease seen in Coach Lane (Fig.6) may therefore be demonstrative of recurrent episodes of poor health and nutrition experienced in a particularly impoverished environment.

Insert Figure 7 here

Considering the influence that vitamin D has on immune status (Snoddy, Buckley, & Halcrow, 2016), it is likely that such deficiencies left children highly susceptible to future health insults, and it has been shown that those living in lower latitudes have a decreased risk of many chronic diseases (Holick, 2004). A heightened prevalence of pathology certainly exists within the Coach Lane sample, as seen in the generally higher prevalence rates for stress indicators (Fig.5). This alongside potential evidence for recurrent episodes of health stress, may indicate a reduction in immune

status conferred by the elevated rates of metabolic disease seen within this group. Cuspal enamel defects have been connected to episodes of vitamin D deficiency in childhood, and this potential link has also been identified recently in Coach Lane (Ogden, Pinhasi, & White, 2007; Gowland et al, 2018), which may explain the high co-occurrence of metabolic diseases and dental enamel defects seen in this collection in the present study (Fig.5 and Fig.6).

Deficiencies in vitamin D can range from mild to severe, with only moderate to severe cases leading to skeletal manifestation (Snoddy et al. 2016; D'Ortenzio et al., 2017). Therefore, the prevalence rates seen within these sites represent only the "...tip of an unseen epidemiological iceberg" (Snoddy et al., 2016, p.193). Studies of non-adult health such as this can therefore serve as indicators of a much wider population issue, as even mild deficiencies can lead to skeletally "invisible" health challenges, such as pain, muscle weakness, cognitive and immune impairment, and susceptibility to future health insults in adulthood such as heightened risks of cancer, infection, cardiovascular disease, and autoimmune disease (Holick, 2006; Shin, Choi, Longtine, & Nelson, 2010; Snoddy et al., 2016).

This heightened risk of vitamin D deficiency in northern regions is, however, confounded by the palaeopathological data for Coronation Street, which demonstrates notably low rates of metabolic disease. It has been suggested that while child labour was common in this region, the children of Coronation Street were more likely to have been employed in industries that involved outside work, such as ship-building, which may have buffered them from vitamin D deficiencies (Raynor et al., 2011). However, while this evidence may be used to infer that this population was perhaps exposed to fewer environmental hazards than the other samples in this study, the growth data contradicts this assertion. Coronation Street demonstrates high infant mortality, alongside some of the lowest growth values for diaphyseal length, vertebral body height, and femoral CT. Evidence for DEH was also seen in 20.7% of non-adults, reflecting episodes of infection and deficiencies in nutrition experienced during infancy and childhood (Goodman & Rose, 1990; Hillson, 2008). It is possible that the non-adults of Coronation Street suffered from acute afflictions, and simply did not survive long enough for skeletal responses to occur (Wood, Milner, Harpending, & Weiss, 1992; Vercellotti et al., 2014; DeWitte & Stojanowski, 2015). For example, in complete absence of vitamin C, an individual may die before skeletal indicators of scurvy can manifest, whether from the deficiency itself, or from

increased susceptibility of the immune system to other infectious agents (Armelagos et al., 2014; Bourbou, 2014; Krenz-Niedbała, 2015). Infectious disease was rife in urban environments of the 18th and 19th centuries, with measles, diphtheria, smallpox, whooping cough, and scarlet fever being common risks to the survival of the very young (Levene, 2012). Those of the lower classes in North and South Shields lived in housing that suffered from a lack of effective drainage and sewerage, and were said to be "struggling too often under the accumulated influences of poverty, disease, and vice…" (The Report of the Commissioners, 1845b: 18). Such an environment would be expected to propagate the types of infectious disease that would be highly detrimental to child health and survival. When viewed through this lens, it is possible that while Coach Lane is also more representative of a lower status group, there may have been some buffering (whether due to superior diet, intra-community care associated with Quaker poor relief strategies, or a combination of many factors) that meant these children were more likely to survive long enough for skeletal indicators of pathology to manifest (Wood et al., 1992; DeWitte and Stojanowski, 2015). Isotopic analysis of these two populations would be an essential avenue of research to not only fill the current gap in northern isotopic data, but also to determine if differences in diet existed between the two populations that may explain these differences in health susceptibility despite their close proximity in geographic location.

