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RESEARCH ARTICLE

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Health inequality in medieval Cambridge, 1200–1500 CE

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Abstract

Health inequality is not only a major problem today; it left its mark upon past societies too. For much of the past, health inequality has been poorly studied, mostly because bioarchaeologists have concentrated upon single sites rather than a broader social landscape. This article compares 476 adults in multiple locations of medieval Cambridge (UK). Samples include ordinary townspeople (All Saints), people living in a charitable institution (the Hospital of St. John), and members of a religious order (the Augustinian Friary). These groups shared many conditions of life, such as a similar range of diseases, risk of injury, and vertebral disk degeneration. However, people living on charity had more indicators of poor childhood health and diet, lower adult stature, and a younger age at death, reflecting the health effects of poverty. In contrast, the Augustinian friars were members of a prosperous, well-endowed religious house. Compared with other groups, they were taller (perhaps a result of a richer diet during their adolescent growth period); their adult carbon and nitrogen isotope values are higher, suggesting a diet higher in terrestrial and/or marine animal protein; and they had the highest prevalence of foot problems related to fashionable late medieval footwear. As this illustrates, health inequality will take particular forms depending upon the specificities of a social landscape; except in unusual circumstances where a site and its skeletal samples represent a real cross-section of society, inequality is best investigated by comparison across sites.

KEYWORDS
friars, inequality, poor childhood environment, poverty, whole town approach

1 | INTRODUCTION: THE BIOARCHAEOLOGY OF HEALTH INEQUALITY

One of the most harmful aspects of social inequality is how it affects health. This is, sadly, a familiar problem today. Poor areas of the world far exceed rich areas in malnutrition and preventable diseases. Within developed countries, there are income-based gaps in longevity. Even the effects of the recent COVID-19 pandemic differed dramatically for different social classes (Bambra et al., 2020). But how long has health inequality affected humanity, and is there a typical way it does so?

Health inequality is central to current bioarchaeological agendas (Buikstra et al., 2022). On the broadest scale, multi-period universalising studies (Steckel & Rose, 2002) use comparative, lowest-common-denominator data to seek broad historic trends. Bioarchaeologists have investigated some aspects of it extensively. Studies of historical enslaved people, sharecroppers and colonized indigenous populations in the Americas have documented how such groups were often subjected to violent repression, crushing work regimes, and poor environmental conditions; the consequence was often poor health and reduced longevity (Corruccini et al., 1982; Rose, 1989; Okumura, 2011; Dent, 2017; Cardoso et al., 2019; Shuler, 2011; Maass, 2023). This is complemented by the bioarchaeology of working-class people. Studies of the urban poor working in the "dark Satanic mills" of England's industrial heartland have revealed many health trends similar to those experienced by colonized populations, though the trends are not entirely uniform across contexts (DeWitte et al., 2016, Newman & Gowland, 2017; Gowland, 2018; Gowland et al., 2018; Newman et al., 2019; Yaussy, 2019; Newman & Hodson, 2021;Buckberry & Crane-Kramer, 2022, Chidimuro et al., 2023). A complementary body of research has focused upon 19th–20th century marginalized groups in hospitals, poorhouses, sanitoria, and asylums, showing how individuals in such institutions may have been both maltreated, malnourished or subjected to medicalized repression in life and treated differently from nonmarginalized people when they died (Austin et al., 2022; Garcia-Putnam et al., 2021; Muller, 2021; Nichols et al., 2023; Nystrom, 2014).

Yet research on other aspects of the historic of inequality is scantier and yields a more ambiguous picture. For both medieval (Schweich & Knüsel, 2003; Sullivan, 2004) and Classical periods (Griffin et al., 2011; Karligkioti et al., 2023; Pitts & Griffin, 2012), studies of possible health inequalities show that sometimes inequality had biological consequences, but in many cases distinctions between social strata are less clear. Instead, it is more common to discuss themes such as urban–rural comparisons or religious-lay comparisons. This may reflect the methodological challenge of identifying members of different social classes in burial sites from these periods, and the fact that many studies focus upon a single site rather than making comparisons across the social spectrum. However, it may also reflect the fact that, even when ancient societies were deeply inegalitarian, different social strata did not necessary inhabit segregated biological environments. The situation is equally ambiguous in studies of prehistoric inequality. In studies which have problematized the issue, "elites" and "commoners" sometimes differ in aspects such as food consumption (Schepartz et al., 2017); but much more commonly, bioarchaeological evidence makes clear that, in spite of status differences, they essentially shared the circumstances of life (Powell, 1988' cf. Beck & Quinn, 2023). In such circumstances, a "bioarchaeology of community" (Juengst & Becker, 2017) approach might be more revealing than a "bioarchaeology of hierarchy" approach.

This diverse literature shows that social inequality could profoundly impact health in ancient groups, yet the relationship may be complex. This article discusses health inequality in later medieval Cambridge, between 1000 and 1500 CE. Medieval England was a class-divided society, but in complex ways (Dyer, 1998).Working people were not a monolithic bloc of "the poor." In the countryside, the image of medieval "peasants" is misleading; people working the land ranged from casually employed landless laborers to prosperous, landowning farmers (Miller & Hatcher, 2014). Similarly, in towns (Miller & Hatcher, 1995), "the poor" formed one end of the social spectrum, and included both working people hovering around the poverty line and the unemployed and unemployable, perhaps homeless, disabled, and/or living by begging, institutional charity, and petty crime. Some of these were trapped in lifelong "structural poverty", whereas others encounted "life cycle poverty", falling into need at some point when they became unable to work and their family or support networks collapsed (Dyer, 2009). The scale extended upwards from them through fully employed laborers, workers with a trade or shop, skilled craftspeople, and senior guild members, merchants, lawyers, and doctors. Thus, the "rich" included a small number of aristocrats and gentry, but, in towns such as Cambridge, also prosperous professionals, merchants and craftspeople. The social landscape also contained religious professionals, who comprised perhaps 2% of adult men and a smaller number of women. Again, these varied hugely. The ordinary (secular) church establishment had its own hierarchy ranging from archbishops, bishops, deans, and canons down to parish priests and lay helpers. Religious houses such as monasteries, friaries, and nunneries formed separate communities governed by their own rules. Although such religious houses varied in prosperity, they often became quite wealthy. While monks, friars, and nuns were personally poor, they were often institutionally prosperous, buffered from need by their house's resources.

The social landscape of burial was equally complex. For Christians, the default option was burial in the local parish church's graveyard. However, more important people could be buried close to the church or even within it. Monasteries, friaries, and nunneries usually had their own cemeteries serving their own members. For laypeople, it was often considered prestigious to be buried in a monastery or friary, but since doing so usually required a donation, laypeople buried in religious houses were usually well-off. A few of the poor lived in charitable institutions such as hospitals, which often had their own cemeteries. Emergency situations sometimes called for emergency solutions (Cessford et al., 2021). Other groups— Jews, executed people, and people dying away from home— may have been buried in other ways.

Cambridge exemplifies this complexity. It was a medium-sized city (Figure 1); its population rose to 5000–6000 people before the Black Death of 1348–9 (Casson et al., 2020), and fell to 3000–4000 afterwards. Cambridge held an unusually high number of religious houses and the University of Cambridge, one of only two universities in England (Cam, 1959). In addition to townspeople, the town thus contained 500–1000 mostly male clerics of various kinds. This skewed the sex ratio in the town to about 60:40; it brought money into the town and created demand for goods and services of all kinds; and it created tensions over control of municipal affairs between a richer clerical/university community and a poorer town community.

There were around 30 places in medieval Cambridge where the dead could be buried, and different groups tended to choose different burial places. Thus, every site represents a situated slice of society, and no one site is likely to highlight contrasts between social groups (Figure 2). Studying inequality here requires a "whole town" approach: constructing a series of collections which span different parts of society, combining their data to create a balanced overall picture of the society, and exploring the gaps and contrasts between groups.

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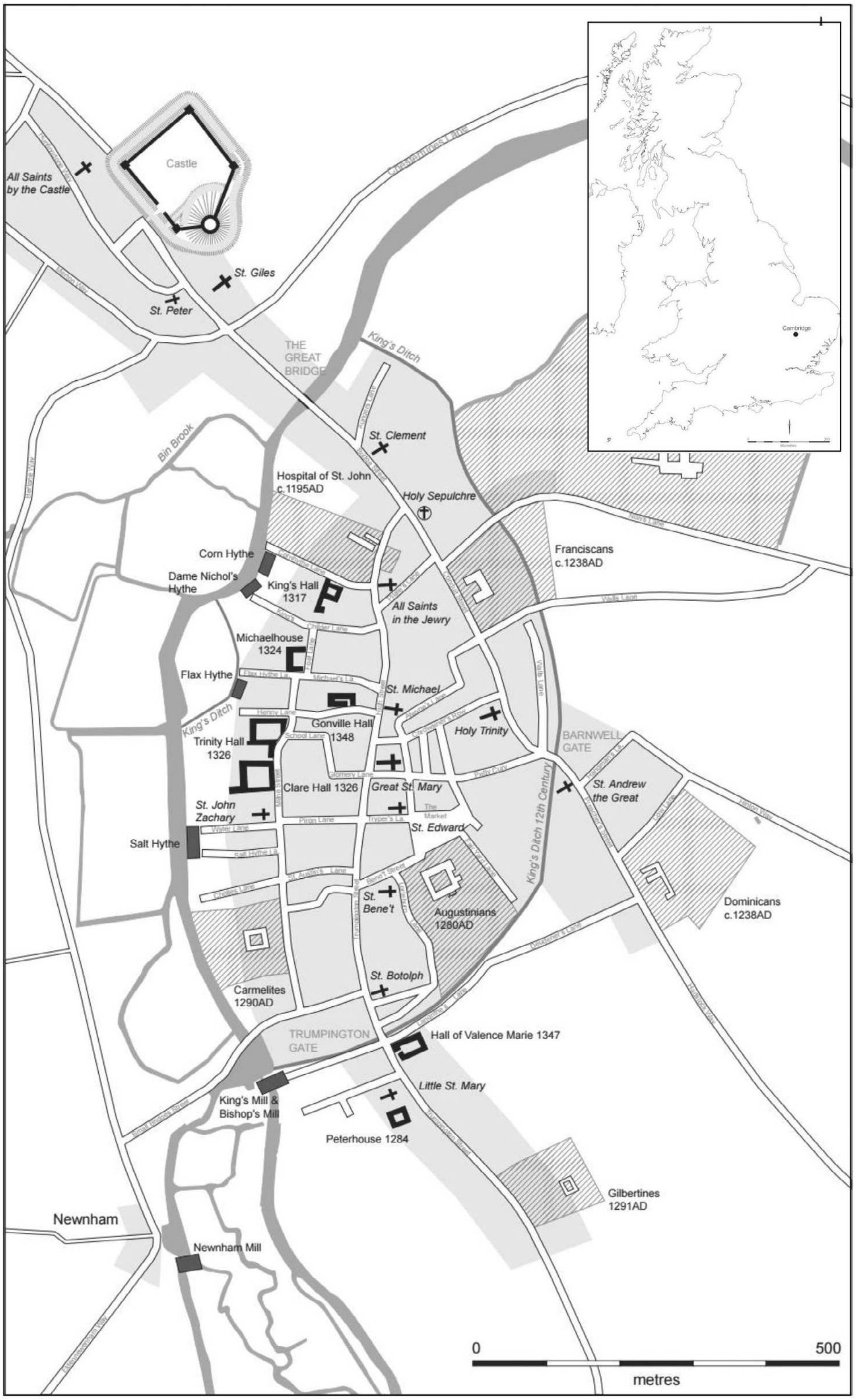

FIGURE 1 Cambridge, ca. 1350. All Saints parish church is in the north-western corner; the Augustinian Friary is at the South edge of the town, and the Hospital of St. John is north of the town center (map by Vicki Herring).

