**[Supplementary information]**

**Pathways to the medieval hospital: collective osteobiographies of poverty and charity**

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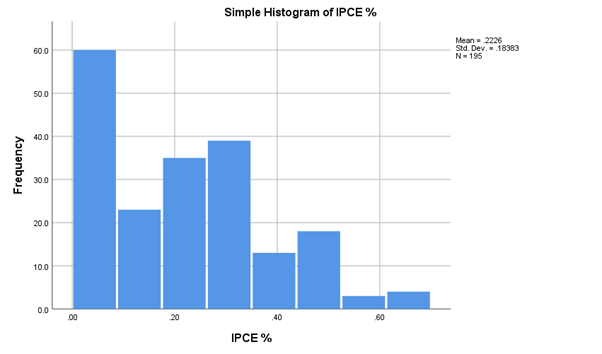
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**Methods and standards**

The following data were collected:

* Age and sex, adults (Phenice 1969; İşcan *et al.* 1984, 1985; Brooks & Suchey 1990; Buikstra & Ubelaker 1994; Buckberry & Chamberlain 2002; Brickley & McKinley 2004; Falys & Prangle 2015).
* Age and sex, non-adults (Ubelaker 1989; Scheuer & Black 2000).
* Burial treatment: from Cambridge Archaeological Unit archive records (compiled by C. Cessford, excavation director).
* Palaeopathology, including enamel hypoplasia, cribra orbitalia, infectious diseases, traumas, and other conditions (Brickley & McKinley 2004; Mitchell & Brickley 2017).
* Entheseal changes (Mariotti *et al.* 2004, 2007).
* Schmorl’s nodes and activity-related skeletal changes (Quarry-Wood 1920; Barnett 1954; Finnegan 1978; Ubelaker 1979; Brothwell 1981; Molleson 1989; Capasso *et al.* 1999; Boulle 2001; Inskip 2013).
* Index of Poor Childhood Experience (IPCE). A new index, this is designed to provide a proxy for conditions of childhood growth. Many skeletons in a sample may display one or another marker potentially reflecting childhood stresses, and since each indicator responds to varied conditions, the presence of a single indicator may not have significant implications for interpretation, but an individual displaying most, or all, indicators probably grew up in challenging conditions. The index was compiled by observing six indicators (see below) and dividing the number observed by the number of these traits which were observable. To avoid statistical anomalies, it was used only for individuals for whom three or more of these indicators were observable. In the overall database from multiple sites in medieval Cambridge, the IPCE proved to be trimodal (Figure S1), and these modes were used as a categorical classification (slight, moderate, severe). The indicators include:
  + presence of more than one hypoplastic lesion in the dentition
  + presence of cribra orbitalia
  + adult stature falling below sex-specific 20th percentile of adults from medieval Cambridge
  + dentine C isotope values falling below 20th percentile of adults from medieval Cambridge
  + dentine N isotope values falling below 20th percentile of adults from medieval Cambridge
  + Skeletal evidence of vitamin D deficiency
* long bone lengths and estimated stature (Trotter 1970: formula for “white” individuals)
* humerus functional anatomy: bones were CT-scanned with 720 projections and a resolution of 125µm. After scanning and reconstruction, bone models were digitally reoriented in anatomical position following Ruff (2002) and exported as a stack of images. The image at 50% of the stack thus represents a transverse cross-section through the midshaft of the diaphysis. This image was used to quantify bone geometry. Diaphyseal cross-sections imported into ImageJ and the structural properties of the generated binary images were analysed using the BoneJ plugin (v. 1.4.3) for ImageJ (v. 1.51h) (Doube *et al.* 2010). The sum of Imin and Imax is the polar second moment of area (J), an indicator of torsional rigidity. Cortical properties were standardised for estimated body mass and/or bone length, following recommendations of Ruff (2008; Ruff *et al.* 2012). Asymmetry in J was calculated as . Individuals with a left-biased asymmetry greater than 5% were considered left-handed and excluded from further consideration.
* Isotope analysis: all material was sampled following destructive sampling guidelines and requirements (e.g. Mays *et al.* 2013). Samples for C and N isotope analysis were prepared and analysed using IRMS following Cambridge McDonald Institute for Archaeological Research protocols; collagen extraction methods were based on Longin 1971, Collins and Galley 1998, and Richards and Hedges 1999; data quality indicators from DeNiro 1985 and Ambrose 1990. Samples were prepared for Sr isotope analysis using methods based on Nafplioti 2008, 2009; strontium isolation via column chemistry, ICP-OES and TIMS analysis all followed Cambridge Isotope Geochemistry Laboratory protocols.
* Ancient DNA: samples were processed in the clean room of the dedicated ancient DNA laboratory of the Institute of Genomics, University of Tartu, Estonia, following established protocols as detailed most recently in Saupe *et al.* 2021. DNA was sequenced using the Illumina NextSeq500/550 High-Output single-end 75 cycle kit. Both the low-coverage sequencing data and genotypes imputed with the help of modern reference panels have been used to explore genetic ancestry, relatedness and phenotype/disease risk variation.