Recent research on a skeletal collection from Bethnal Green, London revealed the substantial impact that life in urban centres had on childhood health at this time, due to the influence of artificial infant feeding practices and deleterious environmental and sanitary conditions (Ives & Humphrey, 2017). The present study indicates that this was also true for northern industrial centres. Overall there were no prominent differences in growth between northern and London based non-adults. Very few of the skeletal parameters revealed statistically significant differences between the archaeological samples; however, all showed significant deficits when compared to modern data. All six sites also generally demonstrated high prevalence rates of dental enamel hypoplasia and cribra orbitalia. This suggests that the industrialised centres of both the North and the South created adverse environmental conditions, which proved to be highly detrimental to child health at this time. A generalised geographical approach to health obviously has the potential to mask intra-regional heterogeneity that relates to other social factors such as ethnicity, class,

gender and religion (Whitehead 2014). This is perhaps reflected in the dichotomy presented in the health patterns of Coach Lane and Coronation Street. The Coach Lane non-adults undoubtedly suffered a higher risk of developing vitamin D deficiency when compared to not only the four London-based samples, but also Coronation Street. This is potentially due to a combination of factors discussed above. Differences between samples are therefore associated with more nuanced local variance in the social gradient, infant feeding practices, and child labour practices, rather than the influence of the North-South divide at this time. However, further study is required from a variety of geographic locations to gain a clearer picture of the influence of geography, and related industries, on child health during the 18th-19th centuries.

Although the results of this study have provided convincing evidence for disruption of growth within the samples due to environmental influences and social factors, the limitations of the methods used must be addressed. Growth studies in archaeological populations are, unavoidably, cross-sectional rather than longitudinal; therefore the possibility that survivors might have demonstrated a different pattern of growth cannot be discounted (Wood et al., 1992). The same principle applies to the prevalence of pathological lesions and potential differences between survivors and non-survivors (Wood et al., 1992).

In addition, the small sample sizes for the growth parameters in several of the sites within this study are a perennial issue within bioarchaeological analyses of non-adults. Even small samples, however, have value for interpretations of past health and disease.

CONCLUSION

The North-East was the first properly industrialised area of England, growing wealthy off the back of industries such as coal-mining, shipbuilding and steel production. While the North-East has undergone economic decline since its heyday in the 19th century due to aggressive de-industrialisation (Warren, 2018), the South-East has continued to prosper, with a buoyant economy reliant on trade and finance rather than manufacturing. The stark health inequalities between the North and South today can largely be attributed, therefore, to income inequality and the social gradient in health.

There were no definitive differences in childhood growth between northern and southern populations in the 18th and 19th centuries, reflecting the ubiquitous detrimental conditions of urban centres at this time. The extremely high rate of vitamin D deficiency (and high rates of pathology in general) in Coach Lane indicates that certain northern populations faced more severe health insults due to the related reduction in immune resistance. Recent clinical studies have highlighted the high prevalence of vitamin D deficiency in northern Britain today and its contribution to North/South health divide (Pearce & Cheetham 2010). The findings of this study suggest that the effects of vitamin D deficiency as a consequence of latitude continues to be a key pervasive, albeit invisible, issue in the present.

This study reaffirms the benefit of using multiple skeletal indicators to strengthen evidence of health stress in the past. The implementation of growth parameters that target different areas of the developing body in children can provide additional resolution to the determination of timings of episodes of stress. As such, comprehensive growth studies such as this have scope to be further strengthened by the addition of incremental isotopic analysis, and new methods in the determination of pubertal stage (Lewis, Shapland, & Watts, 2015). To bring together all of these methods would substantially enhance our understanding of the impact of adversity across the life course.

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FIGURE LEGENDS

Figure 1 - Map of the UK showing location of sites; a) Tyneside region; b) London

Figure 2 - Age-at-death distribution of the non-adult sample. Percentage of non-adults that fall into the age categories "foetal and perinatal" (comprising those less than 36 weeks in utero, and those aged approximately 36 weeks in utero to 4 weeks post-partum), "1-11 months", "1-5 years", "6-11 years", and "12-17 years" of age. Those that could not be assessed for dental age assigned an age category based on indicators of skeletal maturation (diaphyseal length and epiphyseal fusion) (Scheuer and Black, 2000). Italicised numbers above bars represent number of individuals within each age category for each site.

