Received: 19 July 2023 | Revised: 22 August 2024 | Accepted: 27 August 2024
DOI: 10.1002/oa.3347

RESEARCH ARTICLE

The impact of urbanization on growth patterns of non-adults in medieval England

Sina D. White[1,2] | Sophie L. Newman[3,4] | Charlotte Primeau[5] | Patrick Mahoney[1,6] | Chris A. Deter[1,6]

[1]Skeletal Biology Research Centre, School of Anthropology and Conservation, University of Kent, Canterbury, UK
[2]Anatomic Pathology Laboratory, Trinity Health Ann Arbor Hospital, Trinity Health IHA Medical Group, Ann Arbor, MI, USA
[3]School of History, Classics and Archaeology, University of Edinburgh, Edinburgh, UK
[4]Department of Archaeology, University of Sheffield, Sheffield, UK
[5]Warwick Manufacturing Group, University of Warwick, Coventry, UK
[6]School of Chemistry and Forensic Science, University of Kent, Canterbury, UK

Correspondence
Sina D. White, Anatomic Pathology Laboratory, Trinity Health Ann Arbor Hospital, Trinity Health IHA Medical Group, Ann Arbor, MI, USA.
Email: thomasina_white@ihacares.com

Abstract

Increasing urbanization seen during the medieval period (7th to 16th centuries) is associated with adverse living conditions that may have negatively impacted childhood growth via the influence of infectious diseases and nutritional deficiencies due to increasing population density and periodic food shortages. This study aims to compare the growth of non-adults (less than 12 years of age) from urban, proto-urban, and rural environments from medieval England to determine whether settlement type influenced child health, and by proxy overall population health, during this period. Tibial and femoral maximum diaphyseal lengths and dental age of non-adults (0–12 years) from urban St. Gregory's Priory ($n = 60$), urban York Barbican ($n = 16$), proto-urban Black Gate ($n = 38$), and rural Raunds ($n = 30$) were examined using z-scores. The results reveal that non-adults < 2 years from St. Gregory's Priory had the lowest growth values followed by Raunds, Black Gate, and York Barbican with the highest growth values. Further, non-adults 2–12 years from York Barbican had the lowest growth values followed by Raunds, Black Gate, and St. Gregory's Priory with the higher growth values. The femoral and tibial diaphyseal growth values are explored within the context of breastfeeding and weaning practices, stability of economies, and environmental conditions.

KEYWORDS
bioarchaeology, child health, femora diaphyseal length, growth, tibial diaphyseal length, urbanization

1 | INTRODUCTION

Growth and development are influenced by the relationships between genetics, hormones, nutrition, pathogenic mechanisms, socioeconomic factors, physical activity, environmental settings, and psychosocial conditions (Gosman, 2012; Matkovic et al., 2004; Mays, 2018). Longitudinal bone growth (the process of endochondral ossification) is regulated by various hormones such as, but not limited to, growth hormone (GH), insulin-like growth factors (IGFs), thyroid hormones, sex hormones (estrogen and androgens), glucocorticoids, vitamin D, and leptin (Hartmann & Yang, 2020; Ohlsson et al., 1993). Adequate nutrition (i.e., sufficient proportions of lipids, proteins, and essential minerals and vitamins) stimulates hormones that regulate longitudinal bone growth (Gosman, 2012), and influential factors such as diet and nutritional status, disease load, physical activity, and exposure to toxins can alter the genetic potential of long bone maximum growth (Cameron, 2012; Matkovic et al., 2004). Disturbances to long bone growth can cause the growth rate to decrease (Cameron, 2012;

Gosman, 2012), and the main factors known to disrupt bone growth are inadequate nutrition and pathological conditions (Forbes, 1987; Gosman, 2012; Pinhasi et al., 2006).

The imbalances of nutrients such as protein, calcium, iron, zinc, folic acid, vitamin D, vitamin A, and vitamin B12 can cause skeletal growth disturbances (Forbes, 1987; Hans & Jana, 2018; Lejarraga, 2012; Wu et al., 2012). Imbalances of nutrients can promote susceptibility to pathological conditions, whether through the impairment of the immune response causing infections or nutritional deficiencies or via motivation of non-communicable diseases such as diabetes and cardiovascular diseases (Barker, 1999; Bhatia et al., 2012; Scrimshaw, 2003; Scrimshaw & SanGiovanni, 1997). In turn, pathological conditions, such as parasitic infections and respiratory disorders, can cause individuals to become malnourished (Collins & Weeks, 2019; Scrimshaw, 2003; Scrimshaw & SanGiovanni, 1997; Zuzarte-Luís & Mota, 2018). Thus, through these complex interactions and influences, adverse environments can lead to periods of growth faltering of children (Ulijaszek & Strickland, 1993).

Modern urban environments are commonly recognized as affecting the quality of individuals' health (Ettman et al., 2019; Wuerzer, 2014). Various services and factors, such as easy access to health care services and educational and economic opportunities, can positively influence health in urban areas (DeWitte & Betsinger, 2020). Numerous conditions associated with the physical environment within urban areas can negatively affect human health (DeWitte & Betsinger, 2020). The physical environment, such as industrial and construction waste and emissions, poorly ventilated houses, and water resources polluted by toxic chemicals, sewage spillages, and municipal waste, influence cardiovascular disorders and respiratory diseases (Devien et al., 2018; DeWitte & Betsinger, 2020; Ettman et al., 2019; Holguin, 2008; Ségala et al., 2008; Spengler & Chen, 2000) and viral, bacterial, and parasitic infections (DeWitte & Betsinger, 2020; Halder & Islam, 2015; Haseena et al., 2017). Similarly, bioarchaeological research on medieval English urban environments found that overcrowding, air pollution, water pollution, dense housing and structural communities, and inequities in access to social and economic resources have influenced respiratory conditions and the spread of viral and parasitic infections (DeWitte & Betsinger, 2020; Godde et al., 2020; Godde & Hens, 2021; Lewis, 2016; Mitchell, 2015; Shapland et al., 2015; Sullivan, 2004; Walter & Dewitte, 2017; Wang et al., 2022). Thus, urban settlements in medieval England may have negatively impacted childhood growth.

1.1 | Medieval English settlement types

The types of settlements in medieval England consisted of urban (town), proto-urban (small town), and rural (village).

Urban centers were built surrounding large cathedrals and/or castles, had population sizes from 5000 to 80,000, and had compact housing and structural communities (Backman, 2003; Dyer, 1989, 2002; Roberts & Cox, 2003). Urban-terraced houses were common, but small areas were also delegated to one-story small homes (Dyer, 1989). Urban-terraced houses were typically two to four stories with an open hall, separate rooms for the kitchen and storage, and upper rooms (Dyer, 1989; Pantin, 1962; Pearson, 2009; Roberts & Cox, 2003). The open hall had a fireplace with a chimney or a hearth (open fireplace) with a suspended smoke hood and a small hole in the roof for smoke to escape, which provided ventilation (Dyer, 1989; Johnson, 2010; Pantin, 1962). The roofs were tiled, regulated by the town's landlord, to limit the spread of fires (Dyer, 1989; Johnson, 2010). Additionally, household and occupational waste were discarded into nearby bodies of water and onto streets in urban areas (Miller & Hatcher, 1995; Roberts & Cox, 2003). Private cesspits in gardens and latrines on the upper floor within homes and placed on bridges over bodies of water were common in urban areas for excretion refuse disposal (Dyer, 1989; Miller & Hatcher, 1995; Rawcliffe, 2013; Roberts & Cox, 2003). Also, people who lived in urban centers would have grown fruit and vegetables on a small plot of private or shared land behind their houses for their personal consumption (Roberts & Cox, 2003). Most would have obtained meat from butchers, and very few would have had livestock in their gardens or yards (Dyer, 2002). Weekly markets would have also allowed urban people to acquire food especially exotic fruits and vegetables (Dyer, 2000; Miller & Hatcher, 1995).

Proto-urban areas were constructed around castles, monasteries, or fortification centers, and contained around 50 to 400 houses, which were widely spaced relative to one another (Backman, 2003; Dyer, 2003). In proto-urban, one-story homes with a sleeping and storage room and an open hall were standard (Dyer, 1989; Johnson, 2010). The open hall had a hearth for heat and small windows and holes in the roof for smoke to escape (Dyer, 1989; Johnson, 2010; Steane, 1985). However, the small windows and holes in the roofs would not have provided much ventilation and caused interior air pollution (Dyer, 1989; Miller & Hatcher, 1978; Rawcliffe, 2013). A separate room or building would have been created for the kitchen (Dyer, 1989; Johnson, 2010). The roofs were thatched, thus influencing the spread of fires (Dyer, 1989). Additionally, in proto-urban areas, latrines were placed over bodies of water, private cesspits were in gardens, and waste was disposed of into nearby bodies of water or unoccupied plots (Dyer, 2003; Rawcliffe, 2013). Those who lived in proto-urban areas had personal gardens and easy access to rural areas' agricultural surplus for food consumption (Dyer, 2003).