This research investigates the general hypothesis that social inequality affected health in this medieval setting. Using 20 skeletal and molecular indicators of health and lifestyle, it compares 476 adults from late medieval Cambridge (1200–1500 CE) representing three of the social groups contributing to Cambridge's complex social landscape: ordinary townspeople, members of a wealthy religious establishment, and people buried in a charitable institution for the poor and needy. To the extent that health reflects social position, we would expect these groups to exhibit different patterns of growth, diet, life risks, disease, and mortality.

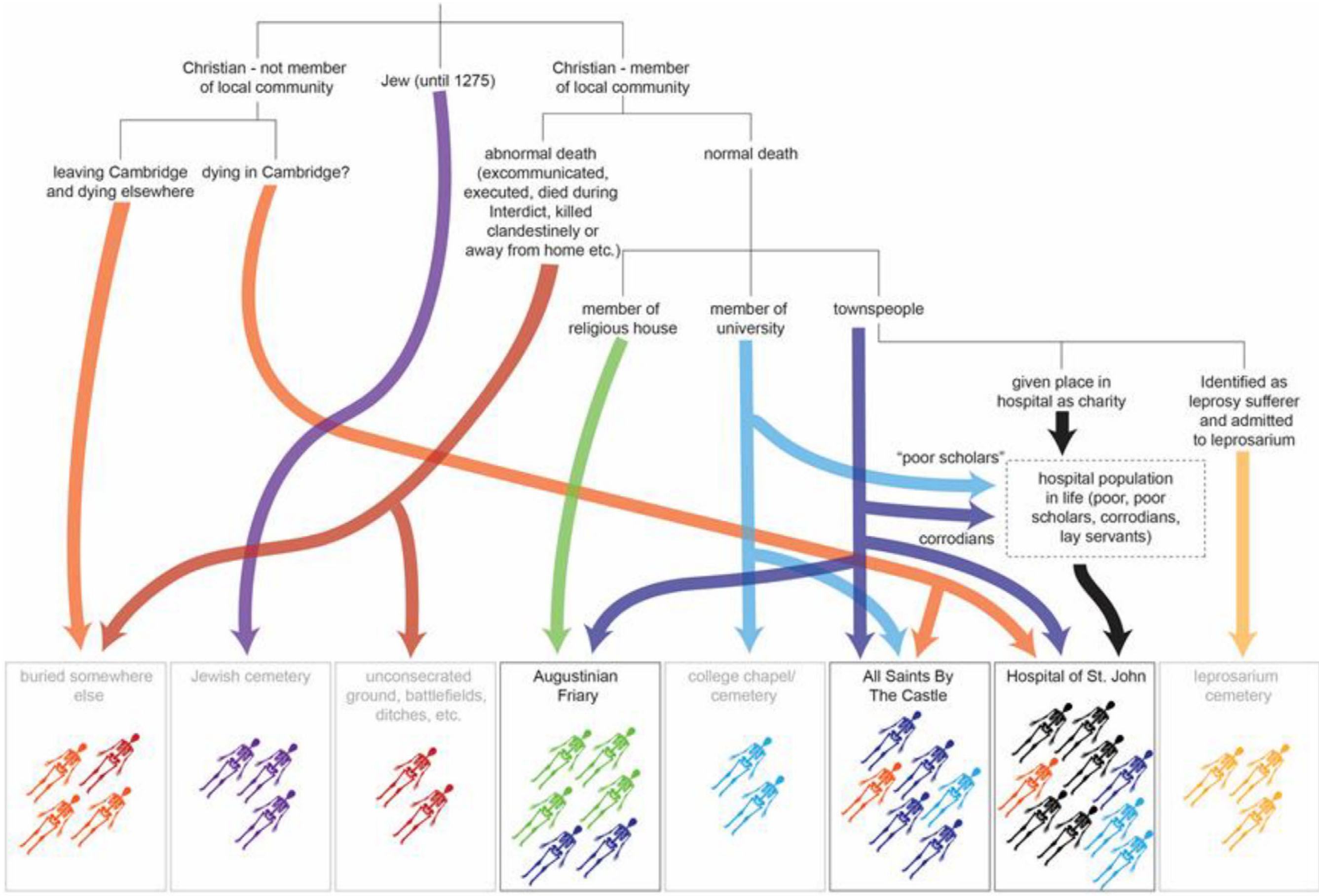

FIGURE 2 Burial as a social sorting mechanism in medieval Cambridge (graphic by Vicki Herring). Not all parish church cemeteries, monasteries, and so on, are shown. Sites analyzed here are outlined in black.

2 | MATERIALS AND METHODS

2.1 | Sites and samples

In this study, we compare three sites, representing different kinds of people (Figure 1). Ordinary townspeople are represented by 104 adult burials from the parish church cemetery of All Saints by the Castle, dating to between 940 and 1365 CE. This was a poor neighborhood on the northern outskirts of Cambridge; it contained urban workers, farm workers and craftspeople (Casson et al., 2020). The parish was substantially depopulated by the Black Death, and the cemetery went out of use in 1366. In the statistical analysis, the "townspeople" group includes both these 104 individuals from All Saints by the Castle and 17 burials and a few disarticulated remains from the Augustinian friary who were not identified archaeologically as friars.

Religious professionals are represented by Augustinian friars. The Augustinian Friary was a large establishment of 40–70 friars, located south of the marketplace. It existed from the 1280s until 1538, when monasteries and friaries were dissolved in England. A wealthy institution, it was both a working friary and a major Augustinian study center. At the Friary, friars were buried identifiably in their clerical garb (Cessford et al., 2022; Cessford & Neil, 2022). In this study, 18 friars represent the religious professionals of medieval Cambridge. Non-friars buried there represent prosperous laypeople; 17 burials and a few disarticulated remains were added to the "townspeople" group.

The Hospital of St. John the Evangelist provided general charity, not medical care: it supplied food, housing, and clothing to about a dozen individuals identified as poor and needy. It remained in use from 1200 through 1511, when St. John's College replaced it (Cessford, 2015; Rubin, 1987; Underwood, 2008). This study includes 337 adults from the hospital. Osteobiographical study shows that these included university scholars, poor people, and a few nonresidents (Inskip et al., 2023; Robb et al., 2019). Like other hospitals (Dyer, 2009; Rawcliffe, 1999), it contained both the lifelong "structural poor" and people experiencing "life-cycle poverty", for instance becoming indigent when unable to work in old age (Inskip et al., 2023).

Here, skeletons were categorized as "townspeople" from All Saints and laypeople buried at the Augustinian friary, "friars" from the Augustinian friary, and "recipients of charity" from St. John's Hospital. As nonadults were routinely buried only at All Saints, to maintain comparability across sites, we include only skeletally-defined adults here (>18 years). The three sites represent mostly overlapping timespans; statistical analysis confirms that differences between groups

TABLE 1 Data collected for this study.

Category	Data collected and references	Statistical test used in comparing samples
Archaeological context	Original excavation records (All Saints: Paul Craddock and Vince Gregory; Hospital of St. John the Evangelist: Cambridge Archaeological Unit; Augustinian Friary: Cambridge Archaeological Unit)	n/a
Demographic estimation	Sex: macroscopic cranial and pelvic features (Buikstra & Ubelaker, 1994; Phenice, 1969; Schwartz, 2007); genetic estimation (Inskip et al., 2019) Age at death: Brooks & Suchey, 1990; Buckberry & Chamberlain, 2002; Wright et al., 1984; Iscan et al., 1985, Falys & Prangle, 2015; Moorrees et al., 1963a, 1963b	Sex: n/a Adult age at death:for statistical analysis, this is condensed to three categories (18–25, 26–45, 46+); analyzed using X^2 test of independence
Linear enamel hypoplasia	Anterior surfaces of teeth were examined under strong oblique light. LEH was recorded as "present" in a dentition when the lesion was palpable and more than one tooth was affected.	Condensed to two categories (0–1 lesions per tooth, >1 lesion per tooth); analyzed using X^2 test of independence
Cribra orbitalia	Recorded as "present" when areas of porosity were observed on the superior surface of at least one orbit which was more than 50% complete (types 2–5, Stuart-Macadam, 1991:109). Both active and healed/ residual lesions were counted as "present."	Counted as present (including both active and healed/ residual) or absent; analyzed using X^2 test of independence
Vitamin D deficiency	Skeletal signs such as bowed limb bones, flaring of the rib ends and metaphyses, following Mays et al., 2006; Ives, 2014 & Brickley,2007	Counted as present or absent; analyzed using X^2 test of independence
Adult stature	Estimated using Trotter and Gleser "white" equations (White and Folkens (2005:Table 19.2)	Sex-specific groups compared using ANOVA
Index of Poor Childhood Environment	See text	Ordinal data: groups compared using nonparametric tests (Mann–Whitney *U*, Kruskal–Wallis H)
Maxillary sinusitis	Active or healed presence of new reactive bone formation in maxillary sinuses (Boocock et al., 1995)	Counted as present or absent; analyzed using X^2 test of independence
New bone formation	Subperiosteal new bone formation–presence, location and type (i.e., woven, lamellar) recorded	Counted as "present" if subperiosteal new bone formation is present anywhere in skeleton, "absent" if not. Analyzed using X^2 test of independence
Respiratory infection	Presence of subperiosteal new bone formation on the visceral surface of ribs, indicating pleural inflammation	Counted as present or absent; analyzed using X^2 test of independence
Tuberculosis	Pathognomic signs of tuberculosis (Pott's spine) or substantial destructive remodeling of the ribs and/or one or more vertebra (Roberts & Buikstra, 2003; Roberts & Buikstra, 2020). Considered "present" when an individual presented with at least two of the following; (1) subperiosteal new bone formation on the visceral surfaces of the ribs, (2) destructive remodeling or lytic lesions on the visceral surfaces of the ribs, sternum, manubrium, anterior surface of the sacrum, os coxae, and/or cranium, (3) joint destruction (Kelley & Micozzi, 1984; Matos & Santos, 2006; Roberts et al., 1994; Santos & Roberts, 2006)	Counted as present or absent; analyzed using X^2 test of independence
Osteoarthritis	Extra-spinal osteoarthritis, identified following Waldron, 2009:34; counted as "present" if any was observed in the skeleton in locations other than the spinal column	Counted as present or absent; analyzed using X^2 test of independence
DISH	Diffuse Idiopathic Skeletal Hyperostosis, identified as outlined by Rogers and Waldron (2001)	Counted as present or absent; analyzed using X^2 test of independence
Schmorl's nodes	Presence of resorptive lesions >1 mm in depth on upper and/or lower surfaces of vertebral bodies	Converted to categorical data (0, 1–6, 7+ nodes per individual) and to presence/absence (0, 1+ nodes per individual). The former (ordinal data) analyzed using nonparametric tests (Mann–Whitney *U*, Kruskal–Wallis H); the latter analyzed using X^2 test of independence
Hallux valgus	Diagnostic signs of hallux valgus in the first metatarsal (see Dittmar, Mitchell, Cessford, et al., 2021a; Mays, 2005 for full details)	Counted as present or absent; analyzed using X^2 test of independence
Trauma and cranial trauma	Presence of healed or unhealed trauma anywhere in skeleton (Dittmar, Mitchell, Cessford, et al., 2021b)	Counted as present or absent; analyzed using X^2 test of independence

