Socio-economic differences in diet: An isotopic examination of post-Medieval Chichester, West Sussex

Kirandeep Dhaliwal[1], Carolyn Rando[1], Hazel Reade[1], Anne-Lise Jordan[2], Rhiannon E. Stevens[1]

[1]: UCL Institute of Archaeology, 31-34 Gordon Square, London, WC1H 0PY, UK.

[2]: UCL Department of Earth Sciences, Gower Street, London, WC1E 6BT, UK.

Corresponding Author:

Rhiannon Stevens, UCL Institute of Archaeology, 31-34 Gordon Square, London, WC1H 0PY, UK. +44 (0)2076791530

rhiannon.stevens@ucl.ac.uk

Abstract:

Objectives:

Historical evidence suggests that social hierarchy pervaded all aspects of society in post-Medieval England. This study uses stable isotope analysis to explore the extent to which socioeconomic status and sex affected the dietary habits of the inhabitants of post-Medieval Chichester.

Materials and Methods:

Stable carbon and nitrogen isotope ratios were measured on 40 human burials from the post-Medieval site of St. Michael's Litten (Chichester, West Sussex, England). Samples were selected from three burial types that denoted differing socioeconomic status with roughly equal numbers of males and females: tomb burials (n=13) for high status; single coffin burials (n=14) for middle status; and shroud burials (n=13) for low status individuals.

Results:
The data showed a largely terrestrial diet with the possibility of some inclusion of marine resources. The isotope results indicate significant variation in the consumption of terrestrial meat (and marine protein) between high status tomb burials and coffin and shroud burials, showing that socioeconomic status likely played a role in daily dietary patterns. However, the isotope data suggest sex did not influence an individual's diet.

Discussion:
These results mirror trends established in status-based studies from elsewhere in post-Medieval England. However, notably absent from the data is evidence for significant marine resource consumption, that is a well-established dietary trend of the late Medieval and early post-Medieval periods. These results indicate post-Medieval Chichester was a socially stratified society with clear implications that the diet of higher status individuals differed significantly from lower status.

Introduction

During the post-Medieval period (1550-1850), Chichester, West Sussex, England (Figure 1) was a large market town with a thriving trade in grains such as wheat, barley and oats (Morgan, 1992). This was in addition to industries such as tanning, brewing, and the production of needles, bricks, and clay pipes (Reger, 1996; CDC, 2005). Increased trade connections with London and other cities in England helped usher in a period of increased prosperity, that saw the population double from 2,400 people in 1670 to 4,752 in 1801 (Reger, 1996). A diverse array of social groups were represented, from farmers to craftsmen to industry owners. There was a clear desire to display one's status and wealth both in life and in death. The elite individuals of society were able to afford elaborate family burial tombs, while the poor were buried in simple shrouds. The range in burial practices seen in the post-Medieval burials of St. Michael's Litten (Figure 2) are viewed as reflecting a highly socially stratified society, typical of post-Medieval England. Such seemingly fixed social hierarchy pervaded all aspects of English society at this time.

Society was structured like a social ladder, with each rung being a status gradation with its own generally accepted duties and privileges (Lehmberg & Heyck, 2002). Within this rigid social system, status was ascribed at birth and men and women were not afforded the same rights and opportunities. Moreover, social status is thought to have informed all aspects of life, dictating dress, diet, educational and professional opportunities, and social customs (Mitchell, 2009). The consumption of food and drink was a powerful expression of worth and status (Fox, 2013) and the preparation, distribution, and consumption of food is thought to have been closely connected to a society's social structure (Douglas & Isherwood, 1996). In this hierarchy, status distinctions were "carefully defined, observed, and protected" (Lehmberg & Heyck, 2002). This does not, however, mean social mobility was non-existent. The budding middle orders of English society, made up of merchants, wholesalers, manufacturers, and retailers among others, did not fit neatly into the social hierarchy (Earle, 1989; Cherryson, Crossland & Tarlow, 2012). Instead they formed a new rung on the social ladder, with increased status and spending power, and the desire to display this status came to be a hallmark of post-Medieval English society (Cherryson et al., 2012). Thus, the display of status in death may not have reflected the individual's cultural practices throughout life, but have reflected the aspirations of the individual, or possibly those of the relatives who arranged their funeral (Litten, 1991; Mitchell, 2009).