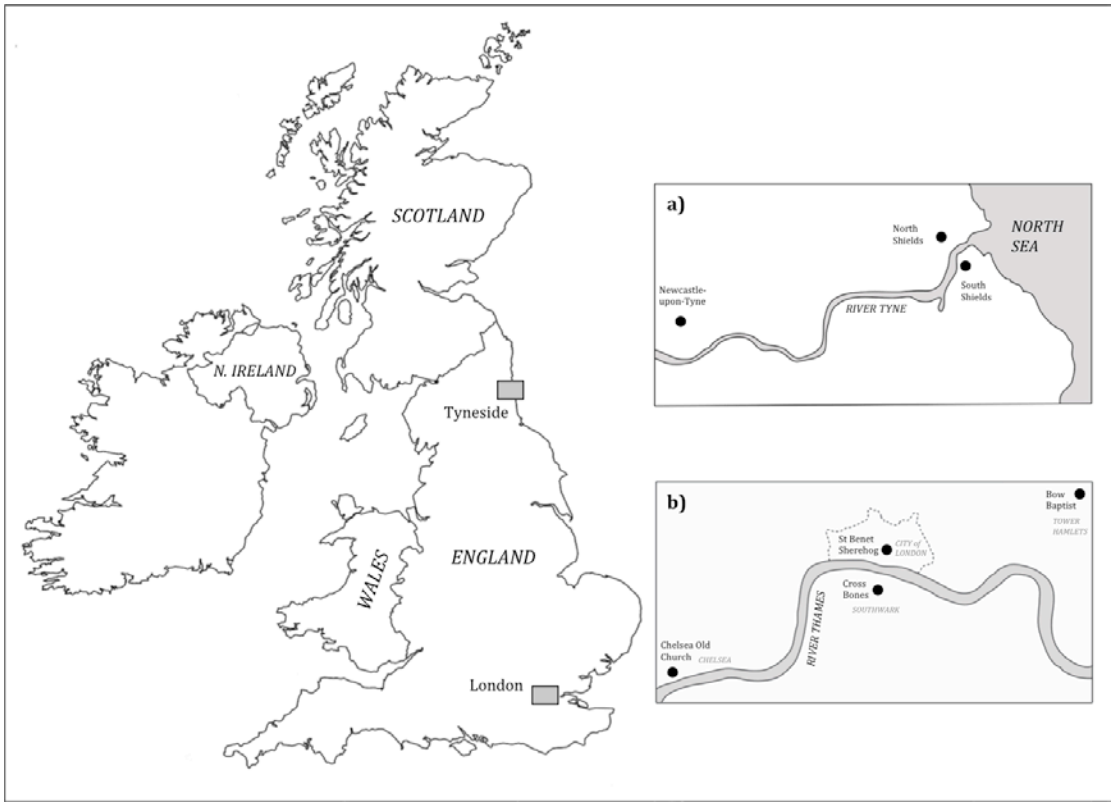
Figure 3 - Growth profiles for long bone skeletal parameters; a) Tibial length – comparative modern data represented by solid black line, taken from Maresh, 1955; b) Femoral CT – comparative modern data represented by solid black line, taken from Virtama and Helelä, 1969)

Figure 4 - Growth profiles for vertebral dimensions; a) Body height measurements for T6-8, plotted with average adult measurements for each site; b) Transverse diameter for T6-8, comparative modern adult data (solid black line) and modern non-adult data (solid grey line) taken from Hinck et al. (1966).

Figure 5 - Crude prevalence rate (CPR) of pathology seen within the non-adult sample of each site. PNBF = periosteal new bone formation; DEH = dental enamel hypoplasia

Figure 6 – Co-morbidity of metabolic disease, DEH, and cribra orbitalia within each site. Calculated as the percentage of non-adults with at least one of the three stress indicators observable.

Figure 7 – Healed and active cases of vitamin D deficiency within the non-adult sample. Expressed as a percentage of the total number of diagnostic cases of vitamin D deficiency within each site.



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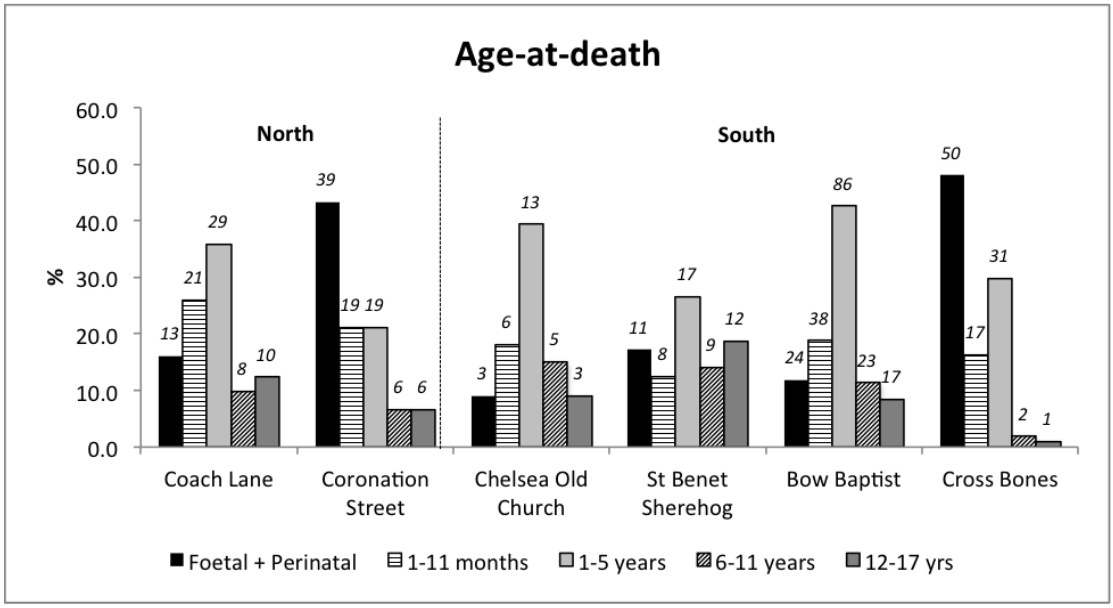