(Continues)

TABLE 1 (Continued)

Category	Data collected and references	Statistical test used in comparing samples
Cranial trauma	Presence of healed or unhealed cranial trauma (Dittmar, Mitchell, Cessford, et al., 2021b)	Counted as present or absent; analyzed using X^2 test of independence
Isotopic analysis	$\delta^{13}C$ and $\delta^{15}N$ were analyzed in rib bone collagen samples to provide insight into nutrition in the last decade or so of life (see Rose, 2020 for full details of methodology and analysis)	Numerical data: groups compared using ANOVA

are not due to chronological change within the medieval period (Robb et al., n.d). Extensive aDNA screening (Hui et al., 2024) shows that the groups compared here do not differ in general genetic composition.

Combined, these 476 individuals represent a cross-section of much of Cambridge's population, omitting only the uppermost strata and particular groups (e.g., Jews, criminals, and nuns). As with all archaeological samples, they do not represent subgroups in realistic proportions; we address such sample biases statistically below.

2.2 | Methods: Data gathered

Because inequality is a complex phenomenon, we collected a wide range of data, representing multiple dimensions of health and lifestyle throughout the lifespan. These signs of pathology, activity, and lifestyle are listed in Table 1, along with diagnostic criteria and statistical tests used to compare them across social groups. Data collection methods were chosen as the standard methods most appropriate for the samples. For example, whereas stature estimation equations used derive from modern samples, no methods based on samples closer to the medieval period are available, and they serve to reveal contrasts between these closely related social groups.

In bioarchaeology, indexes are commonly used to summarize complex data; examples include the Biological Index of Frailty (Zedda et al., 2021), which provides a proxy for overall experience of ill health. Because such measures often include aspects of adult health and here we wanted to characterize early childhood life conditions, we devised a new "Index of Poor Childhood Environment" (IPCE). As measures of childhood well-being (or lack of it), we used enamel hypoplasias, cribra orbitalia, stature, vitamin D deficiency, and relative diet. Enamel hypoplasia is a nonspecific indicator whose etiology may be influenced by poor nutrition, illness, and other sources of stress (Goodman and Rose 1990; Hillson, 2014; Masterson et al., 2017; Ungar et al., 2017). Cribra orbitalia's etiology remains debated, but lesions are associated with variously-caused forms of anemia; it is treated as a nonspecific indicator of physiological stress (Grauer, 2019; Oxenham & Cavill, 2010; Walker et al., 2009). Stature has been shown to reflect a range of childhood stresses, including poor nutrition, disease, and social stresses (Deaton, 2007). For vitamin D deficiency, no clear cases of osteomalacia were found; diagnosis was based on cases of rickets and residual rickets (all cases noted involved bowing of the lower limbs). Vitamin D deficiency is typically caused by multiple factors including lack of sunlight exposure along with cultural, environmental and genetic factors. In chronic cases, it can cause skeletal deformities, greater risk of fracture, poor growth, and immune dysfunction in later life (Chanchlani et al., 2020; Mays et al., 2006; Thomas et al., 1998; Zerofsky et al., 2016).

To calculate this index, we scored 1 for each of six characteristics:

1. The presence of more than one hypoplastic lesion per tooth
2. The presence of cribra orbitalia
3. The presence of skeletal signs of vitamin D deficiency
4. $\delta^{13}C$ (dentine) below the 20th percentile for the medieval Cambridge sample as a whole
5. $\delta^{15}N$ (dentine) below the 20th percentile for the medieval Cambridge sample as a whole
6. Adult stature below the sex-specific 20th percentile for the medieval Cambridge sample as a whole; reduced stature has been shown to reflect a range of childhood stresses affecting growth (Deaton, 2007)

We then divided the total by the number of these features which were observable. To avoid biases due to sparse data, only individuals with three or more indicators observable were scored. Obviously, this approach must be adjusted to reflect the group studied (for example, in a group in which enamel hypoplasia is less common, its simple presence might distinguish individuals better). But the resulting index proved effective in revealing social differences here.

2.3 | Statistical methods for a "whole city" approach

Data were analyzed using standard inferential statistics, including ANOVA for numerical data, nonparametric tests for ordinal and nonnormally distributed data, and chi-squared analysis of categorical data (see Table 1). All prevalences given are true prevalence rate (TPR). Following recent critical discussion (Hurlbert et al., 2019), we use the resulting *p*-values simply to provide a relative measure of how improbable the observed data are.

In a complex social landscape, how can we characterize the overall health of a diverse population? Simply calculating an average of all individual skeletons studied gives greater importance to those sites or subgroups which provided more samples, often for purely archaeological reasons. However, calculating the mean value for each site or subgroup and then averaging these mean values gives equal importance to each site or subgroup sampled, regardless of whether it represents an important or trivial segment of the real population. Here, to

TABLE 2 Using a weighted mean to represent population health: childhood environment.

Observation		Townsfolk	Friars	Hospital	Simple mean	Mean of group means	"Whole town" weighted mean	Difference between "whole town" mean and simple mean (%)	Difference between "whole town" mean and mean of group means (%)
Linear enamel hypoplasia (% with >1 lesion)	F	52.40 ($n = 21$)		70.80 ($n = 24$)	62.20	61.60	52.58	−15.5	−14.6
	M	47.60 ($n = 21$)	68.80 ($n = 16$)	67.60 ($n = 37$)	62.20	61.33	53.95	−13.3	−12.0
	All	50.00 ($n = 42$)	68.80 ($n = 16$)	68.90 ($n = 61$)	62.20	62.57	52.82	−15.1	−15.6
Cribra orbitalia (% affected)	F	43.30 ($n = 30$)		53.80 ($n = 26$)	48.20	48.55	43.41	−9.9	−10.6
	M	33.30 ($n = 21$)	26.70 ($n = 15$)	56.40 ($n = 39$)	44.00	38.80	31.62	−28.1	−18.5
	All	39.20 ($n = 51$)	26.70 ($n = 15$)	55.40 ($n = 65$)	45.80	40.43	37.61	−17.9	−7.0
Vitamin D deficiency (% affected)	F	0.00 ($n = 44$)		7.50 ($n = 53$_	4.10	3.75	0.08	−98.2	−98.0
	M	2.20 ($n = 45$)	0.00 ($n = 17$)	7.20 ($n = 83$)	4.80	3.13	1.61	−66.4	−48.6
	All	1.10 ($n = 89$)	0.00 ($n = 17$)	7.40 ($n = 136$)	4.50	2.83	1.01	−77.6	−64.4
Adult stature (cm)	F	163.08 ($n = 43$)		160.24 ($n = 49$)	161.56	161.66	163.05	0.9	0.9
	M	171.71 ($n = 39$)	173.54 ($n = 17$)	169.15 ($n = 63$)	170.60	171.47	172.22	0.9	0.4
Index of Poor Childhood Environment	F	0.22 ($n = 32$)		0.31 ($n = 26$)	0.26	0.26	0.22	−15.5	−17.0
	M	0.16 ($n = 22$)	0.14 ($n = 17$)	0.27 ($n = 42$)	0.21	0.19	0.16	−27.5	−18.9
	All	0.19 ($n = 54$)	0.14 ($n = 17$)	0.28 ($n = 69$)	0.23	0.21	0.19	−19.0	−9.2

Note: "Simple mean" simply averages all cases studied. "Mean of group means" averages the mean value calculated for each site. "Whole town weighted mean" weights each group's value according to the proportion of the town's population they made up (see text for explanation). Colors highlight values which are substantially changed by use of a socially-weighted mean.

provide a balanced picture of health in medieval Cambridge, we use a weighted average, which represents the overall composition of a population. This involves first calculating the mean value for each site or subgroup, and then weighting its contribution to the overall average according to how much that subgroup is estimated to have contributed to the whole social landscape. We estimate that townswomen made up 99% of the women living in medieval Cambridge and women living in charitable institutions 1%; so in calculating average health parameters for females, the "townswomen" mean was weighted at 99% and the "hospital" mean was weighted at 1%. Among men, with its university and religious orders, Cambridge had more clerics than most medieval towns. We estimate that men living in Cambridge included 70% townsmen, 29% clerics, and 1% people living in charitable institutions. Thus, in creating the "whole town" weighted average for males, the means for townsmen, friars and hospital males were weighted at 70%, 29%, and 1%, respectively. The overall "whole town" average is a mean of the resulting male and female means. (Tables 2–5).

3 | RESULTS: THE HEALTH OF THE WHOLE COMMUNITY, AND HOW GROUPS DIFFERED WITHIN IT

The "whole town" averages for the bioarchaeological parameters studied here are reported in Tables 2–5. How well different characterizations represent the overall population depends on the size of subgroups and how different they are from each other. In this case, 71% of the sample comes from the Hospital of St. John, which represents people living on charity— a group that was numerically marginal and whose health diverged from other groups'. Thus, using an unweighted average overestimates the prevalence of vitamin D deficiency, DISH, and deaths between 18 and 25; it underestimates the prevalence of respiratory infections, osteoarthritis, trauma, and death at ages older than 45. The weighted average corrects these biases; it also raises the average stature by 1.49 cm (females) and 1.62 cm (males).