Rural settlements were established nearby manor houses, small administrative centers, or small market centers (Miller & Hatcher, 1978). They typically had less than 40 landholders (Ackerman, 1976), and each house occupied a plot of 15 or 30 acres that was the same size and shape as its neighbors (Dyer, 2002). The houses were organized along a street or beside vegetation (Hamerow, 2012; Miller & Hatcher, 1978). Similar to proto-urban areas, one-story homes with a thatched roof were common in rural settlements (Johnson, 2010). Additionally, in rural areas, private cesspits were in gardens, and waste was disposed of into nearby bodies of water or used for crop yields (Dyer, 1989; Jones, 2012; Magnusson, 2013; Miller & Hatcher, 1978). Individuals who lived in rural settlements relied on agriculture in order to provide food for themselves and the community (Dyer, 2002; Miller & Hatcher, 1978). They would have had large quantities of grains for bread and vegetables and few pieces of meat for pottage (Dyer, 2002; Miller & Hatcher, 1978).

The different settlement environments suggest parasitic infections from unhygienic waste management, and respiratory disorders from interior air pollution were similarly obtainable. However, due to the differences in access to food and housing conditions concerning the vicinity, it is possible to assume that non-adults from rural and proto-urban areas likely experienced a "healthier" lifestyle than those from urban centers.

1.2 | Bioarchaeology of medieval English urbanization

Many bioarchaeological studies on the influence of medieval English urbanization on health compare urban and rural areas. Unfortunately, there is a lack of studies on health comparisons between urban and proto-urban areas. This may be due to the lack of a clear definition of proto-urban settlements, which leads to them being categorized as rural areas. For example, medieval Barton-upon-Humber, Lincolnshire, has been categorized as proto-urban (Power & Schutkowski, 2010) and rural (Walter & Dewitte, 2017) in bioarchaeological studies. Differences between rural and proto-urban areas can be identified based on population sizes and economic or social purpose. Distinguishing proto-urban areas and comparing them to urban areas will contribute to how settlement types developed and influenced health.

Bioarchaeological studies have identified that medieval English urban centers were more likely to cause people to have poorer health than those who lived in rural areas (Roberts & Manchester, 2005). Urban areas are recognized to have had higher mortality risk, low survivorship patterns (Walter & Dewitte, 2017), and higher prevalence of pathological conditions (Lewis, 2002, 2016; Lewis et al., 1995). Childhood growth is often used as a proxy for health in bioarchaeological studies in relation to urbanization (Gowland et al., 2018; Ives & Humphrey, 2017; Lewis, 2002; Mays et al., 2009; Newman et al., 2019; Newman & Gowland, 2017; Pinhasi et al., 2006). However, few bioarchaeological studies on childhood growth compare medieval English settlement types (Lewis, 2002; Pinhasi et al., 2006). Lewis (2002) found that the femur lengths of individuals from 18th to 19th century Spitalfields (urban) were significantly shorter than those from medieval St. Helen-on-the-Walls (urban) and suggested this was the consequence of detrimental conditions associated with industrialization. Pinhasi et al. (2006) identified deficiencies in growth values in industrial Broadgate (urban) compared to medieval Raunds Furnells (rural) and industrial Spitalfields (urban), with medieval St. Helen-on-the-Walls (urban) having higher growth values than all three comparative groups. They suggested that socioeconomic status had a major impact on growth due to the availability of food resources, infant feeding practices, and health practices (Pinhasi et al., 2006). However, these studies focus on comparing sites from medieval and post-medieval England to provide insight into changes in growth patterns over time. Thus, the current study aims to explore childhood growth during the medieval period and its relationship with environmental influences.

2 | MATERIALS

Figure 1 displays the sites used in this study, representing individuals from the following medieval English cities: Newcastle, York, Raunds, and Canterbury. The skeletal assemblages of St. Gregory's Priory from Canterbury and All Saint's Church (York Barbican) from York are representative of urban populations. Black Gate skeletal assemblage from Newcastle represents a proto-urban population. Raunds Furnells skeletal assemble from Raunds represents a rural population. Table 1 describes each site.

2.1 | St. Gregory's Priory

The skeletal assemblage from St. Gregory's Priory comprises a total of 1342 individuals, excavated by Canterbury Archaeological Trust from 1988 to 1991 (Anderson & Andrews, 2001). Based on the inclusion criteria (see Section 3) and preservation of the skeletal remains, a total of 60 non-adults were analyzed for this study The Priory was founded in c. 1084 by Archbishop Lanfranc for a community of 6 priests and 12 clerks and was built as a sister establishment to the hospital St. John (Hicks & Hicks, 2001). The clergy of St. Gregory's were responsible for providing pastoral care for the people at St. John's

FIGURE 1 Map of United Kingdom showing the locations of the sites used in this study.

TABLE 1 Sample summary of non-adults from each site.

Site	St. Gregory's Priory	York Barbican	Black Gate	Raunds Furnells
Location	Canterbury	York	Newcastle	Raunds
Settlement	Urban	Urban	Proto-urban	Rural
Period	AD c. 1084–1537	AD 1091–1539	AD c. 700–1168	AD 900–1040
Total no. of individuals[a]	1342	547	679	376
Total no. of non-adults[b]	60	16	38	30
No. of individuals with femora present <2 years	4	5	13	5
No. of individuals with femora present 2–12 years	45	10	20	22
No. of individuals with tibiae present <2 years	2	2	4	4
No. of individuals with tibiae present 2–12 years	47	4	15	16

[a]Total number of individuals from the site.
[b]Total number of individuals under 12 years.

Hospital and free burial services for the poor of Canterbury (Hicks & Hicks, 2001; Tatton-Brown, 1995). The burial grounds were in use from c.1084 to 1537 (Hicks & Hicks, 2001).

The pilgrimage culture dominated medieval Canterbury. It consisted of pilgrims receiving miracles and indulgences by visiting shrines of saints who were canonized by the Roman Catholic Church (Clegg, 2003; Ekelund et al., 1996; Hopper, 2002; Sorabella, 2011). In addition to Canterbury Cathedral, people who lived there saw the pilgrimage culture as an opportunity to gain a stable income. Accommodation, food, beverages, and souvenirs were marketed to pilgrims (Lewis, 2014; Lincoln, 1955; Miller & Hatcher, 1995; Page, 1926), and beggars and hospitals would have persuaded them to donate financial goods (Hopper, 2002; Lyle, 2002; Webb, 2000).

2.2 | York Barbican

All Saint's Church, also known as York Barbican, was excavated by On Site Archaeology from 2007 to 2008 (McIntyre & Graham, 2010). These excavations revealed that the site potentially belonged to the church of All Saint's in Fishergate, York (McIntyre & Graham, 2010). It is thought that the church was given to Whitby Abby monastery between 1091 and 1095, and it did not survive much after the dissolution of monasteries in 1539 by King Henry VIII (McIntyre & Graham, 2010). A total of 547 individuals were excavated from this site (McIntyre & Graham, 2010), and 16 non-adults met the criteria for inclusion in this study.

The clothing and trading industry dominated medieval York, which made the city very prosperous (Palliser, 2014). Regulations for crafts were established from the 1370s onwards to control the quality of crafts, tools used to make crafts, and working practices (Palliser, 2014). Cloth making in York was considered high quality, and grains and wine were traded across the British Isles and to mainland Europe (Palliser, 2014). The job market was reasonably open; thus, people migrated from other towns and villages in England, France, and Belgium, and the population size was perhaps around 20–30,000 (Palliser, 2014).

2.3 | Black Gate

Excavations of Black Gate were carried out by Newcastle City Council between 1973 and 1992 (Boulter & Rega, 1993; Nolan, 2010). A total of 679 individuals were excavated (Nolan, 2010), and 38 non-adults met the criteria for inclusion in this study. Based on the coin evidence and radiocarbon dating of shroud pin types found at the site, the earliest burials are thought to have dated to the 8th century (Boulter & Rega, 1993). The burials may be linked to the 7th century monastic settlement and the 8th to 9th century castle excavated (Nolan, 2010). By the 10th century, the cemetery appears to have been well established with burials of individuals potentially from local agricultural and proto-urban communities (Boulter & Rega, 1993; Nolan, 2010). A Norman castle was constructed in 1080, and it is possible that some of the burials at Black Gate were from the castle garrison (Nolan, 2010). It is suggested that burial usage ended in c. 1168 (Nolan, 2010).

There is little to no documentary evidence for this settlement, monastic center, or castle during this period (Nolan, 2010). During the 6th and early 7th centuries, this settlement was a part of the kingdom of Bernicia, which was united with the kingdom of Deira (Nolan, 2010). Both kingdoms created the Anglian kingdom of Northumbria (Nolan, 2010). After the death of King Edwin of Northumbria, the kingdom was unstable due to frequent invasions by neighboring kingdoms (Nolan, 2010). The sustainability of Northumbria declined in the mid-9th century with the Viking invasions along the northeast coast (Nolan, 2010). The first documentary reference to this settlement is in early 12th century chronicles that mentioned William I's army camped in Newcastle after returning from a campaign in Scotland (Raine, 1838; Simeon, 2000).