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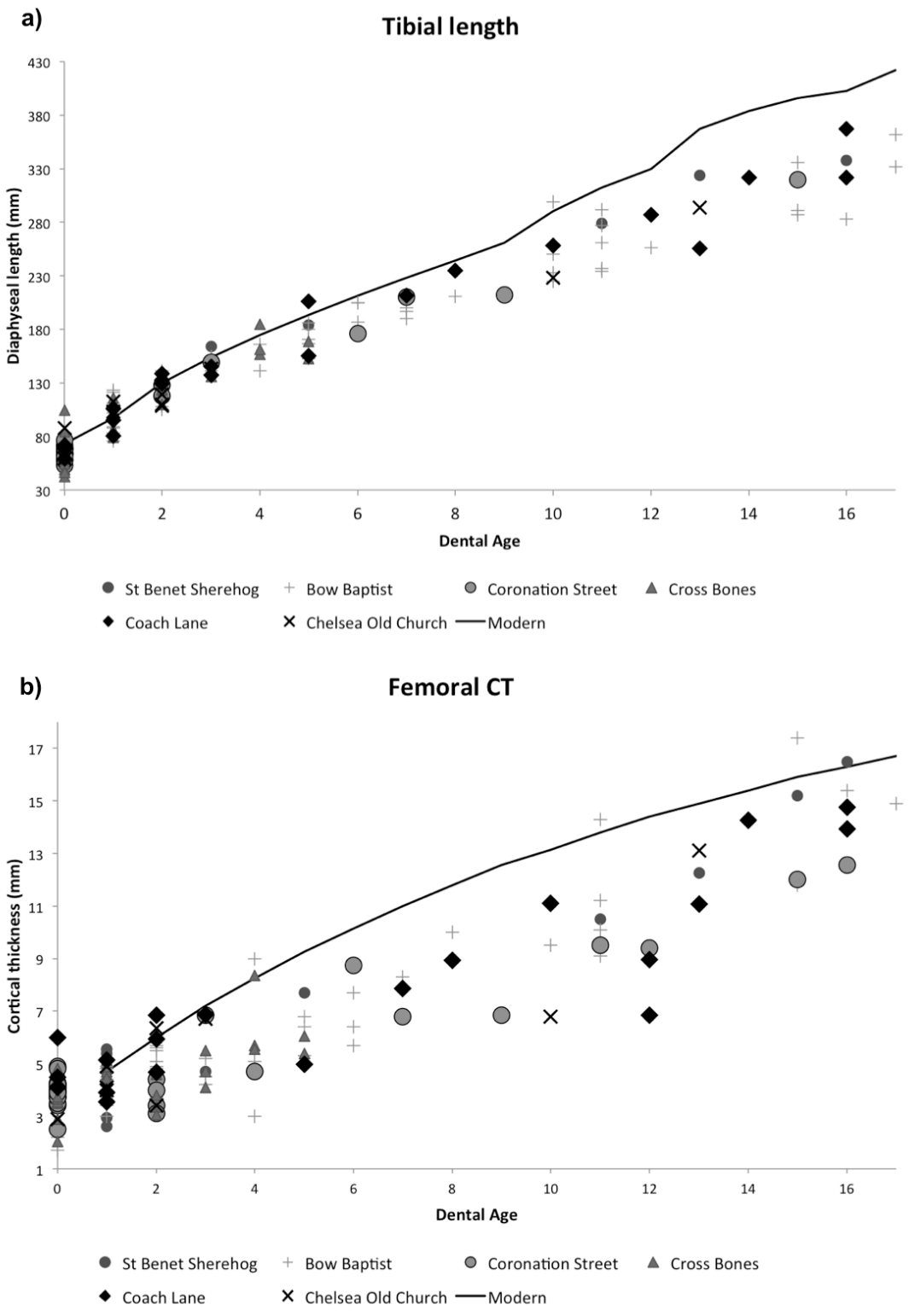