Bioarchaeological data comparing the three groups are presented in Tables 6–9. Some reflect inequality more clearly than others.

TABLE 3 Using a weighted mean to represent population health: palaeopathology.

Observation		Townsfolk	Friars	Hospital	Simple mean	Mean of group means	"Whole town" weighted mean	Difference between "whole town" mean and simple mean (%)	Difference between "whole town" mean and mean of group means (%)
Maxillary sinusitis (% affected)	F	38.90 (n = 18)		70.80 (n = 24)	57.10	54.85	39.22	−31.3	−28.5
	M	50.00 (n = 18)	73.30 (n = 15)	65.70 (n = 35)	63.20	63.00	56.91	−9.9	−9.7
	All	44.40 (n = 36)	73.30 (n = 15)	67.80 (n = 59)	60.90	61.83	48.68	−20.1	−21.3
Periosteal new bone formation (% affected)	F	76.60 (n = 47)		83.60 (n = 61)	80.60	80.10	76.67	−4.9	−4.3
	M	77.10 (n = 48)	88.20 (n = 17)	87.50 (n = 88)	84.30	84.27	80.42	−4.6	−4.6
	All	76.80 (n = 95)	88.20 (n = 17)	85.90 (n = 149)	82.80	83.63	78.49	−5.2	−6.2
Respiratory infection (% affected)	F	38.90 (n = 18)		50.00 (n = 40)	46.60	44.45	39.01	−16.3	−12.2
	M	64.70 (n = 17)	75.00 (n = 8)	29.60 (n = 54)	41.80	56.43	67.34	61.1	19.3
	All	51.50 (n = 35)	75.00 (n = 8)	38.30 (n = 94)	43.80	54.93	54.66	24.8	−0.5
Tuberculosis (% affected)	F	15.40 (n = 39)		24.50 (n = 53)	20.70	19.95	15.49	−25.2	−22.4
	M	5.00 (n = 40)	11.80 (n = 17)	9.50 (n = 74)	8.40	8.77	7.02	−16.5	−20.0
	All	10.10 (n = 79)	11.80 (n = 17)	15.70 (n = 127)	13.50	12.53	10.39	−23.0	−17.1
Extraspinal osteoarthritis (% affected)	F	55.30 (n = 47)		19.30 (n = 57)	35.60	37.30	54.94	54.3	47.3
	M	44.70 (n = 47)	61.10 (n = 18)	36.80 (n = 87)	42.10	47.53	49.38	17.3	3.9
	All	50.00 (n = 94)	61.10 (n = 18)	29.90 (n = 144)	39.50	47.00	51.35	30.0	9.3
DISH (% affected)	F	3.00 (n = 33)		2.30 (n = 43)	2.60	2.65	2.99	15.1	12.9
	M	8.10 (n = 37)	11.10 (n = 18)	24.60 (n = 61)	17.20	14.60	9.14	−46.9	−37.4
	All	5.70 (n = 70)	11.10 (n = 18)	15.40 (n = 104)	11.50	10.73	6.55	−43.0	−38.9
	F				2.03	2.11	2.47	21.8	17.5

TABLE 3 (Continued)

Observation		Townsfolk	Friars	Hospital	Simple mean	Mean of group means	"Whole town" weighted mean	Difference between "whole town" mean and simple mean (%)	Difference between "whole town" mean and mean of group means (%)
Schmorl's nodes (mean number per individual)		2.48 ($n = 31$)		1.73 ($n = 48$)					
	M	2.94 ($n = 35$)	4.35 ($n = 17$)	2.98 ($n = 59$)	3.18	3.42	3.35	5.3	−2.2
	All	2.62 ($n = 69$)	4.35 ($n = 17$)	2.43 ($n = 111$)	2.66	3.13	2.86	7.5	−8.7
Hallux valgus (% affected)	F	16.70 ($n = 18$)		10.00 ($n = 20$)	13.20	13.35	16.63	26.0	24.6
	M	19.20 ($n = 26$)	45.50 ($n = 11$)	32.40 ($n = 34$)	29.60	32.37	26.96	−8.9	−16.7
	All	18.20 ($n = 44$)	45.50 ($n = 11$)	24.10 ($n = 54$)	23.90	29.27	22.08	−7.6	−24.6
Trauma (% affected)	F	39.60 ($n = 48$)		20.00 ($n = 60$)	28.70	29.80	39.40	37.3	32.2
	M	50.00 ($n = 48$)	35.30 ($n = 17$)	38.50 ($n = 91$)	41.70	41.27	45.62	9.4	10.6
	All	44.80 ($n = 96$)	35.30 ($n = 17$)	31.10 ($n = 151$)	36.40	37.07	43.33	19.0	16.9
Cranial trauma (% affected)	F	5.60 ($n = 36$)		7.40 ($n = 27$)	6.30	6.50	5.62	−10.8	−13.6
	M	12.50 ($n = 24$)	7.70 ($n = 13$)	7.30 ($n = 41$)	9.00	9.17	11.06	22.8	20.6
	All	8.30 ($n = 60$)	7.70 ($n = 13$)	7.40 ($n = 68$)	7.80	7.80	8.21	5.2	5.2

Note: See Table 2 caption for explanation.

TABLE 4 Using a weighted mean to represent population health: isotopic data.

Observation		Townsfolk	Friars	Hospital	Simple mean	Mean of group means	"Whole town" weighted mean	Difference between "whole town" mean and simple mean (%)	Difference between "whole town" mean and mean of group means (%)
δ^{13}C (rib)	F	−19.6 ($n = 14$)		−19.2 ($n = 44$)	−19.3	−19.4	−19.6	1.6	1.0
	M	−19.1 ($n = 30$)	−18.4 ($n = 17$)	−18.9 ($n = 64$)	−18.9	−18.8	−18.9	0.1	0.5
	All	−19.3 ($n = 46$)	−18.4 ($n = 17$)	−19.0 ($n = 116$)	−19.0	−18.9	−19.2	0.6	1.3
δ^{15}N (rib)	F	12.4 ($n = 14$)		12.3 ($n = 44$)	12.3	12.3	12.4	0.6	0.4
	M	12.8 ($n = 30$)	13.9 ($n = 17$)	12.6 ($n = 64$)	12.9	13.1	13.1	1.8	−0.1
	All	12.6 ($n = 46$)	13.9 ($n = 17$)	12.5 ($n = 116$)	12.6	13.0	12.8	1.1	−1.7

Note: See Table 2 caption for explanation.

TABLE 5 Using a weighted mean to represent population health: age at death.

Observation		Townsfolk	Friars	Hospital	Simple mean	Mean of group means	"Whole town" weighted mean	Difference between "whole town" mean and simple mean (%)	Difference between "whole town" mean and mean of group means (%)
Age at death–female (% in each category)	18–25	4.20 (2)		20.40 (11)	12.70	12.30	4.36	−65.7	−64.5
	26–45	37.50 (18)		42.60 (23)	40.20	40.05	37.55	−6.6	−6.2
	46+	58.30 (28)		37.00 (20)	47.10	47.65	58.09	23.3	21.9
Age at death–male (% in each category)	18–25	10.40 (5)	22.20 (4)	18.40 (16)	16.70	17.00	13.90	−16.8	−18.2
	26–45	50.00 (24)	38.90 (7)	36.80 (32)	41.20	41.90	46.65	13.2	11.3
	46+	39.60 (19)	38.90 (7)	44.80 (39)	42.50	41.10	39.45	−7.2	−4.0
Age at death–all (% in each category, followed by *n*)	18–25	7.30 (7)	22.20 (4)	19.10 (27)	14.90	16.20	9.50	−36.2	−41.3
	26–45	43.80 (42)	38.90 (7)	39.00 (55)	40.80	40.57	43.07	5.6	6.2
	46+	49.00 (47)	38.90 (7)	41.80 (59)	44.30	43.23	47.51	7.3	9.9

Note: See Table 2 cation for explanation.

3.1 | Childhood and growth

Skeletal indicators of childhood health and growth consistently reveal social differences between groups. Linear enamel hypoplasia is inconclusive; it was very common in all samples from medieval Cambridge (with 62.2% of individuals displaying more than one lesion). However, cribra orbitalia is notably more common in Hospital males (56.4%) than in other males (33.3% townsmen, 26.7% friars), and in Hospital adults as a whole (55.4%). Vitamin D deficiency is also higher in people buried at the Hospital (7.4%, as opposed to 1.1% for townspeople and 0% among friars). The total number of cases is small, and virtually all from the later 14th–15th centuries.

In adult stature, Hospital females and males are both smaller than townspeople (by 2.8 and 2.6 cm, respectively) (Figure 3). Without genetic differences between these groups (Hui et al., 2024), this suggests that people granted charity in the Hospital as adults had previously experienced stressful childhoods. Conversely, the friars are taller than "town" males (by 1.7 cm).

The IPCE reflects these indicators and relative d13C and d15N ratios in dentine (as a proxy for childhood nutrition). It tells a clear

TABLE 6 Differences in health-related bioarchaeological data among adults in medieval Cambridge: childhood environment.

Observation		Townsfolk	Friars	Hospital	Prevalence in all individuals	Test, significance
Linear enamel hypoplasia (>1 lesion)	F	11/21 (52.4%)	n/a	17/24 (70.8%)	28/45 (62.2%)	$X^2 = 1.622$, 1 df, $p = 0.203$, $v = 0.190$
	M	10/21 (47.6%)	11/16 (68.8%)	25/37 (67.6%)	46/74 (62.2%)	$X^2 = 2.643$, 2 df, $p = 0.267$, $v = 0.189$
	All	21/42 (50%)	11/16 (68.8%)	42/61 (68.9%)	74/119 (62.2%)	$X^2 = 4.098$, 2 df, $p = 0.129$, $v = 0.186$
Cribra orbitalia	F	13/30 (43.3%)	n/a	14/26 (53.8%)	27/56 (48.2%)	$X^2 = 0.617$, 1 df, $p = 0.432$, $v = 0.105$
	M	7/21 (33.3%)	4/15 (26.7%)	22/39 (56.4%)	33/75 (44.0%)	$X^2 = 5.236$, 2 df, $p = 0.073$, $v = 0.264$
	All	20/51 (39.2%)	4/15 (26.7%)	36/65 (55.4%)	60/131 (45.8%)	$X^2 = 5.508$, 2 df, $p = 0.064$, $v = 0.205$
Vitamin D deficiency	F	0/44 (0)%)	n/a	4/53 (7.5%)	4/97 (4.1%)	$X^2 = 3.464$, 1 df, $p = 0.063$, $v = 0.189$
	M	1/44 (2.2%)	0/17 (0%)	6/83 (7.2%)	7/145 (4.8%)	$X^2 = 2.569$, 2 df, $p = 0.277$, $v = 0.133$
	All	1/89 (1.1%)	0/17 (0%)	10/136 (7.41%)	11/242 (4.5%)	$X^2 = 5.682$, 2 df, $p = 0.058$, $v = 153$
Adult stature	F	163.08 ± 4.84 (43)	n/a	1.60.24 ± 5.88 (49)	161.56 ± 5.57 (92)	ANOVA $F = 6.894$, 91 df, $p = 0.014$, $\epsilon = 0.065$
	M	171.71 ± 5.37 (39)	173.43 ± 4.95 (17)	169.15 ± 4.44 (63)	170.60 ± 5.09 (119)	ANOVA $F = 6.777$, 118 df, $p = 0.002$, $\epsilon = 0.105$
Index of Poor Childhood Environment	F	0.217 ± 0.19 (32)	n/a	0.308 ± 0.16 (26)	0.258 ± 0.18 (58)	Mann–Whitney, $U = 300.500$, $n = 58$, $p = 0.065$
	M	0.158 ± 0.159 (22)	0.144 ± 0.15 (17)	0.272 ± 0.18 (42)	0.214 ± 0.176 (81)	Kruskal–Wallis, $H = 10.177$, 2 df, $p = 0.006$
	All	0.193 ± 0.18 (54)	0.144 ± 0.15 (17)	0.281 ± 0.17 (69)	0.231 ± 0.18 (140)	Kruskal–Wallis, $H = 12.075$, 2 df, $p = 0.002$