*Figure S1. The Index of Poor Childhood Environment (data for the overall Cambridge sample, including adults from multiple medieval sites).*

**Data analysis strategy**

This project presented a complex data analysis task. It involved understanding the variability within a skeletal sample. In some ways it is a classification problem, but one in which both the existence of groups and individuals’ affiliation to them are not defined in advance using external evidence such as burial location or historic documentation, but must be discovered through data exploration. Moreover, patterns of data defining categories may be based on different observations for each category, groups may be fuzzily bounded rather than sharply defined, and once they are defined, they may be too small to use formal inferential statistics to define their characteristics. We also dealt with the problem of missing data, both from skeletal fragmentation and because not all data were collected for all skeletons (for instance, Sr isotopic data were collected for about a quarter of the sample), which means that, even with large numbers of well-preserved skeletons, only 10–20% will work for formal multivariate classification such as cluster analysis. There is no single statistical method to address the task; instead, it involved a heuristic process of data analysis using multiple techniques.

Data analysis proceeded in iterative stages. The first stage used standard exploration of variability through descriptive statistics and graphs, combined with inferential statistics comparing people of different ages and sexes and from different sites in medieval Cambridge. The key conclusions drawn from this were that (i) people buried at the Hospital of St. John the Evangelist differed from townspeople in several important respects, but that (ii) they also encompassed a much greater range of variability; (iii) it was also clear that for many bioarchaeological variables, all groups within medieval Cambridge overlapped substantially, reflecting their shared environment in a medieval town. The latter suggested that sub-groups within the hospital were likely to be distinguished by one or a few variables rather than by across-the-board variation in most or all data. We also did extensive data screening to check the possibility of historical change within the 300-year period under examination here and to ensure this was not biasing patterns detected.

We then tried looking for meaningful sub-groupings within the Hospital population in several ways. One was to systematically look for correlations among bioarchaeological variables (e.g. did individuals with feature X also tend to have feature Y). This generally did not provide a useful tool for systematically grouping individual cases, mostly because correlation seeks relationships across the entire dataset rather than within sub-groups or branches of a classification tree. But it served to help understand the structure of the data (for instance, which pathologies tended to be associated with an early age at death and were proportionally more common in the hospital, and which were associated with survival to old age and were more prevalent at other sites). It also provided an idea of what the core of some groupings (such as the ‘young, poor and ill’ group) might be as they showed recurrent associations between several variables on scatterplots. A second, complementary approach was simply to examine the outstanding cases of each variable and ask if they shared other features in common. This began by simply asking all specialists working with each form of data to identify ‘Persons of Interest’ based on their data who might provide subjects for osteobiographies. We then collected, as far as possible, all the other data available for the same individuals. For some forms of data, screening for variability in a single variable is in fact a standard method; for instance, using strontium isotope data to identify people with non-local origins is based upon screening for individuals with values in specific ranges. For other forms of data, however, we did not assume that such cases necessarily represented important groupings or identities. Instead, we examined them to see if cases with unusual values for one variable were also noteworthy for others.

As the project progressed, we did this more systematically. This was done most easily using visual pattern-spotting. The most straightforward method was to first colour-code cells in the master data spreadsheet according to variation in the value of each bioarchaeological variable using Excel’s conditional formatting option. One can then sort the datasheet from lowest to highest values of one variable and see if blocks of colour emerge in columns representing other variables. In many cases, such attempts led to dead ends; for example, people with *os acromiale*, Vitamin D deficiency or Schmorl’s nodes did not generally share more features than they shared with other people. However, in some cases, such as asymmetry of the humerus’ architecture in males, it turned out to be very useful.

Having gained a sense of covariation within the data, we then tried defining groups based upon specific combinations of variables, such as the difference between dentine and rib nitrogen isotope values or asymmetry in humerus J. Given the inherent variability in biological data, using such cut-off points does not guarantee that all individuals so identified will necessarily form a coherent group and that others not so identified would not also belong to the group, but it provides a systematic and reproducible way of selecting a subset of individuals for analysis. We then examined the resulting subsets to see what characterised their skeleton and molecular lives.