2.4 | Raunds Furnells

Trial excavations between 1977 and 1984 of the site Raunds Furnells led to the establishment of the Raunds Areas Project in 1985 (Boddington, 1996a). The Raunds Area Project was jointly managed by the Northamptonshire County Council and the Historic Building Monuments Commission (English Heritage) (Boddington, 1987). A church was discovered outside and adjacent to the manor house complex (Furnells manor) and estimated to have been constructed during the late 9th to early 10th century (Boddington, 1996c). It has been identified that extensions to the church and a graveyard were constructed in the mid-10th century (Boddington, 1996c). Ditches were cut to define a graveyard in the early 10th century (Boddington, 1987). Radiocarbon dates of charcoal and human bones suggest the graveyard was in use from 978 to 1040 (Boddington, 1996b). A total number of 376 individuals were excavated from this site (Powell, 1996), and 30 non-adults met criteria for inclusion in this study.

Raunds was perhaps an open-field agriculture and little woodland settlement. The farming system consisted of the relationship between livestock and arable farming (Banham & Faith, 2014). Arable crops, such as wild oats, relied on the manure and labor of animals for development (Banham & Faith, 2014). The Domesday Book indicates that in the late 11th century Raunds was held by two chief holdings identified with Furnells and Burystead manors (Courtney, 2009a). Burystead estate was a subordinate element of Higham and perhaps regarded as a distant manor (Courtney, 2009a). Furnells manor was held by a King's thegn (a nobleman or lord), known as Burgred, in 1066 (Courtney, 2009b).

3 | METHODS

Age-at-death estimates were based on dental development and eruption stages developed from modern and historical English children (AlQahtani et al., 2010). Teeth were examined macroscopically or radiographically when radiographs were available. Those older than 12 years, based on dental age, were also excluded from this study, due to the timing of fusion of the epiphyses and apophyses, and the influence of the pubertal growth spurt, in concordance with the analytical method (Spake & Cardoso, 2021). Thus, non-adults 0 to 12 years of age were included in this research.

The femora and tibiae were chosen as proxies for growth status as they directly contribute to stature and are potentially more sensitive than other long bones to periods of growth faltering (Bogin & Varela-Silva, 2010). An osteometric board was used to measure the maximum diaphyseal lengths in millimeters (mm). Individuals with evidence of fractures or bowing impacting the long bone were not included due to the potential influence on diaphyseal measurements.

Following the methodology by Spake and Cardoso (2021), z-scores were calculated for left tibiae and femora while substituting with the right when absent. Z-scores below −2 standard deviation (SD) in clinical settings are classified as low height-for-age (i.e., "failing to grow" or "stunting") (de Onis & Blössner, 1997; WHO Expert Committee, 1995). Z-scores were analyzed by site and split into two age categories: <2 years and 2–12 years. From birth to 2 years of age is a period of rapid growth (Humphrey, 2003; Larsen, 2015; Lejarraga, 2012; Lewis, 2007). After 2 years of age, growth velocity slows down and becomes stable (Lejarraga, 2012), thus reflecting the development transition period from infancy to childhood (Bogin, 2021). The Spake and Cardoso (2021) interpolated Maresh data set has been used as a reference sample against the archaeological sites for the z-scores. The Maresh data set consists of children of the upper middle class who participated in a longitudinal growth study, the Denver Growth Study, that included radiographs of long bones in 1935 and onwards (Maresh & Beal, n.d.; Maresh, 1970). Box plots were used to show the z-score distribution of the diaphyseal lengths between the sites. Kruskal-Wallis tests, using a Dunn's post hoc test if the output was significant, were used to compare total z-scores by site. Mann–Whitney *U* tests were used to compare z-scores of those <2 years and 2 to 12 years within each site. Statistical tests were not applied when one or more of the groups being compared had a sample size of less than 5. Confidence intervals were set to 95%, and the alpha level was set to 0.05. SPSS version 29 was used to conduct the statistical analysis.

4 | RESULTS

Figures 2 and 3 display the femoral and tibial z-score distributions for each site. For all three sites, the mean femoral and tibial z-scores were all less than −2, indicative of significantly lower femoral and tibial lengths for age compared to the reference sample (Tables 2 and 3).

For St Gregory's Priory (urban), 51.0% (25/49) had femoral z-scores indicative of growth stunting, and 61.2% (30/49) had tibial z-scores indicative of growth stunting. For those <2 years of age, 50% (2/4) and 50% (1/2) had z-scores of less than −2 for the femur and tibia, respectively. For those 2–12 years of age, 51.1% (23/45) and 61.7% (29/47) had z-scores of less than −2 for the femur and tibia, respectively. Due to the small sample size of individuals in the <2 years category, statistical comparison of the z-scores between the age groups was not undertaken. However, those <2 years on average had lower z-scores for both the femur and tibia compared to those 2–12 years (Tables 2 and 3). In addition, a wide distribution of z-scores was seen for this site in comparison to the other sites, with many individuals demonstrating expected femoral and tibial lengths for age (Figures 2 and 3).

Of the individuals from York Barbican (urban), 53.3% (8/15) had femoral z-scores indicative of growth stunting, and 66.7% (4/6) had tibial z-scores indicative of growth stunting. For those <2 years, none had z-scores of less than −2 for the femur and tibia. For those 2–12 years of age, 80.0% (8/10) and 100% (4/4) had z-scores of less than −2 for the femur and tibia, respectively. For the femur, z-scores for those aged <2 years were significantly higher compared to those 2–12 years of age ($U = 2.000$, $p = 0.003$). However, due to small sample size, statistical comparison was not undertaken for the tibial values.

Within Black Gate (proto-urban), 54.5% (18/33) had femoral z-scores indicative of growth stunting, and 47.4% (9/19) had tibial z-scores indicative of growth stunting. For those <2 years, 30.8% (4/13) and 0% (0/4) had z-scores of less than −2 for the femur and

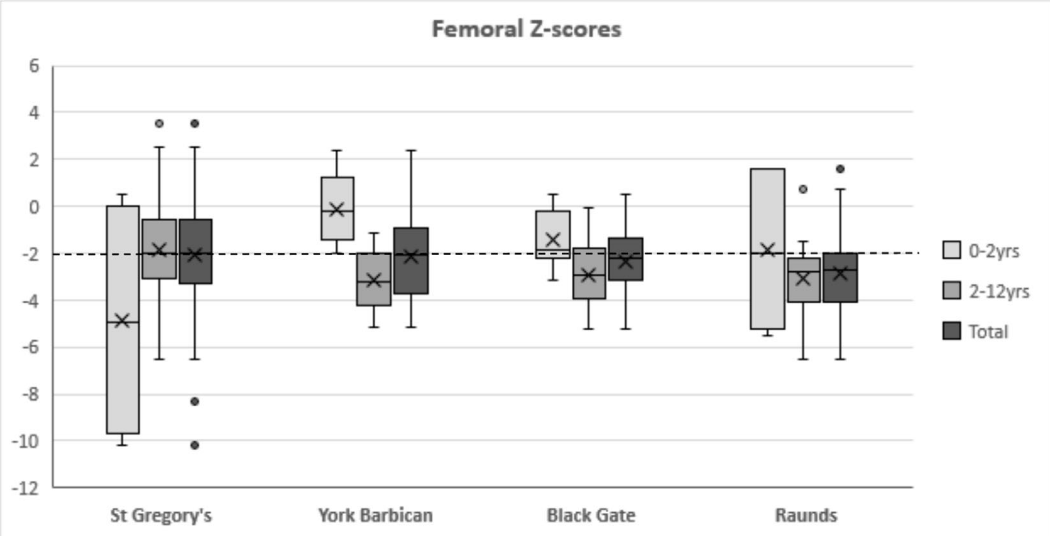

FIGURE 2 Box plots of femoral z-score distribution.

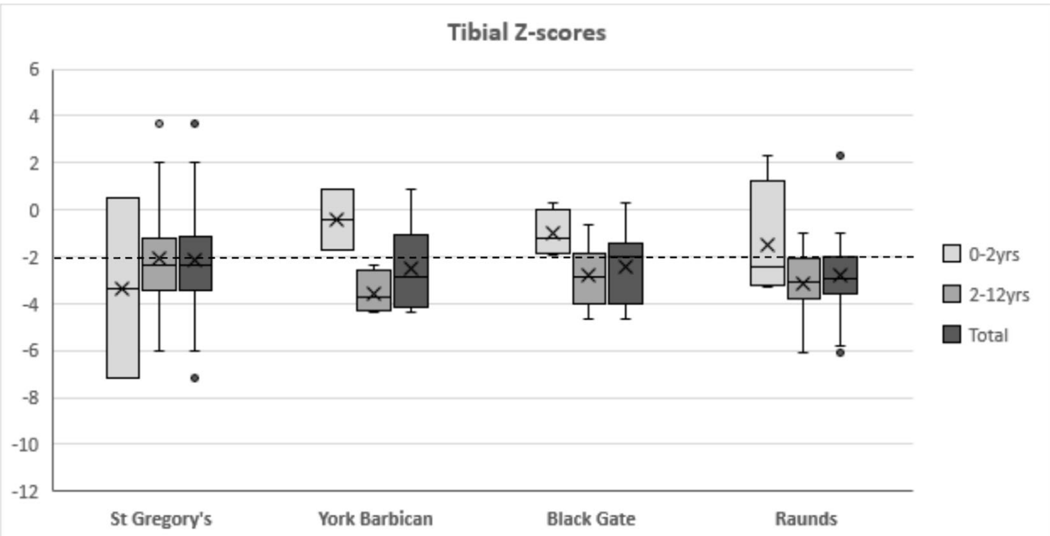

FIGURE 3 Box plots of tibial z-score distribution.

tibia, respectively. For those 2–12 years of age, 70.0% (14/20) and 60.0% (9/15) had z-scores of less than −2 for the femur and tibia, respectively. For the femur, z-scores for those aged <2 years were significantly higher compared to those 2–12 years of age ($U = 57.000$, $p = 0.006$). Again, due to small sample size, this was not undertaken for the tibial values.