Note: Text in purple: comparison between groups yields $p < 0.1$. Text in red: comparison between groups yields $p < 0.05$.

story: both males and females buried at the Hospital had distinctly higher IPCE values (0.272 and 0.308, respectively) than townsfolk (0.193 and 0.158) and friars (0.144, males only) (Figure 4). Thus, at least some of the people receiving charity at the Hospital seem to have suffered childhood deprivation and/or poor health to a greater degree than the rest of the sample.

3.2 | Infections and diseases

Infectious disease is less clear. Maxillary sinusitis is lower among townspeople (44.4%), and equally high among friars (73.3%) and Hospital residents (67.8%). Periosteal new bone formation was very common (above 75%) in all groups. Chronic respiratory infections were similarly common in all females, but, rather mysteriously, less common in Hospital males than in other males; it may be that they lived shorter lives and had less opportunity for low-level, chronic conditions to manifest skeletally. Skeletal tuberculosis was similarly prevalent in all groups, at 10%–15% of individuals. Since only a fraction of tuberculosis cases result in pathognomic skeletal lesions (Roberts & Buikstra, 2003), this ϵprevalence suggests that the disease was rife throughout medieval Cambridge. What differed, however, was its age distribution: Hospital people with tuberculosis tended to die in early adulthood, while sufferers at other sites died older (Table 10). Both Augustinian friars and All Saints parishioners had roundworm and whipworm parasites, although the prevalence in friars (58%) was higher than in townsfolk (32%) (Wang et al., 2022).

Overall, infectious disease was common among all groups in medieval Cambridge. Differing prevalences in various conditions probably reflected not social status and wealth per se but specific, local factors such as the microenvironments members of each group tended to spend time in. Similarly, each group's particular pattern of longevity affected how illness manifested skeletally in it.

3.3 | The hazards of life

Traumatic injury affecting bones was common in all groups, usually affecting between a third and a half of people in each group. No differences in cranial trauma were observed between groups, but

TABLE 7 Differences in health-related bioarchaeological data among adults in medieval Cambridge: palaeopathology.

Observation		Townsfolk	Friars	Hospital	Prevalence in all individuals	Test, significance
Maxillary sinusitis	F	7/18 (38.9%)	n/a	17/24 (70.8%)	24/42 (57.1%)	$X^2 = 4.286$, 1 df, $p = 0.038$, $v = 0.319$
	M	9/18 (50.0%)	11/15 (73.3%)	23.35 (65.7%)	43/68 (63.2%)	$X^2 = 2.107$, 2 df, $p = 0.349$, $v = 0.176$
	All	16/36 (44.4%)	11/15 (73.3%)	40/59 (67.8%)	67/110 (60.9%)	$X^2 = 6.247$, 2 df, $p = 0.044$, $v = 0.238$
Periosteal new bone formation	F	36/47 (76.6%)	n/a	51/61 (83.6%)	87/108 (80.6%)	$X^2 = 0.833$, 1 df, $p = 0.361$, $v = 0.088$
	M	37/48 (77.1)	15/17 (88.2%)	77/88 (87.5%)	129/153 (84.3%)	$X^2 = 2.771$, 2 df, $p = 0.250$, $v = 0.135$
	All	73/95 (76.8%)	15/17 (88.2%)	128/149 (85.9%)	216/261 (82.8%)	$X^2 = 3.722$, 2 df, $p = 0.155$, $v = 0.119$
Respiratory infection	F	7/18 (38.9%)	n/a	20/40 (50.0%)	27/58 (46.6%)	$X^2 = 0.616$, 1 df, $p = 0.433$, $v = 0.103$
	M	11/17 (64.7%)	6/8 (75.0%)	15/54 (29.6%)	33/79 (41.8%)	$X^2 = 10.581$, 2 df, $p = 0.005$, $v = 0.366$
	All	18/35 (51.4%)	6/8 (75.0%)	36/94 (38.3%)	60/137 (43.8%)	$X^2 = 5.147$, 2 df, $p = 0.076$, $v = 0.194$
Tuberculosis	F	6/39 (15.4%)	n/a	13/53 (24.5%)	19/92 (20.7%)	$X^2 = 1.146$, 2 df, $p = 0.284$, $v = 0.112$
	M	2/40 (5.0%)	2/17 (11.8%)	7/74 (9.5%)	11/120 (8.4%)	$X^2 = 0.969$, 2 df, $p = 0.619$, $v = 0.086$
	All	8/79 (10.1%)	2/17 (11.8%)	20/127 (15.7%)	30/223 (13.5%)	$X^2 = 1.367$, 2 df, $p = 0.505$, $v = 0.078$
Extraspinal osteoarthritis	F	26/47 (55.3%)	n/a	11/57 (19.3%)	37/104 (35.6%)	$X^2 = 14.583$, 1 df, $p = 0.000$, $v = 0.374$
	M	21/47 (44.7%)	11/18 (61.1%)	32/87 (36.8%)	64/152 (42.1%)	$X^2 = 3.807$, 2 df, $p = 0.149$, $v = 0.158$
	All	47/94 (50.0%)	11/18 (61.1%)	43/144 (29.9%)	101/256 (39.5%)	$X^2 = 13.458$, 2 df, $p = 0.001$, $v = 0.229$
DISH	F	1/33 (3.0%)	n/a	1/43 (2.3%)	2/74 (2.6%)	$X^2 = 0.036$, 1 df, $p = 0.849$, $v = 0.022$
	M	3/37 (8.1%)	2/18 (11.1%)	15/61 (24.6%)	20/116 (17.2%)	$X^2 = 4.946$, 2 df, $p = 0.084$, $v = 0.206$
	All	4/70 (5.7%)	2/18 (11.1%)	16/104 (15.4%)	22/192 (11.5%)	$X^2 = 3.859$, 2 df, $p = 0.145$, $v = 0.142$
Schmorl's nodes (mean number per individual)	F	2.48 ± 4.02 (31)	n/a	1.73 ± 2.17 (48)	2.03 ± 3.03 (79)	Mann–Whitney, $U = 0.721$, $p = 0.803$
	M	2.94 ± 4.41 (35)	4.35 ± 4.58 (17)	2.98 ± 3.99 (59)	3.18 ± 4.21 (111)	Kruskal–Wallis, $H = 2.111$, 2 df, $p = 0.348$
	All	2.62 ± 4.14 (69)	4.35 ± 4.58 (17)	2.43 ± 3.33 (111)	2.66 ± 3.76 (197)	Kruskal–Wallis, $H = 3.973$, 2 df, $p = 0.137$
Schmorl's nodes per individual (in categories)–females	None	20 (64.5%)	n/a	24 (50.0%)	44 (55.7%)	$X^2 = 7.480$, 2 df, $p = 0.024$, $v = 0.308$
	1–6	6 (19.4%)		22 (45.8%)	28 (35.4%)	
	7+	5 (16.1%)		2 (4.2%)	7 (8.9%)	
	total	31		48	79	
Schmorl's nodes per individual (in categories)–males	None	18 (51.4%)	5 (29.4%)	22 (37.3%)	45 (40.5%)	$X^2 = 4.388$, 4 df, $p = 0.356$, $v = 0.199$
	1–6	12 (34.3%)	7 (41.2%)	28 (47.5%)	47 (42.3%)	
	7+	5 (14.3%)	5 (29.4%)	9 (15.3%)	19 (17.1%)	
	total	35	17	59	111	
Schmorl's nodes per individual (in categories)–all	None	38 (57.6%)	5 (29.4%)	46 (43.0%)	89 (46.8%)	$X^2 = 11.076$, 4 df, $p = 0.026$, $v = 0.241$
	1–6	18 (27.3%)	7 (41.2%)	50 (46.7%)	75 (39.5%)	
	7+	10 (15.2%)	5 (29.4%)	11 (10.3%)	26 (13.7%)	
	total	66	17	107	190	

TABLE 7 (Continued)

Observation		Townsfolk	Friars	Hospital	Prevalence in all individuals	Test, significance
Hallux valgus	F	3/18 (16.7%)	n/a	2/20 (10%)	5/38 (13.2%)	$X^2 = 0.368$, 1 df, $p = 0.544$, $v = 0.088$
	M	5/26 (19.2%)	5/11 (45.5%)	11/34 (32.4%)	21/71 (29.6%)	$X^2 = 2.773$, 2 df, $p = 0.247$, $v = 0.198$
	All	8/44 (18.2%)	5/11 (45.5%)	13/54 (24.1%)	26/109 (23.9%)	$X^2 = 0.361$, 2 df, $p = 0.165$, $v = 0.182$
Trauma	F	19/48 (39.6%)	n/a	12/60 (20.0%)	31/108 (28.7%)	$X^2 = 4.997$, 1 df, $p = 0.025$, $v = 0.215$
	M	24/48 (50%)	6/17 (35.3%)	35/91 (38.5%)	65/156 (41.7%)	$X^2 = 2.040$, 2 df, $p = 0.361$, $v = 0.114$
	All	43/96 (44.8%)	6/17 (35.3%)	47/151 (31.1%)	96/264 (36.4%)	$X^2 = 4.745$, 2 df, $p = 0.093$, $v = 0.134$
Cranial trauma	F	2/36 (5.6%)	n/a	2/27 (7.4%)	4/63 (6.3%)	$X^2 = 0.089$, 1 df, $p = 0.765$, $v = 0.038$
	M	3/24 (12.5%)	1/13 (7.7%)	3/41 (7.3%)	7.78 (9.0%)	$X^2 = 0.529$, 2 df, $p = 0.768$, $v = 0.082$
	All	5/60 (8.3%)	1/13 (7.7%)	5/68 (7.4%)	11/141 (7.8%)	$X^2 = 0.043$, 2 df, $p = 0.979$, $v = 0.017$

Note: Text in purple: comparison between groups yields $p < 0.1$. Text in red: comparison between groups yields $p < 0.05$.

postcranial trauma was highest in "town" males, reflecting the risks of accidents in an active working life. It was lower in both Hospital males and females; this probably reflects both a younger age at death and a less active life due to unemployment and/or chronic illness (Dittmar, Mitchell, Cessford, et al., 2021b). Probably for similar reasons, extra-spinal osteoarthritis was also lowest in Hospital residents. Schmorl's nodes are often interpreted as caused by trauma, including both acute and repetitive stresses such as heavy loading of the vertebral column, although other factors may also be implicated (Fahey et al., 1998; Lai & Lovell, 1992; Pfirrmann & Resnick, 2001). They showed no clear differences between males in all three groups; the pattern among females was less clear but suggested that, although the average number of lesions per woman was similar, the distributions within the group may have differed (Figure 5). Schmorl's nodes were common among the friars, underlining the fact that many of them probably undertook manual labor, as was prescribed for Augustinians.