A final phase was multivariate analysis, especially cluster analysis. A variety of cluster analyses were run, using between five and ten variables reflecting the range of bioarchaeological dimensions explored. Classification using cluster analysis with a range of input variables and algorithms was inevitably limited by missing data, as mentioned above, limiting its use as a method for classifying most burials rather than simply exploring the nature of variability in the sample. However, it nevertheless showed groupings which emerged repeatedly, validating our exploratory sense of how the data vary. A typical result was that the probable scholars grouped together, as did the ‘young, poor and ill’ individuals; there are ‘aged poor’ individuals at both the Hospital and the parish church, and the remainder of the Hospital burials tended to mix with the friars and the townspeople. It also showed the degree to which groups such as the townspeople, friars and ‘other hospital residents’ overlap, making the point that people in different social positions often shared aspects of their biosocial environments.

**Bioarchaeological data on burials at the Hospital of St. John, Cambridge**

The purpose of this data is to provide a baseline for interpreting individual cases.

**Table S1. Summary bioarchaeological data on adults buried at the Hospital of St. John the Evangelist. Comparative data for townspeople come from adults from multiple sites combined (All Saints by The Castle, Augustinian Friary laypeople, Benet Street); comparative data for friars are adult males identified archaeologically as friars from the Augustian Friary, Cambridge.**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **F** | **M** | **All Adults** | **Townspeople** | **Friars** |
| Total n | 62 | 92 | 337 | 121 | 18 |
| >1 hypoplasia (%) | 70.8 | 67.6 | 68.3 | 50.0 | 68.8 |
| Cribra orbitalia (%) | 53.8 | 56.4 | 54.4 | 39.2 | 26.7 |
| Vitamin D deficiency (%) | 7.5 | 7.2 | 6.2 | 1.1 | 0 |
| Mean stature (cm), females  Mean stature (cm), males |  |  | 160.3  169.5 | 163.1  171.7 | 173.5 |
| Index of Poor Childhood Environment (mean) | 0.308 | 0.272 | 0.281 | 0.19 | 0.14 |
| Schmorl's nodes (mean number per individual for affected individuals) | 1.73 | 2.98 | 2.43 | 2.62 | 4.35 |
| Osteoarthritis (%) | 19.3 | 36.8 | 28.3 | 50.0 | 61.1 |
| Trauma (presence, %) | 20.0 | 38.5 | 27.7 | 44.8 | 35.3 |
| Cranial trauma (%) | 7.4 | 7.3 | 7.2 | 8.3 | 7.7 |
| Maxillary sinusitis (%) | 70.8 | 65.7 | 66.7 | 44.0 | 73.0 |
| Tuberculosis (%) | 24.5 | 9.5 | 15.7 | 10.1 | 11.8 |
| Diffuse idiopathic skeletal hyperostosis (DISH) (%) | 2.3 | 24.6 | 14.7 | 5.7 | 11.1 |
| Hallux valgus (%) | 10.0 | 32.4 | 19.7 | 18.2 | 45.5 |
| Age at death: 18–25 (%) | 20.4 | 18.4 | 26.4 | 7.3 | 22.2 |
| Age at death: 26–45 (%) | 42.6 | 36.8 | 35.6 | 43.8 | 38.9 |
| Age at death: 45+ (%) | 37.0 | 44.8 | 38.0 | 49.0 | 38.9 |

**Statistical information relevant to the ‘young, poor and wretched’ group**

**Table S2. Summary of IPCE statistic showing that more people buried at the Hospital of St. John the Evangelist have higher values than individuals buried at other sites around Cambridge.**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | | | Hospital | Other sites | Total |
| IPCE | low | Count | 92 | 113 | 205 |
| % | 44.9% | 55.1% | 100.0% |
| medium | Count | 45 | 39 | 84 |
| % | 53.6% | 46.4% | 100.0% |
| severe | Count | 39 | 24 | 63 |
| % | 61.9% | 38.1% | 100.0% |
| Total | | Count | 176 | 176 | 352 |
| % | 50.0% | 50.0% | 100.0% |

**Table S3. Summary of adult age at death statistics showing that proportionally more individuals buried at the Hospital of St. John the Evangelist died as young adults compared to other sites around Cambridge.**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | | Adult age | | | Total |
| 18–25 | 26–45 | 45+ |
| Hospital | Count | 43 | 58 | 62 | 163 |
| % | 26.4% | 35.6% | 38.0% | 100.0% |
| Other sites | Count | 9 | 49 | 62 | 120 |
| % | 7.5% | 40.8% | 51.7% | 100.0% |
| Total | Count | 52 | 107 | 124 | 283 |
| % | 18.4% | 37.8% | 43.8% | 100.0% |