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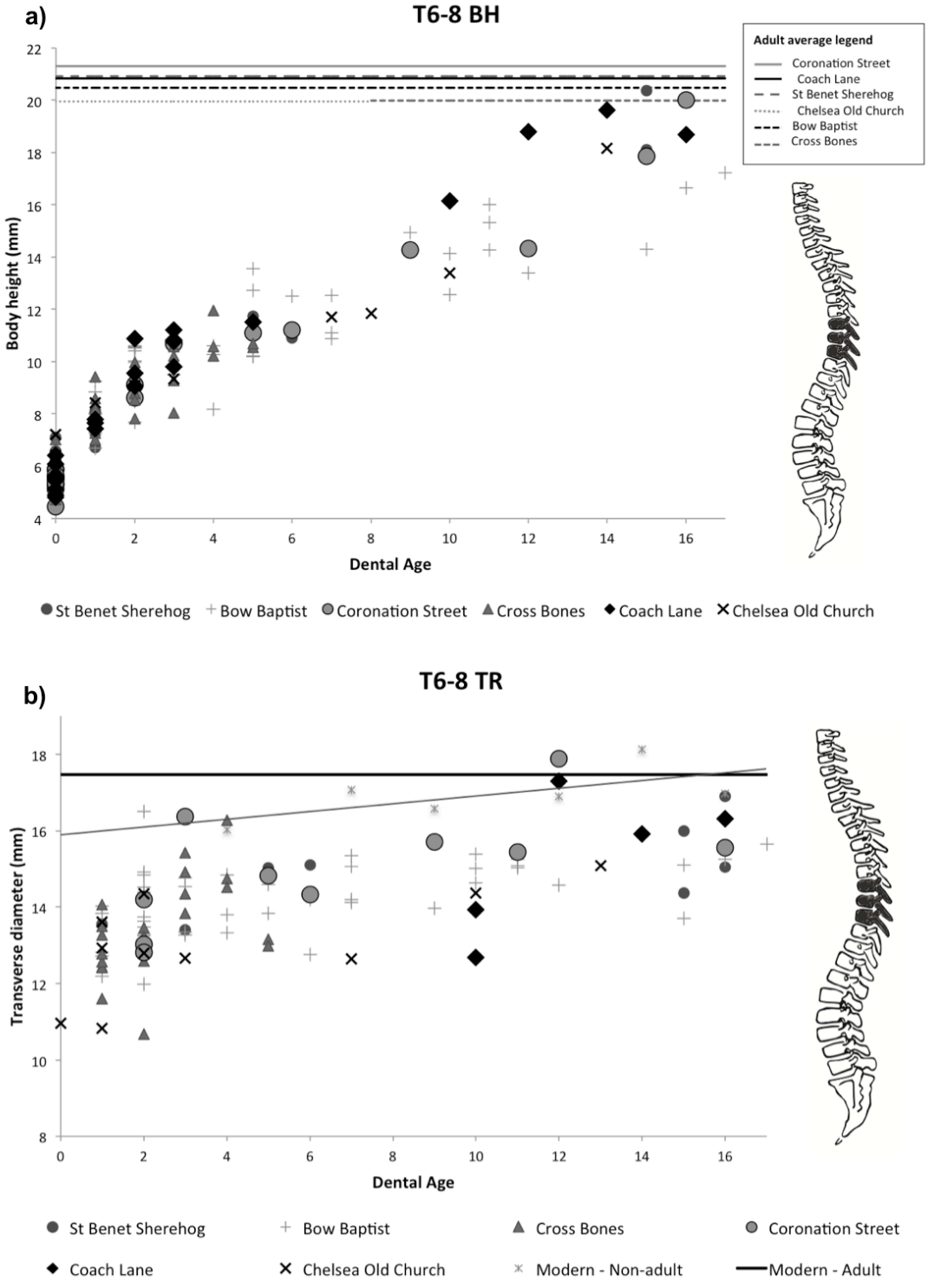