Lastly, for Raunds (rural), 74.1% (20/27) had femoral z-scores indicative of growth stunting, and 80.0% (16/20) had tibial z-scores indicative of growth stunting. For those <2 years, 40.0% (2/5) and 50.0% (2/4) had z-scores of less than −2 for the femur and tibia, respectively. For those 2–12 years, 81.8% (18/22) and 87.5% (14/16) had z-scores of less than −2 for the femur and tibia, respectively. There were no significant differences in femoral z-score values for those <2 years and 2–12 years of age ($U = 44.000$, $p = 0.524$), and statistical comparison of the tibial values was not undertaken due to small sample size. A large range of femoral z-scores was noted for those <2 years (Figure 2; Table 2).

Overall, there does not appear to be much difference between the sites, but that Raunds has the lowest mean and median z-score values (see Tables 2 and 3). Indeed, there were no significant differences between the total samples for each site for the femoral z-scores ($H = 4.373$, $p = 0.224$) and the tibial z-scores ($H = 1.936$, $p = 0.586$).

When split by age, St Gregory's Priory (urban) has the lowest femoral and tibial z-scores for those <2 years of age, followed by Raunds (rural), Black gate (proto-urban), and York Barbican (urban) (Tables 2 and 3). However, the very small sample size for this age category must be acknowledged, and statistical tests were not applied.

TABLE 2 Descriptive statistics for femoral z-scores (SD = standard deviation). Values in bold associated with growth stunting (<−2; de Onis & Blössner, 1997).

		Femur					
Site	**Age group**	***N***	**Median**	**Mean**	**SD**	**Min**	**Max**
St. Gregory's Priory (U)	0–2 years	4	**−4.98**	**−4.90**	5.16	−10.18	0.54
	2–12 years	45	**−2.03**	−1.82	2.05	−6.55	3.57
	Total	49	**−2.03**	**−2.07**	2.50	−10.18	3.57
York Barbican (U)	0–2 years	5	−0.03	−0.12	1.61	−1.99	2.36
	2–12 years	10	**−3.22**	**−3.11**	1.31	−5.17	−1.11
	Total	15	**−2.06**	**−2.12**	1.99	−5.17	2.36
Black Gate (P-U)	0–2 years	13	−1.83	−1.39	1.21	−3.16	0.54
	2–12 years	20	**−2.92**	**−2.93**	1.42	−5.24	−0.06
	Total	33	**−2.25**	**−2.32**	1.53	−5.24	0.54
Raunds (R)	0–2 years	5	−1.98	−1.85	3.41	−5.50	1.59
	2–12 years	22	**−2.8**	**−3.07**	1.57	−6.49	0.76
	Total	27	**−2.75**	**−2.84**	2.00	−6.49	1.59

Abbreviations: U, urban; P-U, proto-urban; R, rural.

TABLE 3 Descriptive statistics for tibial z-scores (SD = standard deviation). Values in bold associated with growth stunting (<−2; de Onis & Blössner, 1997).

		Tibia					
Site	**Age group**	***N***	**Median**	**Mean**	**SD**	**Min**	**Max**
St. Gregory's Priory (U)	0–2 years	2	**−3.34**	**−3.34**	5.42	−7.17	0.49
	2–12 years	47	**−2.38**	**−2.10**	1.88	−6.05	3.70
	Total	49	**−2.38**	**−2.15**	2.02	−7.17	3.70
York Barbican (U)	0–2 years	2	0.89	−0.41	1.84	−1.71	0.89
	2–12 years	4	**−3.75**	**−3.56**	0.91	−4.39	−2.34
	Total	6	**−2.87**	**−2.51**	1.95	−4.39	0.89
Black Gate (P-U)	0–2 years	4	−1.22	−1.01	1.00	−1.90	0.28
	2–12 years	15	**−2.85**	**−2.78**	1.30	−4.62	−0.64
	Total	19	−1.97	**−2.40**	1.42	−4.62	0.28
Raunds (R)	0–2 years	4	**−2.44**	−1.47	2.56	−3.26	2.28
	2–12 years	16	**−3.05**	**−3.16**	1.40	−6.11	−1.02
	Total	20	**−2.9**	**−2.82**	1.75	−6.11	2.28

Abbreviations: U, urban; P-U, proto-urban; R, rural.

For those 2–12 years of age, York Barbican (urban) had the lowest femoral and tibial z-scores, followed by Raunds (rural), Black Gate (proto-urban), and St Gregory's Priory (urban). The differences seen between the femoral z-scores for this age category was statistically significant ($H = 9.747$, $p = 0.021$), due to individuals from St Gregory's Priory having significantly higher femoral z-scores (median = −2.03) compared to York Barbican (median = −3.22, $p = 0.042$), Black Gate (median = −2.92, $p = 0.035$) and Raunds (median = −2.80, $p = 0.012$). Due to the small sample size of tibial z-scores for those aged 2–12 years of age in the York Barbican assemblage, differences in tibial z-scores for this age category could not be statistically assessed.

5 | DISCUSSION

Overall, there is evidence for growth disruption compared to modern reference values for all sites. All generally demonstrate a greater level of discrepancy between age-at-death estimates and expected growth attainment in those 2–12 years of age. However, there appears to be much more variability in growth values for <2 years of age from St. Gregory's Priory (urban), with some individuals exhibiting severe growth delays. In addition, for those 2–12 years of age from St. Gregory's Priory (urban), there appears to be significantly higher z-scores overall, compared to the other sites. Also, Raunds (rural) demonstrated some of the lowest growth values for the femora and tibiae in total.

Nutrition is crucial during the rapid growth period during infancy (birth to 2 years) (Lejarraga, 2012). The brain requires a substantial amount of essential nutrients and energy (kilocalories) to allow its structures to engage in rapid growth, including the endocrine system (Bogin, 2021). The endocrine system releases and controls the secretion of hormones such as the growth hormone and thyroid hormone (Hiller-Sturmhöfel & Bartke, 1998; Saper & Lowell, 2014). Adequate nutrition plays an essential role in regulating hormones that engage in skeletal growth (Bonjour et al., 2004; Leathem, 1966). Poor nutrition influences the secretion of hormones that promote bone growth to decrease while those that inhibit growth increase (Campisi et al., 2018). Breastfeeding provides infants with essential nutrients to support not only rapid growth, but also their immune system, providing protection against infectious diseases during infancy and chronic diseases in childhood and later life (Allen & Hector, 2005).

During infancy, growth patterns are also reflective of maternal nutritional status, and perhaps of the general population; breastfeeding women who lack essential nutrients in their diet will result in infants not receiving nutrients that are vital for fueling their early physical development and bolstering their immune system (Christian et al., 2015; Gosman, 2012; Hanson et al., 2003). Historical and bioarchaeological evidence show that infants, during the medieval period, were breastfed and consumed other foods (weaning) between 1 and 3 years of age (Adamson, 2004; Haydock et al., 2013; Mahoney et al., 2016). Their small digestive tracts and deciduous teeth make it difficult for them to process coarse foods (Bogin, 2021); therefore, foods must be prepared in a specific manner for them to obtain nutrients. Medieval physicians recommended that during weaning, children were fed easily digestible foods such as food soaked in water or chewed first by the mother (Adamson, 2004). Growth deficit patterns between 1 and 2 years of age have been viewed as the impact of onset weaning and cessation of weaning during this period (Lewis, 2002; Newman et al., 2019). Isotopic analysis of non-adults from York (urban) suggests that infants were breastfed from birth to 1.5 years and fully weaned around 2 years (Burt, 2013, 2015). Isotopic analysis of non-adults from Raunds (rural) suggests that infants were exclusively breastfed until about 1 year and mixed fed from 2 to 3 years (Beaumont et al., 2018; Haydock et al., 2013). Microwear texture analysis of non-adults from St. Gregory's Priory (urban) suggests that mixed feeding could have started during or after the first year and cessation of weaning started around 2 years (Mahoney et al., 2016). Hence, non-adults from York, Raunds, and Canterbury had similar weaning practices. In contrast, isotopic analysis suggests that non-adults from Black Gate (proto-urban) were weaned approximately after 9 months until 1 year (Macpherson, 2005). Thus, perhaps growth deficit patterns between 1 and 2 years for the current study reflect the nutritional status of mothers and wet nurses from breastfeeding rather than onset weaning and cessation of weaning considering non-adults less than 2 years from St. Gregory's potentially had greater growth disruption compared to the other sites.