Hallux valgus was more prevalent in males (29.6%) than females (13.2%) generally. It was less common in people buried at All Saints than those buried at the Friary or the Hospital. This probably reflects the consequences of wearing the pointed footwear fashionable among men in the later 14th–15th centuries (see Dittmar, Mitchell, Cessford, et al., 2021a, Dittmar, Mitchell, Jones, et al., 2021 for detail and historical context). DISH, a metabolic condition related to both advanced age and rich diet, showed little group differences among females, but was surprisingly higher in Hospital males (24.6%, compared with 5.7% among townsmen and 11.1% among friars), perhaps due to the presence of some older males from university backgrounds buried there (Inskip et al., 2023).

3.4 | Eating as adults

Different social groups ate differently. In medieval Europe, food was a social diacritic; the prosperous ate differently than the poor, often doing so publicly as a mark of status (for instance, serving different foods at tables for people of different status within a hall). Ordinary people's basic diet relied upon bread, ale, and vegetables, supplemented by eggs, cheese, and small amounts of meat. The prosperous typically ate more meat, fish, and wine (Woolgar, 2010). Food consumption does not translate directly into differential health, of course; indeed, consuming richer foods can lead to health problems. However, as a way of performing status, which altered the body, food consumption was a medieval form of bodily inequality.

Although isotope values cannot be translated directly into dietary terms, they add information unavailable from the extremely scanty historical and archaeological records for medieval Cambridge. It is clear that different groups within medieval Cambridge enjoyed different diets (Figures 6 and 7) (Rose, 2020). The "town" group provides a baseline. In comparison, the Augustinian friars are notable for their higher C and N isotope values, probably reflecting higher consumption of meat and fish. The friars are also notable for their isotopic homogeneity, presumably the consequence of following an institutionally prescribed communal diet.

TABLE 8 Differences in health-related bioarchaeological data among adults in medieval Cambridge: isotopic data.

Observation		Townsfolk	Friars	Hospital	Prevalence in all individuals	Test, significance
δ^{13}C (rib)	F	−19.6 ± 0.27 (14)	n/a	−19.2 ± 0.38 (44)	−19.2 ± 0.39 (58)	ANOVA *F* = 9.573, 57 df, *p* = 0.003, = 0.146
	M	−19.1 ± 0.51 (30)	−18.4 ± 0.38 (17)	−18.9 ± 0.39 (64)	−18.9 ± 0.48 (111)	ANOVA *F* = 15.441, 110 df, *p* = 0.000, = 0.222
	All	−19.3 ± 0.47 (46)	−18.4 ± 0.38 (17)	−19.0 ± 0.40 (116)	−19.0 ± 0.47 (179)	ANOVA *F* = 25.605, 178 df, *p* = 0.000, = 0.225
δ^{15}N (rib)	F	12.4 ± 0.59 (14)	n/a	12.3 ± 1.02 (44)	12.3 ± 0.93 (58)	ANOVA *F* = 0.147, 57 df, *p* = 0.703, = 0.003
	M	12.8 ± 0.96 (30)	13.9 ± 0.50 (17)	12.6 ± 1.21 (64)	12.9 ± 1.15 (111)	ANOVA *F* = 10.100, 110 df, *p* = 0.000, = 0.158
	All	12.6 ± 0.88 (46)	13.9 ± 0.50 (17)	12.5 ± 1.13 (116)	12.6 ± 1.11 (179)	ANOVA *F* = 14.868, 178 df, *p* = 0.000, = 0.145

Note: Text in purple: comparison between groups yields *p* < 0.1. Text in red: comparison between groups yields *p* < 0.05.

TABLE 9 Differences in health-related bioarchaeological data among adults in medieval Cambridge: age at death.

Observation		Townsfolk	Friars	Hospital	Prevalence in all individuals	Test, significance
Age at death–female	18–25	2 (4.2%)	n/a	11 (20.4%)	13 (12.7%)	X^2 = 7.484, 2 df, *p* = 0.020, *v* = 0.277
	26–45	18 (37.5%)		23 (42.6%)	41 (40.2%)	
	46+	28 (58.3%)		20 (37.0%)	48 (47.1%)	
	total	48		54	102	
Age at death–male	18–25	5 (10.4%)	4 (22.2%)	16 (18.4%)	25 (16.7%)	X^2 = 3.237, 4 df, *p* = 0.519, *v* = 0.145
	26–45	24 (50.0%)	7 (38.9%)	32 (36.8%)	63 (41.2%)	
	46+	19 (39.6%)	7 (38.9%)	39 (44.8%)	65 (42.5%)	
	total	48	18	87	153	
Age at death–all	18–25	7 (7.3%)	4 (22.2%)	27 (19.1%)	38 (14.9%)	X^2 = 7.198, 4 df, *p* = 0.126, *v* = 0.168
	26–45	42 (43.8%)	7 (38.9%)	55 (39.0%)	104 (40.8%)	
	46+	47 (49.0%)	7 (38.9%)	59 (41.8%)	113 (44.3%)	
	total	96	18	141	255	

Note: Text in purple: comparison between groups yields *p* < 0.1. Text in red: comparison between groups yields *p* < 0.05.

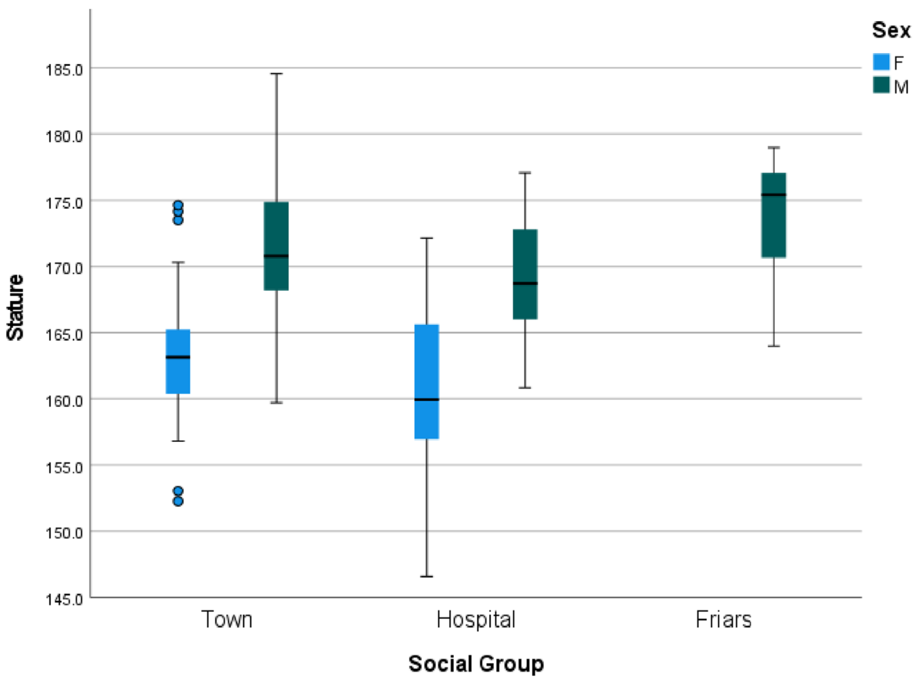

FIGURE 3 Stature in townspeople, Augustinian friars and residents of the Hospital of St. John.

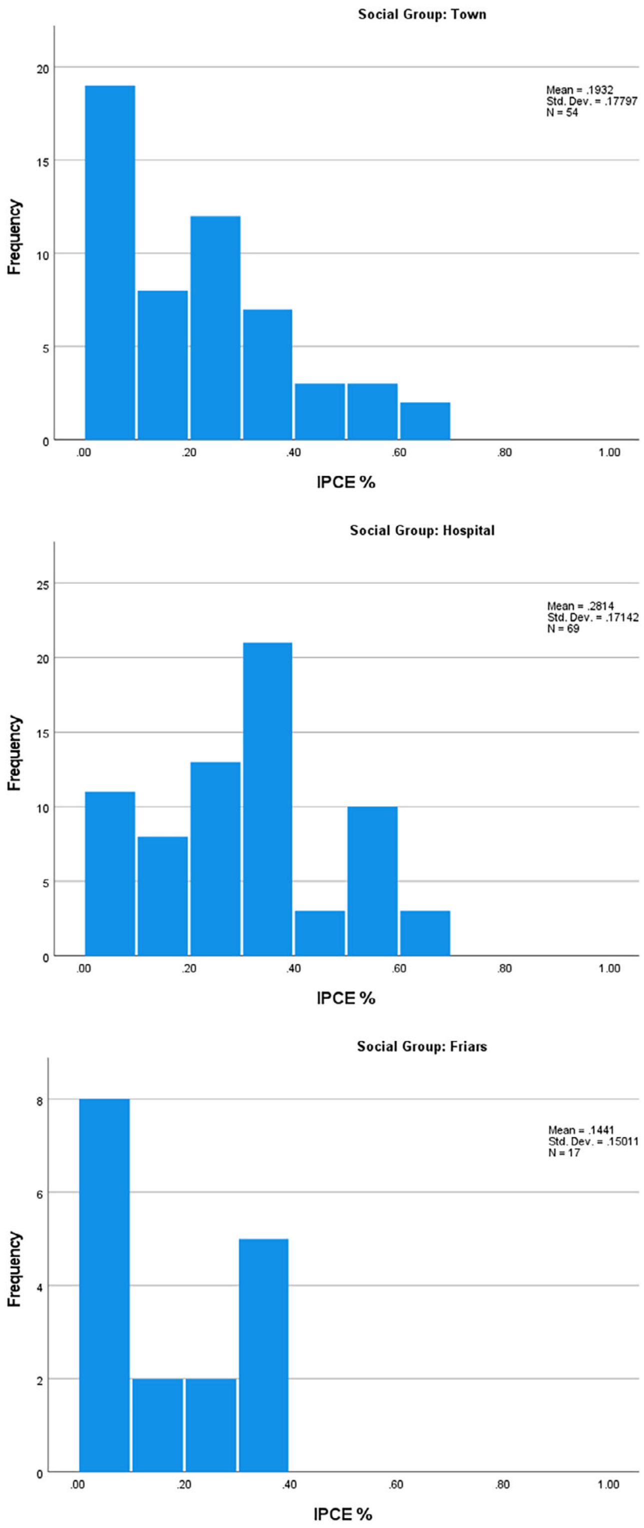

FIGURE 4 Histograms of Index of Poor Childhood Environment (IPCE) for townsfolk, residents of the Hospital and Augustinian friars.