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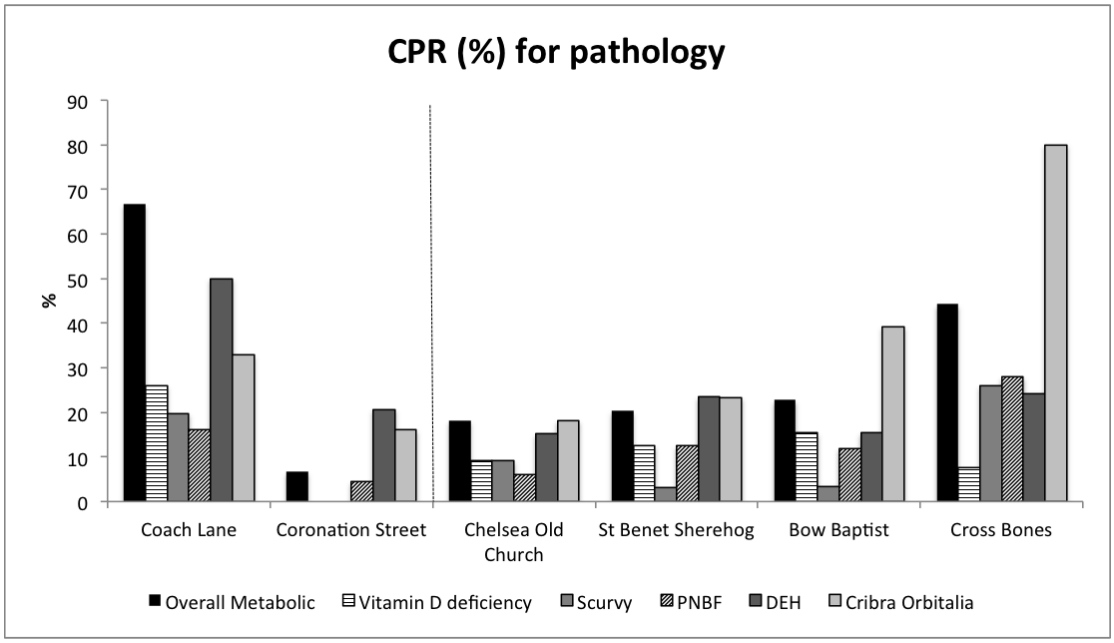

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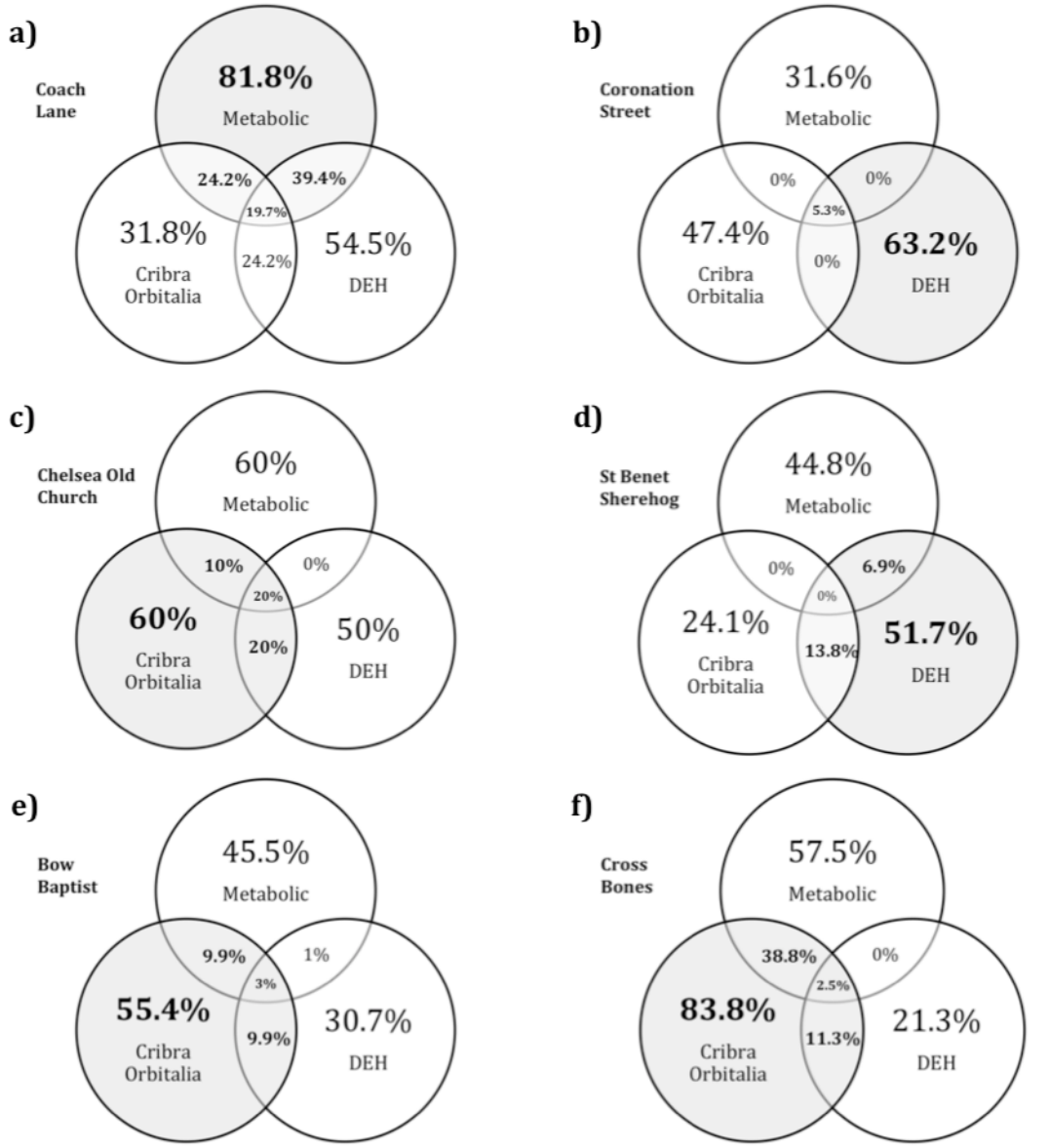