**Table S4. Summary data showing that individuals with a higher IPCE tended to die at a younger age than individuals with a lower IPCE.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | | | Adult age | | | Total |
| 18–25 | 26–45 | 45- |
| IPCE | low | Count | 24 | 72 | 95 | 191 |
| % | 12.6% | 37.7% | 49.7% | 100.0% |
| medium | Count | 15 | 48 | 44 | 107 |
| % | 14.0% | 44.9% | 41.1% | 100.0% |
| severe | Count | 15 | 34 | 22 | 71 |
| % | 21.1% | 47.9% | 31.0% | 100.0% |
| Total | | Count | 54 | 154 | 161 | 369 |
| % | 14.6% | 41.7% | 43.6% | 100.0% |

**Table S5. Number of individuals with skeletal markers of tuberculosis within adult age categories. Affected individuals at the Hospital of St. John the Evangelist tended to die at a younger age than at other sites around Cambridge.**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Age at death | 18–25 | 26–35 | 36–45 | 45+ | Total |
| Hospital of St. John | 6 | 3 | 0 | 5 | 14 |
| Other sites | 1 | 4 | 2 | 7 | 14 |
| Total | 7 | 7 | 2 | 12 | 28 |

**Table S6. Some individuals buried at St. John’s Hospital who cluster together in multivariate analyses as ‘young, poor and ill’.**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Individual Number | Sex | Age | Dentine  δ13C | Dentine  δ15N | Stature | Vit. D deficiency | Cribra orbitalia | Maximum hypoplasia per tooth | IPCE | TB | Rib δ13C | Rib δ15N |
| 30 | F | 18–25 | -18.7 | 12.3 | 156.1 | 1 | 0 | 3 | 0.50 | yes | -18.6 | 11.7 |
| 62 | F | 26–45 | -19.3 | 10.8 | 166.0 | 0 | 0 | 2 | 0.17 | yes | -19.8 | 10.8 |
| 88 | F | 18–25 | -19.2 | 11.6 | 157.8 | 0 | 1 | 4 | 0.33 | yes | -19.2 | 12.7 |
| 90 | F | 18–25 | -19.4 | 11.0 | 150.2 | 0 | 1 | 5 | 0.50 | yes | -19.3 | 12.0 |
| 94 | F | 18–25 | -18.1 | 13.8 | 156.3 | 0 | 1 | 2 | 0.33 | no | -18.7 | 13.5 |
| 291 | F | 18–25 |  |  | 156.0 | 0 |  |  |  | no | -18.7 | 12.2 |
| 337 | F | 18–25 |  |  | 158.7 | 0 |  |  |  | no | -19.0 | 11.5 |
| 339 | F | 26–45 | -20.2 | 12.0 | 163.8 | 0 | 1 | 0 | 0.33 | yes | -19.7 | 11.6 |
| 342 | F | 18–25 |  |  | 168.8 | 0 |  |  |  | yes | -19.1 | 11.4 |
| 31 | M | 18–25 | -19.5 | 9.9 | 166.8 | 0 | 1 | 2 | 0.33 | no | -19.5 | 9.8 |
| 128 | M | 18–25 | -18.7 | 12.8 | 176.1 | 0 | 1 | 2 | 0.17 | no | -18.3 | 12.5 |
| 239 | M | 18–25 |  |  | 162.7 | 0 | 0 | 3 | 0.50 | yes | -19.3 | 11.9 |
| 338 | M | 18–25 | -18.6 | 13.2 |  |  | 1 | 3 | 0.50 | no | -18.7 | 13.3 |

**Statistical information relevant to the ‘lifelong poor’ group**

**Table S7. Summary data showing that the Hospital of St. John the Evangelist contained more individuals with a severe IPCE than other sites in all adult age categories.**

|  |  |  |
| --- | --- | --- |
| Age at death | Hospital | Other town sites |
| 18-25 | 9/31 (29.0%) | 1/9 (11.1%) |
| 25-45 | 13/56 (23.2%) | 6/49 (12.2%) |
| 45+ | 14/59 (22.7%) | 5/61 (8.2%) |