The clinical literature suggests that the composition of breast milk reflects the dietary intakes of fatty acids and fat- and water-soluble vitamins such as vitamins A, C, B6, and B12 in the maternal diet (Bravi et al., 2016; Innis, 2014; Lönnerdal, 1986). Thus, perhaps the dietary intake of mothers or wet nurses from Canterbury, who were breastfeeding, was impacted by food and beverages primarily advocated towards pilgrims (Lincoln, 1955; Lyle, 2002) and rationing out their food to provide more to husbands and older children (Bardsley, 2014) that influenced greater growth disruption of non-adults less than 2 years from St. Gregory's Priory compared to the other sites. It is possible that this made non-adults < 2 years of age from St. Gregory's Priory (urban) more susceptible to nutritional and infectious diseases compared to those from the other sites.

After weaning, the developing immune system no longer relies on the nutrition obtained from breastfeeding and requires a substantial amount of energy that is acquired from adequate nutrition (Childs et al., 2019; Nobs et al., 2020; Ygberg & Nilsson, 2012). In addition, an adequate diet is essential for a robust immune system that provides protection against nutritional and infectious diseases. Infectious diseases such as smallpox, plague, tuberculosis, leprosy, and respiratory diseases were common during the medieval period (Barnes, 2005; Rawcliffe, 2013; Robb et al., 2021; Roberts & Cox, 2003; Roberts & Manchester, 2005). Infectious diseases and chronic conditions that compromise the immune system cause the body to require twice as much of essential nutrients (Barnes, 2005; Law, 2005; Patel, 2008). Therefore, infections cause individuals to lack adequate nutritional intake (Lejarraga, 2012), which in turn slow the process of normal long bone growth.

Thus, non-adults 2–12 years from York Barbican (urban) were perhaps susceptible to nutritional deficiencies and infectious diseases due to dense populations, disposal of household and industrial waste into water resources, famines, insufficient ventilation for controlled fires within homes and businesses, and superfluous usage of toxic chemicals for businesses (Palliser, 2014; Rawcliffe, 2013; Roberts & Cox, 2003; Roberts & Manchester, 2005). Additionally, York Barbican (urban) having the lower z-scores on average, compared to Raunds (rural), Black Gate (proto-urban), and St. Gregory's Priory (urban), may be a result of the city of York being one of England's highest-taxed cities besides London during medieval England (Palliser, 2014), which would have led York to have had a limited economy, which perhaps caused individuals to have restricted diet. In the case of Raunds (rural), the higher z-scores on average compared to York Barbican (urban) are potentially due to the agricultural nature of rural settlements such as easier and quicker access to nutritious foods. Lipid residue analysis suggests that people who lived in Raunds consumed dairy products (butter and cheese) and leafy vegetables (such as cabbage and leek) cooked with carcass fats (Dunne et al., 2019). Additionally, the distance between households and businesses within Raunds would have exposed people less to contagious diseases.

The lower z-scores of non-adults 2–12 years from Raunds (rural), compared to Black Gate (proto-urban), are perhaps due to proto-urban areas having personal gardens and access to rural communities' agricultural production, whereas rural areas relied on agricultural production within the community. Rural agricultural production would have sold their surplus to other areas, especially during famines, to gain financial stability (Dyer, 2002), thus, perhaps led people to ration out their food. Additionally, agricultural areas used animal and human excretion waste as fertilizer for crop yields (Jones, 2012; Magnusson, 2013), which influenced the quick spread of parasitic infections. Parasites deprive the host of their nutrients (Mahmud et al., 2018), which would have slowed down the process of normal growth. As regards to non-adults aged 2–12 years from Black Gate (proto-urban) with lower z-scores compared to St. Gregory's Priory (urban), Newcastle was frequently invaded by Scottish and English kingdoms and Vikings (Dyer, 2002), which would have left them with little to no resources and consistently caused them to rebuild their economy, while those from St. Gregory's Priory (urban) were influenced by the affluent atmosphere of the pilgrimage culture in Canterbury that allowed a more stable income.

Thus, the medieval English urban environment had the potential for a greater complexity of factors that may have positively or negatively impacted long bone growth compared to rural and proto-urban environments. It has been recognized in bioarchaeological studies that urban environments in the past had a complex influence on the health and mortality of people (Betsinger & DeWitte, 2021; DeWitte & Betsinger, 2020). A stable income would have been gained to obtain nutritious foods in Canterbury through providing pilgrims with essential needs (Lincoln, 1955) and in York through the cloth and trade industry (Palliser, 2014), which caused a positive impact on long bone growth. Children would have migrated to urban areas to work as servants or apprentices (Dyer, 2002; Miller & Hatcher, 1995). These jobs consisted of carrying out domestic tasks or working in a specific trade or craft, which usually meant living where they worked, such as servant's quarters (Dyer, 2002; Ryan, 2013). Employers provided food, accommodation, and clothes for their servants and apprentices (Dyer, 2002). Bioarchaeological studies suggest that children were more vulnerable to infections and respiratory conditions in the urban environment (Lewis, 2016; Yaussy & DeWitte, 2018). The negative impact on long bone growth was perhaps influenced by compact living quarters and unhygienic waste disposal that caused infections and small windows and holes in rooves that did not provide much ventilation that caused interior air pollution (Dyer, 1989; Miller & Hatcher, 1978, 1995; Rawcliffe, 2013; Roberts & Cox, 2003).

6 | LIMITATIONS

The growth patterns seen in this study may not be reflective of those who survived to adulthood in medieval England, due to biological mortality bias (Wood et al., 1992). However, mortality bias may not have been a particularly important determinant in the data presented here because accidental deaths and short stature do not directly correlate with high mortality (Saunders & Hoppa, 1993). Also, Spake et al. (2022) suggest that the impact of biological mortality bias depends on the type of societies being analyzed for comparison. This study focused on growth patterns across medieval England, but Black Gate (AD c. 700–1168) and Raunds Furnells (AD 900–1040) represent early medieval populations compared to the other sites; thus, the potential difference in biological mortality bias between the early medieval period and later medieval period must be considered. A factor to consider is socioeconomic status. Growth patterns could be influenced by different socioeconomic status groups based on income and ideologies of diet. Thus, considering the unknown socioeconomic status groups for non-adults from Black Gate, Raunds Furnells, and York Barbican may misrepresent growth patterns. Other factors such as the small sample size of the sites should also be considered (Saunders & Hoppa, 1993). The small sample size of those aged < 2 years from each site may misrepresent growth disruption patterns. However, the data presented here still provides valuable insight into environmental influences on child health in medieval England.

7 | CONCLUSION

This research suggests that the medieval English urban environment had a complex influence on childhood growth patterns. Non-adults < 2 years from St. Gregory's Priory had the lowest growth values while those from York Barbican had the highest growth values compared to the rural and proto-urban areas. Also, non-adults 2–12 years from York Barbican had the lowest growth values, while those from St. Gregory's Priory had the highest growth values compared to the proto-urban and rural areas. The urban environment could have been detrimental to childhood growth as a result of inadequate nutrition intake during breastfeeding and weaning, and environmental conditions such as insalubrious waste disposal and insufficient ventilation for controlled fires within businesses and homes. However, the urban environment also offered opportunities for greater income stability through various occupations to obtain access to a variety of food.

Additionally, this research suggests that the medieval English rural environment was associated with greater growth deficits compared to the proto-urban area. Non-adults < 2 years and 2–12 years from Raunds Furnells had lower growth values compared to those from Black Gate. Potentially, agricultural production practices within rural communities would have influenced food rations, while accessibility to both personal gardens and rural production within proto-urban areas allowed for access to a variety of food.

ACKNOWLEDGMENTS

We would like to thank Dr. Jo Buckberry (Biological Anthropology Research Centre, University of Bradford) for access to the Raunds Furnells skeletal collection, Dr. Elizabeth Craig-Atkins (Department of Archaeology, The University of Sheffield) for access to the Black Gate and York Barbican skeletal collections, and Dr. Patrick Mahoney (Human Osteology Research Laboratory, University of Kent) for access to St. Gregory's Priory skeletal collection.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Sina D. White https://orcid.org/0000-0003-0068-6439

REFERENCES

Ackerman, C. (1976). The rural demography of medieval England. *Ethnohistory*, *23*, 105–115. https://doi.org/10.2307/481511

Adamson, M. W. (2004). *Food in medieval times*. Greenwood Press. https://doi.org/10.5040/9798400652639

Allen, J., & Hector, D. (2005). Benefits of breastfeeding. *New South Wales Public Health Bulletin*, *16*, 42–46. https://doi.org/10.1071/nb05011

AlQahtani, S. J., Hector, M. P., & Liversidge, H. M. (2010). Brief communication: The London atlas of human tooth development and eruption. *American Journal of Physical Anthropology*, *142*, 481–490. https://doi.org/10.1002/ajpa.21258

Anderson, T., & Andrews, J. (2001). The human remains. In M. Hicks & A. Hicks (Eds.), *St. Gregory's Priory Northgate, Canterbury excavations 1988–1991* (pp. 338–370). Canterbury Archaeological Trust Limited.