TABLE 10 People with skeletal signs of tuberculosis tended to die younger at the hospital than at other sites ($X^2 = 4.76$, $p = 0.029$, $v = 0.41$).

Age at death	18–25	26+	Total
Hospital of St. John	6	8	14
Other sites	1	13	14
Total	7	20	28

The Hospital residents are remarkable in how much they varied isotopically (Rose, 2020). Some of them have the lowest values in the entire sample; others are among the highest. One reason is their highly varied social backgrounds (Inskip et al., 2023). Some were probably extremely poor throughout their lives, and may have subsisted on little more than bread; others may have been prosperous tradespeople or scholars until misfortune, age or infirmity overtook them. Moreover, once they were given shelter in the Hospital, they would have eaten a communal diet based on monastic models and often containing fish and meat (Rubin, 1987; Underwood, 2008). For many, it would have been markedly better than their previous diet, and their rib isotopic values may also reflect how long they resided in the hospital before dying.

3.5 | Getting old and dying

Finally, death. The sample of friars is too small to draw reliable demographic patterns from, but compared with townspeople, the Hospital contained more people dying as young adults (18–25) (Figure 8). This difference primarily consists of young adult females. The Hospital includes people chosen to exemplify need, including poverty (Inskip et al., 2023); but even if its managers were consciously profiling poor, chronically ill young women, this implies that such individuals were likely to die young and one effect of medieval urban poverty could be an earlier age at death.

4 | DISCUSSION: HEALTH INEQUALITY IN MEDIEVAL CAMBRIDGE

The people of medieval Cambridge shared many life risks. All groups had high rates of enamel hypoplasias, maxillary sinusitis, tuberculosis, and traumatic injuries. These must reflect shared conditions of life; the crowded, unsanitary town we know historically must have been awash with pathogens for rich and poor alike, the risk of injury was high, and all social classes shared similar environments. Given this, differences in some bioarchaeological indicators may reflect inequality indirectly or incidentally. Hospital residents had fewer fractures not because they had a privileged, safer life, but because some were probably inactive due to unemployment and/or chronic illness and many died younger. Similarly, townspeople may have had less maxillary sinusitis simply because their working lives may have involved spending less time indoors in poorly-ventilated environments than hospital inmates or friars did.

However, some fundamental health aspects of social inequality emerge, particularly if we integrate historical information and bioarchaeological findings (Figure 9). Taking townspeople as a baseline, males

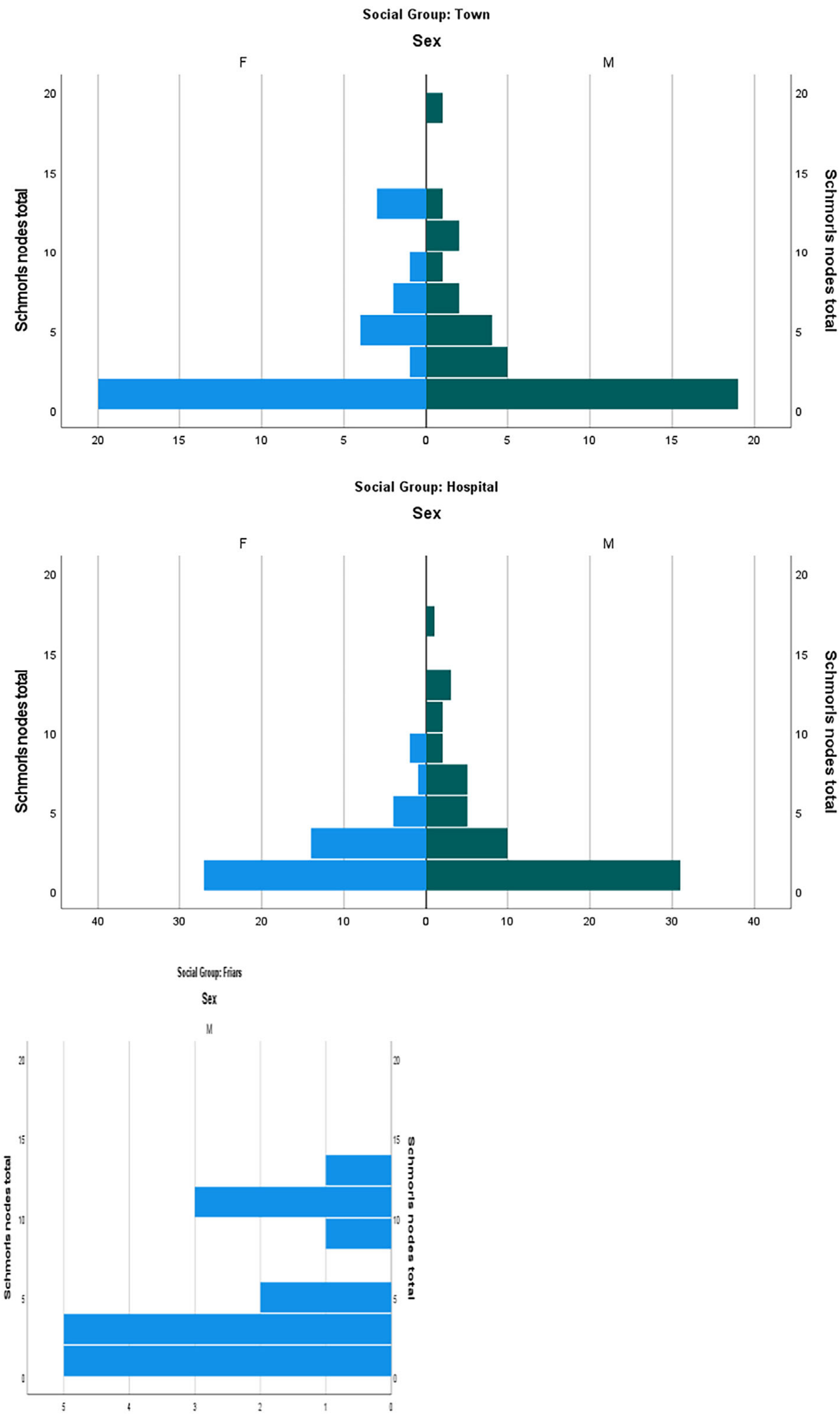

FIGURE 5 Schmorl's nodes in townsfolk, Hospital residents, and Augustinian friars.

and females were of medium stature and generally robust, and often quite long-lived if they survived childhood. Traumatic injuries were common, probably mostly from accidents. Their isotope values, distinctly lower than other groups, suggest a rather basic diet, but their stature and IPCE suggest that it was nutritionally adequate. The Augustinian friars represent an upper stratum of the social hierarchy in the town. Although individually "poor" (as they were not supposed to own personal possessions), most probably came from prosperous families, they belonged to a wealthy religious house and their needs were catered for abundantly. Although some may have been scholars, administrators, copyists, or priests, some of them did more substantial manual labor than wealthy people may generally have done;

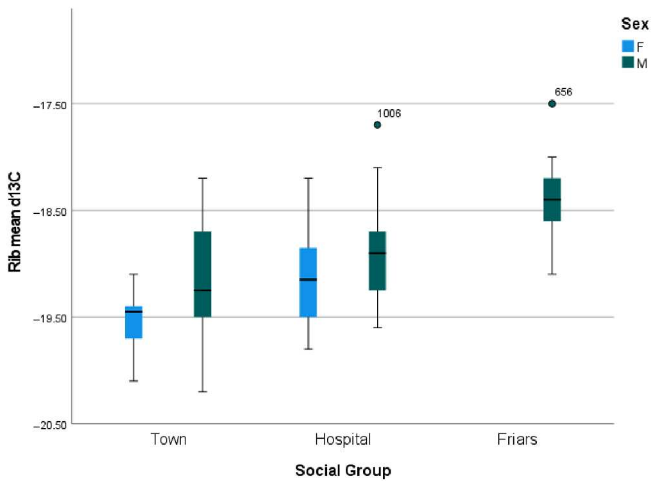

FIGURE 6 Comparing townsfolk, Hospital residents, and Augustinian friars: adult rib collagen δ^{13}C.

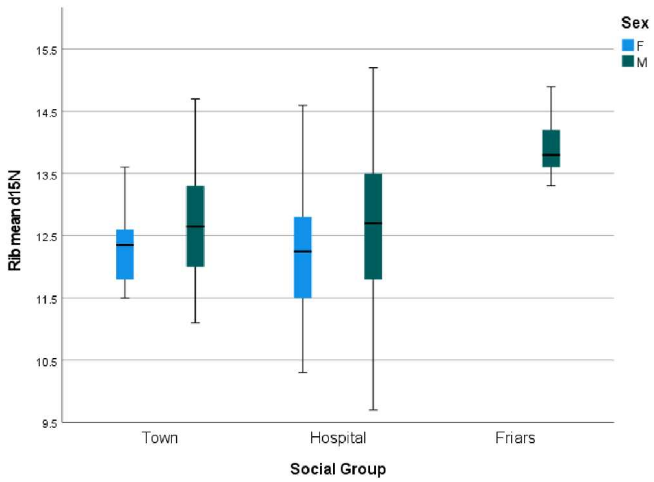

FIGURE 7 Comparing townsfolk, Hospital residents, and Augustinian friars: adult rib collagen δ^{15}N.