**Table S8. Summary data for individuals defined by a severe Index of Poor Childhood Environment, very low adult stature and an age at death >35.**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Individual number** | 40 | 41 | 47 | 48 | 50 | 54 | 57 | 71 | 91 | 151 | 170 | 215 | 217 | 225 | 254 | 269 | 314 | 331 | 365 | 711 | 718 | 727 | 739 |
| **Site** | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | All Saints | All Saints | All Saints | All Saints |
| **earliest possible date** | 1358 | 1428 | 1348 | 1350 | 1310 | 1280 | 1350 | 1300 | 1370 | 1220 | 1204 | 1204 | 1204 | 1204 | 1220 | 1300 | 1280 | 1204 | 1288 | 1050 | 940 | 940 | 940 |
| **Latest possible date** | 1455 | 1471 | 1439 | 1490 | 1450 | 1400 | 1490 | 1380 | 1430 | 1330 | 1350 | 1400 | 1380 | 1380 | 1350 | 1470 | 1330 | 1310 | 1383 | 1250 | 1365 | 1365 | 1250 |
| **Sex** | F | M | F | F | F | M | M | F | F | F | F | F | F | M | F | F | F | F | F | M | F | F | F |
| **Age** | 60+ | 60+ | 46–59 | 60+ | 60+ | 46–59 | 46–59 | 36–45 | 46–59 | 36–45 | 60+ | 46–59 | 36–45 | 60+ | 46–59 | 46–59 | 36–45 | 46–59 | 46–59 | 46–59 | 46–59 | 46–59 | 46–59 |
| **Dentine δ13C** |  | -19.9 |  |  |  | -19.9 |  | -19.7 | -19.5 | -20.0 |  |  |  | -19.7 |  |  | -19.6 |  |  | -19.3 | -19.8 | -19.8 |  |
| **Dentine δ15N** |  | 11.8 |  |  |  | 10.4 |  | 12.7 | 10.7 | 12.8 |  |  |  | 12.6 |  |  | 11.9 |  |  | 10.3 | 11.6 | 10.3 |  |
| **Stature** | 159.435 | 176.84 | 150.79 | 159.929 | 158.2 | 166.854 | 173.032 | 167.339 |  | 159.2452 | 160.2995 | 155.548 | 148.32 | 166.13 | 159.682 | 146.591 | 158.8175 | 150.79 | 157.212 | 164.821 | 159.929 | 163.14 | 170.303 |
| **Vitamin D deficiency** | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Criba orbitalia** |  | 0 |  |  |  | 1 | 1 | 1 | 1 | 0 |  |  |  | 1 |  |  | 1 | 0 |  | 1 |  | 0 | 1 |
| **>1 Hypoplasia** |  |  |  |  |  | 1 |  | 1 | 1 | 1 |  |  |  | 1 |  |  | 1 | 1 |  | 1 | 1 |  | 1 |
| **Max. hypoplasia per tooth** |  |  |  |  |  | 1 |  | 4 | 2 | 3 |  |  |  | 5 |  |  | 1 | 3 |  | 3 | 3 |  | 6 |
| **IPCE** |  | 0.40 |  |  |  | 0.50 | 0.67 | 0.50 | 0.40 | 0.33 |  |  |  | 0.67 |  |  | 0.33 | 0.50 |  | 0.67 | 0.40 | 0.40 | 0.50 |
| **Schmorl’s nodes (presence)** | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 |
| **Schmorl’s nodes (count)** | 2 | 7 | 3 |  | 2 | 0 | 11 | 3 | 0 | 0 | 5 | 0 |  | 1 | 3 | 0 | 0 | 3 | 0 | 0 |  | 7 | 0 |
| **Tuberculosis** | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Extraspinal osteoarthritis** | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| **Gout** | 0 | 0 | 0 |  |  |  |  | 0 | 0 | 0 | 0 |  |  | 0 | 0 |  |  | 0 |  | 0 | 0 | 0 | 0 |
| **DISH** | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 0 |  | 0 | 0 | 0 |  | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Trauma** | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| **Rib** **δ13C** | -18.7 | -19.3 | -19.0 | -18.8 | -19.8 | -19.4 | -18.9 | -19.3 |  | -19.8 | -19.1 | -19.5 | -19.0 | -19.2 | -19.3 | -18.7 | -19.5 | -19.7 | -19.5 | -19.3 | -19.4 | -19.4 |  |
| **Rib δ15N** | 13.8 | 12.6 | 12.0 | 14.6 | 11.5 | 11.6 | 13.6 | 13.5 |  | 12.3 | 12.6 | 12.0 | 14.0 | 13.5 | 11.0 | 11.5 | 12.6 | 10.3 | 10.6 | 12.2 | 11.8 | 12.1 |  |
| **C change** |  | 0.6 |  |  |  | 0.5 |  | 0.4 |  | 0.2 |  |  |  | 0.5 |  |  | 0.1 |  |  | 0.0 | 0.4 | 0.4 |  |
| **N change** |  | 0.8 |  |  |  | 1.2 |  | 0.8 |  | -0.5 |  |  |  | 0.9 |  |  | 0.7 |  |  | 1.9 | 0.2 | 1.8 |  |