Backman, C. R. (2003). *The worlds of medieval Europe*. Oxford University Press.

Banham, D., & Faith, R. (2014). *Anglo-Saxon farms and farming*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199207947.001.0001

Bardsley, S. (2014). Missing women: Sex ratios in England, 1000-1500. *Journal of British Studies*, *53*, 273–309. https://doi.org/10.1017/jbr.2014.9

Barker, D. J. P. (1999). Early growth and cardiovascular disease. *Archives of Disease in Childhood*, *80*, 305–307. https://doi.org/10.1136/adc.80.4.305

Barnes, E. (2005). *Diseases and human evolution*. University of New Mexico Press.

Beaumont, J., Atkins, E. C., Buckberry, J., Haydock, H., Horne, P., Howcroft, R., Mackenzie, K., & Montgomery, J. (2018). Comparing apples and oranges: Why infant bone collagen may not reflect dietary intake in the same way as dentine collagen. *American Journal of Physical Anthropology*, *167*, 524–540. https://doi.org/10.1002/ajpa.23682

Betsinger, T. K., & DeWitte, S. N. (2021). Toward a bioarchaeology of urbanization: Demography, health, and behavior in cities in the past. *American Journal of Biological Anthropology*, *175*, 79–118. https://doi.org/10.1002/ajpa.24249

Bhatia, J., Bhutta, Z. A., & Kalhan, S. C. (2012). Maternal and child nutrition: The first 1,000 days. *Nestlé Nutrition Institute Workshop Series*, *74*, 11–25. https://doi.org/10.1159/000348384

Boddington, A. (1987). Raunds, Northamptonshire: Analysis of a country churchyard. *World Archaeology*, *18*, 411–425. https://doi.org/10.1080/00438243.1987.9980015

Boddington, A. (1996a). Introduction. In A. Boddington (Ed.), *Raunds Furnells: The Anglo-Saxon church and churchyard* (pp. 1–6). English Heritage.

Boddington, A. (1996b). Radiocarbon dates. In A. Boddington (Ed.), *Raunds Furnells: The Anglo-Saxon church and churchyard* (pp. 72–73). English Heritage.

Boddington, A. (1996c). The church and churchyard. In A. Boddington (Ed.), *Raunds Furnells: The Anglo-Saxon church and churchyard* (pp. 5–15). English Heritage.

Bogin, B. (2021). *Patterns of human growth* (Third ed.). Cambridge University Press. https://doi.org/10.2307/2802709

Bogin, B., & Varela-Silva, M. I. (2010). Leg length, body proportion, and health: A review with a note on beauty. *International Journal of Environmental Research and Public Health*, *7*, 1047–1075. https://doi.org/10.3390/ijerph7031047

Bonjour, J.-P., Ammann, P., Chevalley, T., & Rizzoli, R. (2004). Protein intake and bone health. In M. F. Holick & B. Dawson-Hughes (Eds.), *Nutrition and bone health* (pp. 261–277). Humana Press. https://doi.org/10.1007/978-1-59259-740-6_17

Boulter S, & Rega E. (1993). Report of human remains from BlackGate Newcastke-Upon Tyne.

Bravi, F., Wiens, F., Decarli, A., Dal Pont, A., Agostoni, C., & Ferraroni, M. (2016). Impact of maternal nutrition on breast-milk composition: A systematic review. *American Journal of Clinical Nutrition*, *104*, 646–662. https://doi.org/10.3945/ajcn.115.120881

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*, 407–416. https://doi.org/10.1002/ajpa.22370

Burt, N. M. (2015). Individual dietary patterns during childhood: An archaeological application of a stable isotope microsampling method for tooth dentin. *Journal of Archaeological Science*, *53*, 277–290. https://doi.org/10.1016/j.jas.2014.10.019

Cameron, N. (2012). The human growth curve, canalization and catch-up growth. In N. Cameron & B. Bogin (Eds.), *Human growth and development* (pp. 1–22). Academic Press.

Campisi, S. C., Carducci, B., Söder, O., & Bhutta, Z. A. (2018). *The intricate relationship between chronic undernutrition, impaired linear growth and delayed pubery: Is "catch-up" growth possible during asolescence?* Innocenti Working Papers. UNICEF.

Childs, C. E., Calder, P. C., & Miles, E. A. (2019). Diet and immune function. *Nutrients*, *11*, 1933. https://doi.org/10.3390/nu11081933

Christian, P., Mullany, L. C., Hurley, K. M., Katz, J., & Black, R. E. (2015). Nutrition and maternal, neonatal, and child health. *Seminars in Perinatology*, *39*, 361–372. https://doi.org/10.1053/j.semperi.2015.06.009

Clegg, J. (2003). *The medieval church in manuscripts*. The British Library.

Collins, P., & Weeks, C. E. (2019). Respiratory disease. In J. Gandy (Ed.), *Manual of dietetic practice*. John Wiley & Sons.

Courtney, P. (2009a). Historical background: Domesday Raunds. In M. Audouy & A. Chapman (Eds.), *Raunds: The origin and growth of a midland village, AD 450-1500: Excavations in north Raunds, Northamptonshire* (pp. 14–21). Oxbow Books.

Courtney, P. (2009b). Historical background: North Raunds. In M. Audouy & A. Chapman (Eds.), *Raunds: The origin and growth of a midland village, AD 450-1500: Excavations in north Raunds, Northamptonshire* (pp. 14–21). Oxbow Books.

de Onis M, & Blössner M. (1997). WHO global database on child growth and malnutrition.

Devien, L., Giovannelli, J., Cuny, D., Matran, R., Amouyel, P., Hulo, S., Edmé, J. L., & Dauchet, L. (2018). Sources of household air pollution: The association with lung function and respiratory symptoms in middle-aged adult. *Environmental Research*, *164*, 140–148. https://doi.org/10.1016/j.envres.2018.02.016

DeWitte, S. N., & Betsinger, T. K. (2020). Introduction to the bioarchaeology of urbanization. In T. K. Betsinger & S. N. DeWitte (Eds.), *The bioarchaeology of urbanization: The biological, demographic, and social consequences of living in cities* (pp. 1–21). Springer International Publishing AG. https://doi.org/10.1007/978-3-030-53417-2_1

Dunne, J., Chapman, A., Blinkhorn, P., & Evershed, R. P. (2019). Reconciling organic residue analysis, faunal, archaeobotanical and historical records: Diet and the medieval peasant at West Cotton, Raunds, Northamptonshire. *Journal of Archaeological Science*, *107*, 58–70. https://doi.org/10.1016/j.jas.2019.04.004

Dyer, C. (1989). *Standards of living in the later Middle Ages: Social change in England c. 1200–1520*. Cambridge University Press. https://doi.org/10.1017/CBO9781139167697

Dyer, C. (2000). *Everyday life in medieval England*. A&C Black. https://doi.org/10.5040/9781472599407

Dyer, C. (2002). *Making a living in the Middle Ages: The people of Britain 850–1520*. Yale University Press.

Dyer, C. (2003). The archaeology of medieval small towns. *Medieval Archaeology*, *47*, 85–114. https://doi.org/10.1179/med.2003.47.1.85

Ekelund, R. B., Hébert, R. F., Tollison, R. D., Anderson, G. M., & Davidson, A. B. (1996). *Sacred trust: The medieval church as an economic firm*. Oxford University Press. https://doi.org/10.1093/oso/9780195103373.001.0001

Ettman, C. K., Vlahov, D., & Galea, S. (2019). Why cities and health? Cities as determinants of health. In C. K. Ettman, D. Vlahov, & S. Galea (Eds.), *Urban health*. Oxford University Press. https://doi.org/10.1093/oso/9780190915858.003.0002

Forbes, G. B. (1987). *Human body composition: Growth, aging, nutrition, and activity*. Springer-Verlag. https://doi.org/10.1007/978-1-4612-4654-1

Godde, K., & Hens, S. M. (2021). An epidemiological approach to the analysis of cribra orbitalia as an indicator of health status and mortality in medieval and post-medieval London under a model of parasitic infection. *American Journal of Physical Anthropology*, *174*, 631–645. https://doi.org/10.1002/ajpa.24244

Godde, K., Pasillas, V., & Sanchez, A. (2020). Survival analysis of the Black Death: Social inequality of women and the perils of life and death in medieval London. *American Journal of Physical Anthropology*, *173*, 168–178. https://doi.org/10.1002/ajpa.24081

Gosman, J. H. (2012). Growth and development: Morphology, mechanisms, and abnormalities. In C. Crowder & S. Stout (Eds.), *Bone histology: An anthropological perspective* (pp. 23–44). CRC Press.