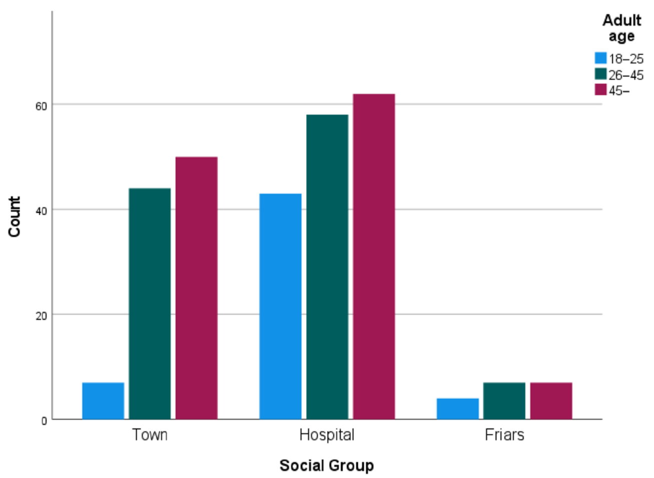

FIGURE 8 Adult age at death, townsfolk versus Hospital residents versus Augustinian friars.

mandated by the Augustinian Rule, this is corroborated by their robustly-built bones, Schmorl's nodes and traumatic injuries. Their economic status is reflected principally by isotope values, which show them enjoying a shared institutional diet higher in terrestrial and/or marine proteins than the townsfolk. They belonged to a prosperous religious order and ate meat regularly. Moreover, on their frequent fast days, they could eat fish (typically herring, cod, and other marine fish) rather than meat. It is also reflected in their stature; they were taller than townsmen. This may reflect selecting novices from more prosperous families. Alternatively, novices were typically admitted in their early teens (or even earlier after the Black Death epidemic of 1348–9), during which many would still be undergoing adolescent growth. The Friary diet probably contained more animal and marine protein than townspeople ate (see below), and switching boys to a richer institutional diet may have stimulated additional growth.

The Hospital of St. John provides a glimpse into Cambridge's underclass. As with workhouses, asylums, and hospitals generally, it was a socially-constructed group; according to its charter, everyone in it not only would have lacked other safety nets such as family support, but would have been selected to conform to specific medieval concepts of people who deserve charity (for instance, bed-ridden orphans, young women with chronic diseases, people encountering poverty in old age, and aging scholars) (Inskip et al., 2023). Its residents thus are a mixture mostly of the lifelong poor, ordinary people who lived much like other townspeople before encountering poverty at some point, and old or ill university scholars (Inskip et al., 2023). Strikingly, their isotopic data show great variation; the residents probably included some of the poorest people in Cambridge, former ordinary tradespeople, people retiring from university life, and people who had lived for years with the Hospital's well-funded institutional diet. Textual records shed no light on how the Hospital's policies for bestowing charity may have changed over time, but policy choices may be visible in skeletal samples; for example, increasing cases of vitamin D deficiency may reflect a shift in Hospital policy toward taking in seriously-ill children and young adults, perhaps orphans (see Inskip et al., 2023). The Hospital's residents make two points about medieval health inequality. First, some let us glimpse how the sharp end of medieval poverty could affect individuals. Second, such people are numerous enough in the sample that they skew the hospital's overall bioarchaeological statistics. Most obviously, Hospital residents had had poorer childhood environments and achieved a lower adult stature than town males and females. Hospital inmates were more likely to die in early adulthood, (including those who died young from tuberculosis rather than surviving it for longer), and they had fewer age-related diseases and injuries.

This raises the question of how health related to poverty in medieval towns. It was a two-way relationship. On one hand, poverty could clearly lead to poor nutrition, reduced growth, and earlier death. Probably everyone in medieval Cambridge was exposed to much the same pathogens and stresses, but people biologically compromised by chronic need may have succumbed to them more often and earlier. This implicates the "structural poverty" (Dyer, 2009) of the lifelong, perhaps intergenerationally impoverished. Conversely, however, ill

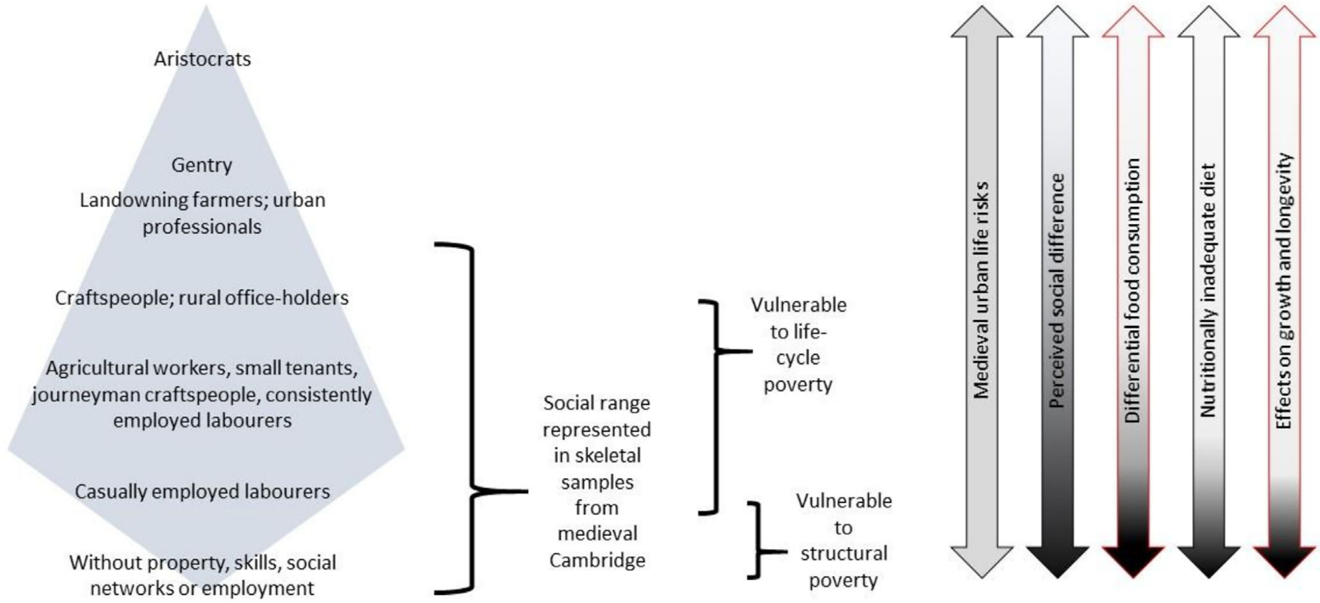

FIGURE 9 Potential dimensions of health inequality in medieval England. Dimensions of inequality evidenced in this study are outlined in red.

health could also cause poverty. For most people without money, property, or other social capital, economic survival would have been based on being able to work, supplemented by the vital safety net of the family. If the family network failed and age or illness prevented one from working, "life cycle" poverty often resulted, especially among people who were economically borderline. Cambridge's medieval hospital sheltered both kinds of the poor.

5 | CONCLUSIONS: HEALTH INEQUALITY AND SOCIAL INEQUALITY IN ANCIENT TIMES

The results of this research confirm the hypothesis that inequality affected health in medieval England. At the same time, they reveal how the relationship can be complex and mediated by both archaeological and social factors. Archaeologically, different kinds of people are often buried in different places; any skeletal sample usually includes only a segment of the social spectrum. Even when we combine multiple samples to contrast different social groups, they may not represent the true proportions of each group in society. To accurately depict the health of a community, a "whole town" approach is needed: contextualizing each site socially, constructing a representative series of samples and using statistical weighting to create a balanced picture of the totality. Socially, while it is easy to designate groups as "well-off" or "poor", both groups may be heterogeneous. Moreover, "inequality" may affect health via multiple, distinct biological pathways, which may have different thresholds and sensitivities (Figure 9). Many episodic causes can trigger an enamel hypoplasia; long-term ill-health or malnutrition may be needed to reduce final adult stature. Moreover, some bioarchaeological signals may be fundamental to inequality (for instance, signs of inadequate nutrition, and shortened lifespan); others may be incidental (for instance, increased diseases of age or occupational hazards of higher-status jobs in the affluent). In medieval England, many people would have been socially recognized as the working poor in terms of their employment and consumption patterns, but there could be significant variation within this group. For many such people, poverty may have meant performing hard, lowly-paid labor and eating a nutritionally adequate but unvaryingly monotonous diet low in foods associated with status such as meat and fish. In terms of the bioarchaeological signals available to us, this would be apparent principally in their relative isotopic values, without impacting upon their growth, health or survival. Others may have led still more marginal lives, possessing few resources and being highly vulnerable to changing circumstances, but may still not have encountered nutritional shortfalls or health crises regularly. A small subset of the poor appear to have experienced serious, long-term hardship, with reduced growth, increased frailty and an earlier age at death.

To generalize this lesson, this implies that health inequality is an important historical phenomenon, but we should not expect to find a single template or pattern for health inequality. Rather, in each historical setting, health inequality may take a different form. Some of the key variables may include to what extent people in different strata have access to nutritionally adequate foods; whether social rank can insulate privileged groups from vectors of infection; how extensive labor specialization and exploitation is; and how much a subordinated group is controlled through direct control and violence rather than simply suffering from poverty. For example, medieval Cambridge may be typical of many pre-modern inegalitarian societies in which activity risks and exposure to infectious diseases reflect widely shared conditions of life more than inequality per se. Instead, the principal axes of health inequality seemed to be poor childhood conditions, growth and shortened lifespan in the segment of the population most affected by structural poverty, and differential food consumption, a well-known dimension of medieval social distinction. Different patterns of health inequality might perhaps be expected in prehistoric groups in which access to food was less differentiated but violence provided a more direct form of social control, in industrial groups in which heavy work, severe poverty and inadequate diet afflicted the poor, in enslaved groups controlled by the threat of direct violence, and in marginalized groups subject to institutional regimes.

AUTHOR CONTRIBUTIONS

Jenna M. Dittmar: Conceptualization (equal); investigation (equal); methodology (equal); writing – original draft (equal). **Sarah A. Inskip:** Conceptualization (equal); investigation (equal); methodology (equal); writing – original draft (equal). **Alice K. Rose:** Conceptualization (equal); investigation (equal); methodology (equal); writing – review and editing (equal). **Craig Cessford:** Investigation (equal); methodology (equal); writing – review and editing (equal). **Piers D. Mitchell:** Investigation (equal); methodology (equal); writing – review and editing (equal). **Tamsin C. O'Connell:** Investigation (equal); methodology (equal); writing – review and editing (equal). **John E. Robb:** Conceptualization (equal); data curation (equal); formal analysis (equal); funding acquisition (equal); investigation (equal); methodology (equal); project administration (equal); visualization (equal); writing – original draft (equal).

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DATA AVAILABILITY STATEMENT

Isotopic data used in this work are available in Rose (2020), https://doi.org/10.17863/CAM.72221. Skeletal data are in preparation to be made fully available in association with monographic publication of the “After the Plague” project, and will be made available on the University of Cambridge's “Apollo” data repository and via the McDonald Institute for Archaeological Research website.

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