**Statistical information relevant to the ‘shame-faced poor’ group**

**Table S9. Summary data for individuals, from all sites, whose δ15N isotope values dropped more than 0.5‰ between childhood (dentine sample) and the last decade of life (rib sample).**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Individual number** | 29 | 60 | 92 | 139 | 231 | 353 | 357 |
| **Site** | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital |
| **Start date** | 1350 | 1340 | 1375 | 1211 | 1240 | 1250 | 1270 |
| **End date** | 1511 | 1380 | 1427 | 1253 | 1350 | 1400 | 1490 |
| **Age** | 36–45 | 36–45 | 60+ | 36–45 | 46–59 | 60+ | 46–59 |
| **Dentine δ13C** | -18.3 | -18.3 | -18.8 | -19.7 | -18.8 | -19.8 | -20.0 |
| **Dentine δ15N** | 13.4 | 14.2 | 12.8 | 12.9 | 15.4 | 14.8 | 11.9 |
| **Stature** | 155.977 | 166.13 | 166.328 |  |  | 169.343 | 165.61 |
| **Vitamin D deficiency** | 0 | 0 | 0 |  | 0 | 0 | 1 |
| **Cribra orbitalia** | 0 | 1 | 1 | 1 | 0 | 1 | 1 |
| **Hypoplasia (presence)** | 1 | 1 |  | 0 | 0 | 1 | 1 |
| **Hypoplasia (Max.** **defects per tooth)** | 3 | 4 |  | 1 | 1 | 1 | 2 |
| **IPCE** | 0.33 | 0.50 | 0.20 | 0.50 | 0.00 | 0.33 | 0.50 |
| **Schmorl’s nodes** | 6 | 0 | 2 | 0 |  | 1 | 3 |
| **Periosteal new bone growth (excluding ribs)** | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| **Osteomyelitis** | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Tuberculosis** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Extraspinal osteoarthritis** | 0 | 1 | 1 |  | 0 | 1 | 1 |
| **Gout** | 0 | 0 | 0 |  | 0 | 0 | 0 |
| **DISH** | 0 | 0 | 0 | 0 |  | 2 | 0 |
| **Traumas** | 1 | 0 | 3 | 0 |  | 1 | 2 |
| **Rib** **δ13C** | -18.8 | -18.7 | -19.4 | -19.6 | -18.6 | -18.8 | -19.7 |
| **Rib δ15N** | 12.8 | 13.5 | 10.1 | 11.8 | 14.2 | 13.3 | 11.1 |
| **C change** | -0.5 | -0.4 | -0.6 | 0.1 | 0.2 | 1.0 | 0.3 |
| **N change** | -0.6 | -0.7 | -2.7 | -1.1 | -1.2 | -1.5 | -0.8 |