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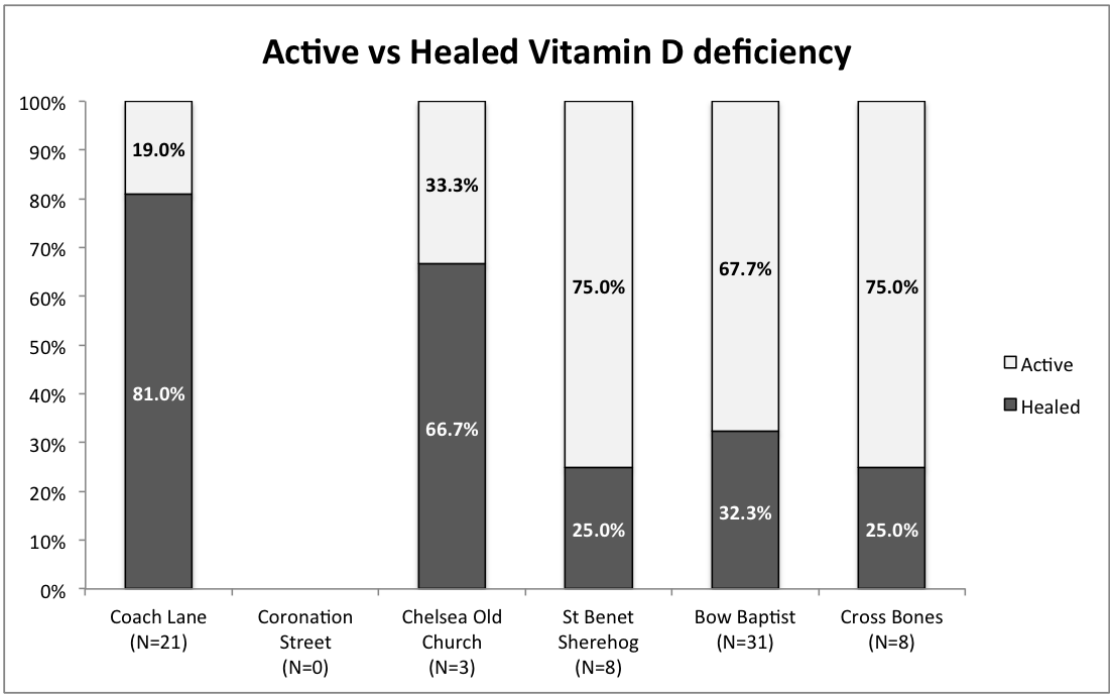

Figure 7 – Healed and active cases of vitamin D deficiency within the non-adult sample. Expressed as a percentage of the total number of diagnostic cases of vitamin D deficiency within each site.

Table 1 – Summary of sites (Original site reports - Brickley and Miles, 1999; Cowie et al., 2008; Miles et al., 2008; Raynor et al., 2011; Proctor et al., 2014; Henderson et al., 2013). † Only sites containing 18th century material

	Site	Date	Status	No. Individuals	No. Non-adults
North	†Coach Lane, N. Shields	1711-1857	Low/Middle	236	81
	Coronation Street, S. Shields	1816-1855	Low	204	90
South (London)	†Chelsea Old Church	1712-1842	High	198	33
	St Benet Sherehog	<1853	Middle	230	64
	Bow Baptist	1816-1856	Middle	416	202
	Cross Bones	1800-1853	Low	148	104

Table 2 – Sample sizes for pathological and metric analysis (BH= body height; TR = transverse diameter; adult sample size in brackets)

Site	Pathology	Tibial length	Femoral CT	BH (T6-8)	TR (T6-8)
Coach Lane	81	22	21	23 (11)	5
Coronation Street	90	19	31	20 (14)	10
Chelsea Old Church	33	10	10	10 (9)	10
St Benet Sherehog	64	9	13	16 (11)	8
Bow Baptist	202	70	48	42 (27)	46
Cross Bones	104	36	37	38 (5)	22
Total	574	166	160	149 (77)	101

Table 3 – Diagnostic criteria for the pathology categories 'Scurvy', 'Possible scurvy', 'vitamin D deficiency', 'Possible vitamin D deficiency', and 'Metabolic disease' in accordance with – Ortner et al (1997), Ortner and Mays (1998), Brickley and Ives (2006), Mays et al (2006), Pinhasi et al (2006), Brickley and Ives (2008), Armelagos et al (2014), Klaus (2014a), and Stark (2014). NBF = New bone formation.