Gowland, R. L., Caffell, A. C., Newman, S. L., Levene, A., & Holst, M. (2018). Broken childhoods: Rural and urban non-adult health during the industrial revolution in northern England (eighteenth-nineteenth centuries). *Bioarchaaeology International*, *2*, 44–62. https://doi.org/10.5744/bi.2018.1015

Halder, J. N., & Islam, M. N. (2015). Water pollution and its impact on the human health. *Journal of Environment and Human*, *2*, 2373–8332. https://doi.org/10.15764/EH.2015.01005

Hamerow, H. (2012). Rural settlements and society in Anglo-Saxon England. In *Rural settlements and society in Anglo-Saxon England* (pp. 1–208). https://doi.org/10.1093/acprof:oso/9780199203253.001.0001

Hans, B. K., & Jana, T. (2018). Micronutrients in the life cycle: Requirements and sufficient supply. *NFS Journal*, *11*, 1–11. https://doi.org/10.1016/j.nfs.2018.03.001

Hanson, L. Å., Korotkova, M., Lundin, S., Håversen, L., Silfverdal, S. A., Mattsby-Baltzer, I., Strandvik, B., & Telemo, E. (2003). The transfer of immunity from mother to child. *Annals of the new York Academy of Sciences*, *987*, 199–206. https://doi.org/10.1111/j.1749-6632.2003.tb06049.x

Hartmann, C., & Yang, Y. (2020). Molecular and cellular regulation of intramembranous and endochondral bone formation during embryogenesis. In J. P. Bilezikian, T. J. Martin, T. L. Clemens, & C. Rosen (Eds.), *Principles of bone biology* (pp. 5–44). Elsevier Academic Press. https://doi.org/10.1016/B978-0-12-814841-9.00001-4

Haseena, M., Malik, M. F., Javed, A., Arshad, S., Asif, N., Zulfiqar, S., & Hanif, J. (2017). Water pollution and human health. *Environmental Risk Assessment and Remediation*, *1*. https://doi.org/10.4066/2529-8046.100020

Haydock, H., Clarke, L., Craig-Atkins, E., Howcroft, R., & Buckberry, J. (2013). Weaning at Anglo-Saxon raunds: Implications for changing breastfeeding practice in britain over two millennia. *American Journal of Physical Anthropology*, *151*, 604–612. https://doi.org/10.1002/ajpa.22316

Hicks, A., & Hicks, M. (2001). The site. In M. Hicks & A. Hicks (Eds.), *St Gregory's Priory, Northgate, Canterbury excavations 1988-1991* (pp. 1–49). Canterbury Archaeological Trust Limited.

Hiller-Sturmhöfel, S., & Bartke, A. (1998). The endocrine system: An overview. *Alcohol Health & Research World*, *22*, 153–164. https://doi.org/10.1007/978-3-319-19207-9_25

Holguin, F. (2008). Traffic, outdoor air pollution, and asthma. *Immunology and Allergy Clinics of North America*, *28*, 577–588. https://doi.org/10.1016/j.iac.2008.03.008

Hopper, S. (2002). *To be a pilgrim: The medieval pilgrimage experiece*. Sutton Publishing Limited.

Humphrey, L. T. (2003). Linear growth variation in the archaeological record. In J. L. Thompson, G. E. Krovitz, & A. J. Nelson (Eds.), *Patterns of growth and development in the genus homo* (pp. 144–169). Cambridge University Press. https://doi.org/10.1017/CBO9780511542565.006

Innis, S. M. (2014). Impact of maternal diet on human milk composition and neurological development of infants. *American Journal of Clinical Nutrition*, *99*, 734S–741S. https://doi.org/10.3945/ajcn.113.072595

Ives, R., & Humphrey, L. (2017). Patterns of long bone growth in a mid-19th century documented sample of the urban poor from Bethnal Green, London, UK. *American Journal of Physical Anthropology*, *163*, 173–186. https://doi.org/10.1002/ajpa.23198

Johnson, M. H. (2010). *English houses 1300–1800: Vernacular architecture, social life*. Taylor & Francis.

Jones, R. (2012). *Manure matters: Historical, archaeological and ethnographic perspectives*. Ashgate.

Larsen, C. S. (2015). *Bioarchaeology: Interpreting behavior from the human skeleton*. Cambridge University Press. https://doi.org/10.1017/CBO9781139020398

Law, C. (2005). Early growth and chronic disease: A public health overview. *Maternal and Child Nutrition*, *1*, 169–176. https://doi.org/10.1111/j.1740-8709.2005.00023.x

Leathem, J. H. (1966). Nutritional effects on hormone production. *Journal of Animal Science*, *25*, 68–78. https://doi.org/10.2527/jas1966.25Supplement68x

Lejarraga, H. (2012). Growth in infancy and childhood: A pediatric approach. In N. Cameron & B. Bogin (Eds.), *Human growth and development* (pp. 23–56). Academic Press.

Lewis, M. (2014). *Saints and their badges: Saints' lives and medieval pilgrim badges*. Green Light Publishing.

Lewis, M. E. (2002). Impact of industrialization: Comparative study of child health in four sites from medieval and postmedieval England (A.D. 850-1859). *American Journal of Physical Anthropology*, *119*, 211–223. https://doi.org/10.1002/ajpa.10126

Lewis, M. E. (2007). *The bioarchaeology of children: Perspectives from biological and forensic anthropology*. Cambridge University Press. https://doi.org/10.1017/cbo9780511542473.001

Lewis, M. E. (2016). Work and the adolescent in medieval England AD 900-1550: The osteological evidence. *Medieval Archaeology*, *60*, 138–171. https://doi.org/10.1080/00766097.2016.1147787

Lewis, M. E., Roberts, C. A., & Manchester, K. (1995). Comparative study of the prevalence of maxillary sinusitis in later medieval urban and rural populations in northern England. *American Journal of Physical Anthropology*, *98*, 497–506. https://doi.org/10.1002/ajpa.1330980409

Lincoln, E. F. (1955). *The story of Canterbury*. Staples Press Limited.

Lönnerdal, B. (1986). Effects of maternal dietary intake on human milk composition. *The Journal of Nutrition*, *116*, 499–513. https://doi.org/10.1093/jn/116.4.499

Lyle, M. (2002). *Canterbury: 2000 years of history*. Tempus.

Macpherson, P. M. (2005). *Tracing change: An isotopic investigation of Anglo-Saxon childhood diet*. University of Sheffield.

Magnusson, R. J. (2013). Medieval urban environmental history. *History Compass*, *11*, 189–200. https://doi.org/10.1111/hic3.12038

Mahmud, R., Lim, Y. A. L., & Amir, A. (2018). *Medical parasitology*. Springer. https://doi.org/10.1007/978-3-319-68795-7_10

Mahoney, P., Schmidt, C. W., Deter, C., Remy, A., Slavin, P., Johns, S. E., Miszkiewicz, J. J., & Nystrom, P. (2016). Deciduous enamel 3D microwear texture analysis as an indicator of childhood diet in medieval Canterbury, England. *Journal of Archaeological Science*, *66*, 128–136. https://doi.org/10.1016/j.jas.2016.01.007

Maresh, M. M. (1970). Measurments from Roentgenogramgs. In R. W. McCannon (Ed.), *Human growth and development* (pp. 157–200). Springfield.

Maresh, M. M., & Beal, V. A. (n.d.). A longitudinal survey of nutrition intake, body size, and tissue measurements in healthy subjects during growth. *Monographs of the Society for Research in Child Development*, *35*, 33–39. https://doi.org/10.2307/1165811

Matkovic, V., Badenhop-Steven, N., Ha, E.-J., Crncevic-Orlic, Z., & Clairmont, A. (2004). Nutrition and bone health in children and adolescents. In M. F. Holick & B. Dawson-Hughes (Eds.), *Nutrition and bone health* (pp. 173–195). Humana Press.

Mays, S. (2018). The study of growth in skeletal populations. In S. Crawford, D. M. Hadley, & G. Shepherd (Eds.), *The Oxford handbook of the archaeology of childhood* (pp. 71–89). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199670697.013.4

Mays, S., Brickley, M., & Ives, R. (2009). Growth and vitamin D deficiency in a population from 19th century Birmingham, England. *International Journal of Osteoarchaeology*, *19*, 406–415. https://doi.org/10.1002/oa.976

McIntyre, L., & Graham, B. (2010). Excavating All Saint's: A medieval church rediscovered. *Current Anthropology*.

Miller, E., & Hatcher, J. (1978). *Medieval England: Rural society and economic change 1086–1348*. Routledge.

Miller, E., & Hatcher, J. (1995). *Medieval England: Towns, commerce and crafts 1086–1348*. Longman Group Limited.

Mitchell, P. D. (2015). *Human parasites in medieval Europe: Lifestyle, sanitation and medical treatment*. Elsevier Ltd. https://doi.org/10.1016/bs.apar.2015.05.001

Newman, S. L., & Gowland, R. L. (2017). Dedicated followers of fashion? Bioarchaeological perspectives on socio-economic status, inequality, and health in urban children from the industrial revolution (18th–19th C), England. *International Journal of Osteoarchaeology*, *27*, 217–229. https://doi.org/10.1002/oa.2531

Newman, S. L., Gowland, R. L., & Caffell, A. C. (2019). North and south: A comprehensive analysis of non-adult growth and health in the industrial revolution (AD 18th–19th C), England. *American Journal of Physical Anthropology*, *169*, 104–121. https://doi.org/10.1002/ajpa.23817

Nobs, S. P., Zmora, N., & Elinav, E. (2020). Nutrition regulates innate immunity in health and disease. *Annual Review of Nutrition*, *40*, 189–219. https://doi.org/10.1146/annurev-nutr-120919-094440

Nolan, J. (2010). The early medieval cemetery at the Castle Newcastle upon Tyne. *Archaeologia Aeliana*, *39*, 147–287.