**Statistical information relevant to the ‘probable scholars’ group**

**Table S10. Males with humeral J asymmetry between -0.5 and 0.5. Note that the two Augustinian Friars (505, 508) may well be professional scholars as well. Of the two males from All Saints parish church cemetery, PSN725 has robust limbs but poorer nutrition and many Schmorl’s nodes; he may have had a manual occupation which stressed his arms symmetrically (by lifting heavy weights, for instance). Unfortunately, few data are available for PSN764.**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Individual number** | 505 | 508 | 36 | 38 | 93 | 108 | 99 | 114 | 124 | 203 | 244 | 265 | 279 | 725 | 764 |
| **Site** | Friary | Friary | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | St Johns Hospital | All Saints | All Saints |
| **Date** | 14th | 14th | 14th–15th | 14th | 15th | 13th | 14th | 14th | 15th | 14th | 13th | 15th | 14th–15th |  |  |
| **Age** | 46–59 | 60+ | 46–59 | 36–45 | 60+ | 46–59 | 26–35 | 46–59 | 46–59 | 60+ | 36–45 | 46–59 | 36–45 | 36–45 | 46–59 |
| **Dentine δ13C** | -19.4 |  | -18.9 |  | -18.9 |  | -18.9 |  |  | -18.0 |  | -19.0 | -19.2 | -19.5 |  |
| **Dentine δ15N** | 11.5 |  | 11.0 |  | 14.0 |  | 11.1 |  |  | 15.3 |  | 10.6 | 12.7 | 12.9 |  |
| **Stature** | 171.723 | 169.819 | 172.556 | 165.654 | 165.297 | 168.51 | 177.1 | 161.251 | 165.892 | 166.249 | 160.848 | 174.936 | 168.153 | 168.391 | 181.362 |
| **Vitamin D deficiency** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Cribra orbitalia** | 0 | 0 | 0 | 0 |  |  | 0 |  |  | 1 |  | 0 | 1 | 1 |  |
| **Hypoplasia (Max. defects per tooth)** | 2 | 3 | 2 | 0 |  |  | 0 |  |  | 1 |  | 1 | 1 | 1 |  |
| **IPCE** | 0.00 | 0.25 | 0.00 | 0 | 0.25 |  | 0 |  |  | 0.17 |  | 0.17 | 0.17 | 0.17 |  |
| **Schmorl's nodes** | 3 | 0 |  | 4 | 6 | 0 | 2 |  | 4 | 3 | 0 | 0 | 2 | 11 | 0 |
| **Maxillary sinusitis** | 1 | 0 | 1 |  |  |  |  |  |  | 1 |  | 1 | 1 |  |  |
| **Osteomyelitis** | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Tuberculosis** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Extraspinal osteoarthritis** | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 |
| **Gout** | 0 | 0 | 0 |  | 0 |  | 0 | 0 | 0 | 0 |  | 0 | 0 |  | 0 |
| **DISH** | 0 | 1 | 0 | 0 | 1 | 0 | 0 |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Hallux valgus** |  |  | 1 |  | 0 |  | 0 | 1 | 1 |  |  | 1 | 1 | 0 | 1 |
| **Trauma** | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 |
| **Rib** **δ13C** | -18.2 | -18.5 | -18.8 | -19.2 | -18.8 | -19.4 | -19.2 | -19.0 | -18.6 | -18.3 | -18.9 | -19.3 | -18.9 | -20.2 | -19.6 |
| **Rib δ15N** | 13.7 | 14.9 | 13.2 | 12.5 | 13.9 | 10.6 | 11.3 | 12.5 | 13.5 | 15.2 | 12.7 | 11.4 | 13.6 | 11.6 | 12.7 |
| **Bilateral asymmetry in humeral strength (J)** | 0.0210 | -0.0450 | 0.0027 | 0.0031 | -0.0040 | -0.0090 | -.0230 | 0.0460 | 0.0370 | 0.0350 | 0.0140 | 0.0140 | 0.0030 | 0.0190 | 0.0110 |

**References**

Ambrose, S.H. 1990. Preparation and characterization of bone and tooth collagen for stable carbon and nitrogen isotope analysis. *Journal of Archaeological Science* 17: 431–51. https://doi.org/10.1016/0305-4403(90)90007-R

Barnett, C.N. 1954. Squatting facets on the European talus. *Journal of Anatomy* 88: 509–13.

Boulle, E. 2001. Osteological features associated with ankle hyperdorsiflexion. *International Journal of Osteoarchaeology* 11: 345–9. https://doi.org/10.1002/oa.572

Brickley, M. & J.I. McKinley. 2004. *Guidelines to standards for recording human remains* (Institute of Field Archaeologists technical paper 7). Southampton: IFA

Brooks, S. & J.M. Suchey. 1990. Skeletal age determination based on the *os pubis*: a comparison of the Acsádi-Nemeskéri and Suchey-Brooks methods. *Human Evolution* 5: 227–38. https://doi.org/10.1007/BF02437238

Brothwell, D. 1981. *Digging up bones*. New York: Cornell University Press.

Buckberry, J.L. & A.T. Chamberlain. 2002. Age estimation from the auricular surface of the ilium: a revised method. *American Journal of Physical Anthropology* 119: 231–9. https://doi.org/10.1002/ajpa.10130

Buikstra, J. & D.H. Ubelaker. 1994. *Standards for data collection from human remains*. Fayetteville, AR: Arkansas Archeological Survey.

Capasso, L., K.A.R. Kennedy & C. Wilczak. 1999. *Atlas of occupational markers on human remains*. Teramo: Edigrafital.

Collins, M.J. & P. Galley. 1998. Towards an optimal method of archaeological collagen extraction: the influence of pH and grinding. *Ancient Biomolecules* 2: 209–23.

DeNiro, M.J. 1985. Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. *Nature* 317: 806–9 https://doi.org/10.1038/317806a0

Doube, M. *et al.* 2010. BoneJ: Free and extensible bone image analysis in ImageJ. *Bone* 47: 1076–9. https://doi.org/10.1016/j.bone.2010.08.023

Falys, C.G. & D. Prangle. 2015. Estimating age of mature adults from the degeneration of the sternal end of the clavicle. *American Journal of Physical Anthropology* 156: 203–14. https://doi.org/10.1002/ajpa.22639

Finnegan, M. 1978. Non-metric variation of the infracranial skeleton. *Journal of Anatomy* 125: 23–37.