Region	Feature	Diagnostic criteria for 'Scurvy'	Criteria for 'Possible scurvy'	Diagnostic criteria for 'Vitamin D deficiency'	Criteria for 'Possible Vitamin D deficiency'	Criteria for 'Metabolic disease'
Cranium	Porosity/NBF on sphenoid	✔				
	Porosity/NBF on maxillae	✔				
	Porosity/NBF on mandible	✔				
	Porosity/NBF in orbits	✔				
	Porosity/NBF on cranial vault		✔		✔	✔
	Medial angulation of mandibular ramus			✔		
Ribs	Alteration of neck angle			✔		
	Lateral straightening			✔		
	Flaring/swelling of rib ends		✔		✔	
Dentition	DEH					✔
	Caries				✔	✔
Scapulae	Porosity/NBF on infra- and supra-spinous regions	✔				
Long bones	NBF		✔		✔	✔
	Flaring/swelling of metaphyses		✔	✔		
	Porosity of growth plate				✔	
	Cupping deformities		✔	✔		
	Bowing			✔		
	Thickening		✔		✔	✔
	Coxa vara			✔		
	Osteopenia (Radiograph)		✔		✔	✔
	Irregularity and thinning of cortex (Radiograph)		✔		✔	✔

Table 4 – ANCOVA results for measurements of tibial length, femoral CT, body height (BH) and transverse diameter (TR) from the four archaeological samples, and compared to modern data. P=<0.05, significant values in bold.

		Tibial length		**Femoral CT**		**BH**		**TR**	
		F	***p***	**F**	***p***	**F**	***p***	**F**	***p***
Chelsea Old Church vs	St Benet Sherehog	0.106	0.750	0.334	0.571	0.018	0.894	4.444	0.061
	Bow Baptist	0.415	0.522	0.007	0.934	3.414	0.071	10.420	**0.002**
	Cross Bones	0.111	0.741	0.021	0.885	0.159	0.692	3.236	0.083
	Coach Lane	0.580	0.454	1.720	0.203	1.349	0.256	0.000	0.992
	Coronation Street	2.245	0.147	0.003	0.960	2.401	0.134	6.235	**0.025**
St Benet Sherehog vs	Bow Baptist	0.000	0.999	0.527	0.471	4.858	**0.032**	0.455	0.504
	Cross Bones	0.010	0.919	0.470	0.497	0.000	0.985	0.132	0.720
	Coach Lane	0.033	0.857	0.200	0.659	0.125	0.726	2.518	0.188
	Coronation Street	2.043	0.167	0.707	0.406	5.785	**0.023**	0.012	0.915
Bow Baptist vs	Cross Bones	3.234	0.075	0.338	0.563	7.768	**0.007**	1.045	0.311
	Coach Lane	0.296	0.588	0.317	0.576	0.466	0.498	0.408	0.527
	Coronation Street	6.564	**0.012**	0.006	0.940	16.189	**0.000**	3.690	0.061
Cross Bones vs	Coach Lane	0.637	0.428	4.129	**0.047**	0.093	0.762	3.851	0.062
	Coronation Street	1.602	0.211	0.008	0.928	7.327	**0.009**	0.467	0.500
Coach Lane vs	Coronation Street	5.412	**0.026**	2.996	0.091	7.914	**0.008**	2.941	0.120
Modern vs	Archaeological	4.606	**0.000**	10.145	**0.000**	-	-	4.351	**0.001**

Table 5 – Breakdown of metabolic disease by age category. Metabolic disease referring number of individuals within the skeletal sample demonstrating any sign of vitamin D deficiency, possible vitamin D deficiency, possible scurvy, and scurvy. Percentage in brackets.

Site	No. Non-adults	Foetal + Perinatal	1-11 mths	1-5 years	6-11 years	12-17 years	Unknown	Overall
Coach Lane	81	7 (8.6)	14 (17.3)	20 (24.7)	3 (3.7)	10 (12.3)	0 (0)	54 (66.7)
Coronation Street	90	0 (0)	3 (3.3)	2 (2.2)	1 (1.1)	0 (0)	0 (0)	6 (6.7)
Chelsea Old Church	33	0 (0)	0 (0)	3 (9.1)	1 (3)	2 (6.1)	0 (0)	6 (18.2)
St Benet Sherehog	64	2 (3.1)	1 (1.6)	6 (9.4)	1 (1.6)	0 (0)	3 (4.7)	13 (20.3)
Bow Baptist	202	4 (2)	18 (8.9)	21 (10.4)	2 (1)	1 (0.05)	0 (0)	46 (22.8)
Cross Bones	104	24 (23.1)	11 (10.6)	11 (10.6)	0 (0)	0 (0)	0 (0)	46 (44.2)