Ohlsson, C., Isgaard, J., Törnell, J., Nilsson, A., Isaksson, O., & Lindahl, A. (1993). Endocrine regulation of longitudinal bone growth. *Acta Paediatrica*, *391*, 33–40. https://doi.org/10.1159/000328119

Page, W. (1926). Hospitals: Hospitals in and around Canterbury. In *A history of the County of Kent* (Vol. 2) (pp. 209–216). British History Online.

Palliser, D. M. (2014). *Medieval York 600–1540*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199255849.001.0001

Pantin, W. A. (1962). Medieval English town-house plans. *Medieval Archaeology*, *6*, 202–239. https://doi.org/10.1080/00766097.1962.11735667

Patel, L. (2008). Growth and chronic disease. *Annales Nestle*, *65*, 129–136. https://doi.org/10.1159/000112235

Pearson, S. (2009). Medieval houses in English towns: Form and location. *Vernacular Architecture*, *40*, 1–22. https://doi.org/10.1179/030554709X12528296422527

Pinhasi, R., Shaw, P., White, B., & Ogden, A. R. (2006). Morbidity, rickets and long-bone growth in post-medieval Britain - A cross-population analysis. *Annals of Human Biology*, *33*, 372–389. https://doi.org/10.1080/03014460600707503

Powell, F. (1996). The human remains. In A. Boddington (Ed.), *Raunds Furnells: The Anglo-Saxon church and churchyard* (pp. 113–124). English Heritage.

Power, R., & Schutkowski, H. (2010). Differential infant and child mortality and morbidity in Late Anglo-Saxon England. *American Journal of Physical Anthropology*, *141*, 192.

Raine J. (1838). Vita Oswini Regis Deirorum. : 1–59.

Rawcliffe, C. (2013). *Urban bodies: Communal health in late medieval English towns and cities*. Boydell & Brewer Ltd.

Robb, J., Cessford, C., Dittmar, J., Inskip, S. A., & Mitchell, P. D. (2021). The greatest health problem of the Middle Ages? Estimating the burden of disease in medieval England. *International Journal of Paleopathology*, *34*, 101–112. https://doi.org/10.1016/j.ijpp.2021.06.011

Roberts, C. A., & Cox, M. (2003). *Health & disease in Britain*. Sutton Publishing Limited.

Roberts, C. A., & Manchester, K. (2005). *The archaeology of disease* (3rd ed.). Cornell University Press.

Ryan, P. J. (2013). *Master-servant childhood: A history of the idea of childhood in medieval English culture*. Palgrave Macmillan. https://doi.org/10.1057/9781137364791

Saper, C. B., & Lowell, B. B. (2014). The hypothalamus. *Current Biology*, *24*, R1111–R1116. https://doi.org/10.1016/j.cub.2014.10.023

Saunders, S. R., & Hoppa, R. D. (1993). Growth deficit in survivors and non-survivors: Biological mortality bias in subadult skeletal samples. *American Journal of Physical Anthropology*, *36*, 127–151. https://doi.org/10.1002/ajpa.1330360608

Scrimshaw, N. S. (2003). Symposium: Nutrition and infection, prologue and progress since 1968 historical concepts of interactions, synergism and antagonism between nutrition and infection 1. *Experimental Biology*, 316–321.

Scrimshaw, N. S., & SanGiovanni, J. P. (1997). Synergism of nutrition, infection, and immunity: An overview. *American Journal of Clinical Nutrition*, *66*, 464–477. https://doi.org/10.1093/ajcn/66.2.464S

Ségala, C., Poizeau, D., Mesbah, M., Willems, S., & Maidenburg, M. (2008). Winter air pollution and infant bronchiolitis in Paris. *Environmental Research*, *106*, 96–100. https://doi.org/10.1016/j.envres.2007.05.003

Shapland, F., Lewis, M. E., & Watts, R. (2015). The lives and deaths of young medieval women: The osteological evidence. *Medieval Archaeology*, *59*, 272–289. https://doi.org/10.1080/00766097.2015.1119392

Simeon, D. (2000). *Libellus de exordio atque procursu istius, hoc est Dunhelmensis, ecclesie*. Rollason.

Sorabella, J. (2011). Pilgrimage in medieval Europe. *Heilbrunn timeline of art history, New York: The Metropolitain Museum of Art* [online] Available from: https://www.metmuseum.org/toah/hd/pilg/hd_pilg.htm (Accessed 23 April 2020)

Spake, L., & Cardoso, H. F. V. (2021). Interpolation of the Maresh diaphyseal length data for use in quantitative analyses of growth. *International Journal of Osteoarchaeology*, *31*, 232–242. https://doi.org/10.1002/oa.2942

Spake, L., Hoppa, R. D., Blau, S., & Cardoso, H. F. V. (2022). Biological mortality bias in diaphyseal growth of contemporary children: Implications for paleoauxology. *American Journal of Biological Anthropology*, *1–19*, 89–107. https://doi.org/10.1002/ajpa.24486

Spengler, J. D., & Chen, Q. (2000). Indoor air quality factors in designing a healthy building. *Annual Review of Energy and the Envrionment*, *25*, 567–600. https://doi.org/10.1146/annurev.energy.25.1.567

Steane, J. (1985). *The archaeology of medieval England and Wales*. Routledge.

Sullivan, A. (2004). Reconstructing relationships among mortality, status, and gender at the medieval Gilbertine priory of St. Andrew, Fishergate, York. *American Journal of Physical Anthropology*, 330–345. https://doi.org/10.1002/ajpa.10271

Tatton-Brown, T. (1995). The beginnings of St Gregory's Priory and St John's Hospital in Canterbury. In H. E. J. Cowdrey (Ed.), *Canterbury and the Norman conquest: Churches, saints, and scholars, 1066–1109* (pp. 41–52). Open University Press.

Ulijaszek, S. J., & Strickland, S. S. (1993). *Nutritional anthropology: Prospects and perspectives*. Smith-Gordon.

Walter, B. S., & Dewitte, S. N. (2017). Urban and rural mortality and survival in medieval England. *Annals of Human Biology*, *44*, 338–348. https://doi.org/10.1080/03014460.2016.1275792

Wang, T., Cessford, C., Dittmar, J. M., Inskip, S., Jones, P. M., & Mitchell, P. D. (2022). Intestinal parasite infection in the Augustinian friars and general population of medieval Cambridge, UK. *International Journal of Paleopathology*, *39*, 115–121. https://doi.org/10.1016/j.ijpp.2022.06.001

Webb, D. (2000). *Pilgrimage in medieval England*. Bloomsbury Publishing.

WHO Expert Committee. (1995). Physica status: The use and interpretation of anthropomety. Geneva.

Wood, J. W., Milner, G. R., Harpending, H. C., Weiss, K. M., Cohen, M. N., Eisenberg, L. E., Hutchinson, D. L., Jankauskas, R., Cesnys, G., Katzenberg, M. A., Lukacs, J. R., McGrath, J. W., Roth, E. A., Ubelaker, D. H., & Wilkinson, R. G. (1992). The Osteological Paradox. *Current Anthropology*, *33*, 343–370. https://www.jstor.org/stable/2743861

Wu, G., Imhoff-Kunsch, B., & Webb, G. A. (2012). Biological mechanisms for nutritional regulation of maternal health and fetal development. *Paediatric and Perinatal Epidemiology*, *26*, 4–26. https://doi.org/10.1111/j.1365-3016.2012.01291.x

Wuerzer, T. (2014). Urban health. In A. C. Michalos (Ed.), *Encyclopedia of quality of life and well-being research*. Dordrecht. https://doi.org/10.1007/978-94-007-0753-5_3127

Yaussy, S. L., & DeWitte, S. N. (2018). Patterns of frailty in non-adults from medieval London. *International Journal of Paleopathology*, *22*, 1–7. https://doi.org/10.1016/j.ijpp.2018.03.008

Ygberg, S., & Nilsson, A. (2012). The developing immune system - From foetus to toddler. *Acta Paediatrica, International Journal of Paediatrics*, *101*, 120–127. https://doi.org/10.1111/j.1651-2227.2011.02494.x

Zuzarte-Luís, V., & Mota, M. M. (2018). Parasite sensing of host nutrients and environmental cues. *Cell Host and Microbe*, *23*, 749–758. https://doi.org/10.1016/j.chom.2018.05.018

How to cite this article: White, S. D., Newman, S. L., Primeau, C., Mahoney, P., & Deter, C. A. (2024). The impact of urbanization on growth patterns of non-adults in medieval England. *International Journal of Osteoarchaeology*, e3347. https://doi.org/10.1002/oa.3347