Inskip, S.A. 2013. Islam in Iberia or Iberian Islam: Sociobioarchaeology and the analysis of emerging Islamic identity in early medieval Iberia. Unpublished PhD dissertation, University of Southampton.

İşcan, M.Y., S.R. Loth & R.K. Wright. 1984. Age estimation from the rib by phase analysis: white males. *Journal of Forensic Science* 29: 1094–104. https://doi.org/10.1520/JFS11776J

İşcan, M.Y., S.R. Loth & R.K. Wright. 1985. Age estimation from the rib by phase analysis: white females. *Journal of Forensic Science* 30: 853–63. https://doi.org/10.1520/JFS11018J

Longin, R. 1971. New method of collagen extraction for radiocarbon dating. *Nature*, 230: 241–2. https://doi.org/10.1038/230241a0

Mariotti, V., F. Facchini & M.G. Belcastro. 2004. Enthesopathies – Proposal of a standardized scoring method and applications. *Collegium Antropologicum* 28: 145–59

Mariotti, V., F. Facchini & M.G. Belcastro. 2007. The study of entheses: Proposal of a standardized scording method for twenth-three entheses of the postcranial skeleton. Collegium Antropologicum 31: 291-313.

Mays, S., J. Elders, L. Humphrey, W. White & P. Marshall. 2013. *Science and the dead. A guideline for the destructive sampling of archaeological human remains for scientific analysis.* English Heritage Publishing.

Mitchell, P.D. & M. Brickley. (ed.) 2017. *Updated guidelines to the standards for recording human remains*. Reading: Chartered Institute for Archaeologists/British Association for Biological Anthropology and Osteoarchaeology.

Molleson, T. 1989. Seed preparation in the Mesolithic: the osteological evidence. *Antiquity* 63: 356–62. https://doi.org/10.1017/S0003598X00076079

Nafplioti, A. 2008. ‘Mycenaean’ political domination of Knossos following the Late Minoan IB destructions on Crete: negative evidence from strontium isotope ratio analysis (87 Sr/ 86 Sr). *Journal of Archaeological Science* 35: 2307–17. https://doi.org/10.1016/j.jas.2008.03.006

– 2009. Mycenae revisited part 2. Exploring the local versus non-local geographical origin of the individuals from grave circle A: Evidence from strontium isotope ratio (87Sr/86Sr) analysis. *Annual of the British School at Athens* 104: 279–91. https://doi.org/10.1017/S0068245400000253

Phenice, T.W. 1969. A newly developed visual method of sexing the *os pubis*. *American Journal of Physical Anthropology* 30: 297–301. https://doi.org/10.1002/ajpa.1330300214

Quarry-Wood, W. 1920. The tibia of the Australian Aborigine. *Journal of Anatomy* 54: 232–57.

Richards, M.P. & R.E.M. Hedges. 1999. Stable isotope evidence for similarities in the types of marine foods used by Late Mesolithic humans at sites along the Atlantic Coast of Europe. *Journal of Archaeological Science* 26: 717–22. https://doi.org/10.1006/jasc.1998.0387

Ruff, C.B. 2002. Long bone articular and diaphyseal structure in old world monkeys and apes. I: locomotor effects. *American Journal of Physical Anthropology* 119: 305–42. https://doi.org/10.1002/ajpa.10117

– 2008. Biomechanical analyses of archaeological human skeletons, in M.A. Katzenberg & A.L. Grauer (ed.) *Biological Anthropology of the Human Skeleton*: 189-224. Hoboken (NJ): Wiley. https://doi.org/10.1002/9781119151647.ch6

Ruff, C.B. *et al.* 2012. Stature and body mass estimation from skeletal remains in the European Holocene. *American Journal of Physical Anthropology* 148: 601–17. https://doi.org/10.1002/ajpa.22087

Saupe, T. *et al.* 2021. Ancient genomes reveal structural shifts after the arrival of Steppe-related ancestry in the Italian Peninsula. *Current Biology* 31: 2576–91. https://doi.org/10.1016/j.cub.2021.04.022

Scheuer, L. & S. Black. 2000. *Developmental juvenile osteology*. Elsevier: London. https://doi.org/10.1016/B978-012624000-9/50004-6

Trotter, M. 1970. Estimation of stature from intact long limb bones, in T.D. Stewart (ed.) *Personal identification in mass disasters*: 71–83. Washington D.C.: National Museum of Natural History.

Ubelaker, D.H. 1979. Skeletal evidence for kneeling in prehistoric Ecuador. *American Journal of Physical Anthropology* 51: 679–86. https://doi.org/10.1002/ajpa.1330510417

– 1989. *Human skeletal remains: Excavation, analysis, interpretation*. Chicago: Aldine.