Stable isotope studies have been widely used to explore Medieval and post-Medieval diet. These have focused on diet changes through time (Richards, Fuller & Molleson, 2006; Müldner & Richards, 2007b), weaning (Richards, Mays & Fuller, 2002; Fuller, Richards & Mays, 2003), status-based variation (Mays, 1997; Müldner & Richards, 2005; Müldner & Richards, 2007a; Kjellström, Storå, Possnert & Linderholm, 2009; Reitsema & Vercellotti, 2012; Quintelier, Ervynck, Müldner, Van Neer, Richards & Fuller, 2014), and sex-based variation (Müldner & Richards, 2007a; Kjellström et al., 2009; Reitsema & Vercellotti, 2012; Quintelier et al., 2014, Bleasdale et al., 2019). In general, the data indicate an increase in marine contribution to the diet in the Medieval and post-Medieval periods (Richards et al., 2006; Müldner & Richards, 2007b) as well as sex and status-based differences (Reitsema & Vercellotti, 2012; Quintelier et al., 2014). To date, however, studies on status and sex-based variation within the post-Medieval period are few and have largely been conducted on skeletal assemblages from continental Europe.

This study uses stable isotope analysis of skeletal remains to gain a better understanding of the relationship between a person's diet, sex, and social status in post-Medieval Chichester. Furthermore, this study provides new insight into how societal norms affected the type of food consumed by individuals who occupied different strata within the social hierarchy of post-Medieval England.

Historical evidence for diet

For much of England's history, the diet of the average individual has revolved around three main staples: grain, meat, and alcohol. In many ways, the first half of the post-Medieval period was a continuation of culinary traditions long established in the Medieval period. "A table groaning with prodigious quantities of best meat" was one of the ways that the wealthy proclaimed their status (Fox, 2013: 174). A typical meal for Queen Anne in 1705 consisted of nine different types of meat, without any vegetables, while each of her servants received at least two different types of meat (Mennell, 1996). However, it is during the post-Medieval period that changes in the way society thought about diet and nutrition occurred. Diet and food preparation became a subject debated by scientists and intellectuals alike, while new foodstuffs from abroad made waves as a result of England's widening internal and foreign trade (Thirsk, 2006). Nevertheless, the adoption of new foods into local culinary traditions occurred sporadically across different parts of England, and while the culinary tastes of the upper classes rapidly developed, the poor were largely unaffected by transformations in culinary ideas (Wilson, 1973; Mennell, 1996).

In the early part of the post-Medieval period, foodstuffs such as cereal pottages, coarse breads and ale formed the constituent parts of diet for the majority of the population (Stead, 1993; Stone, 2006), with higher quality foods – such as white, wheaten bread – remaining the purview of the wealthier strata of society (Wilson, 1973). By the latter parts of the period, wheat replaced other grains (Black, 1993) and bread tended not to be made at home, but rather bought from bakeries – making it more accessible to all social classes, although the whitest bread was still restricted to the upper classes. Additionally, it is during this time that vegetables, such as peas, were becoming more readily incorporated into the diet for their high protein content, a change that happened across all social classes and that was especially apparent in London and the surrounding Home Counties (Thirsk, 2006), although beans remained associated with the poor (Thirsk, 2006). Potatoes also gained in popularity after 1750 throughout the social classes, owing to their high starch content "to fill empty stomachs" in times of famine and deprivation, which were a regular occurrence in parts of England throughout the first half of the post-Medieval period (Thirsk, 2006).

Additionally, the cow gradually became the chief milk producing animal for dairy products such as cheese and butter (Wilson, 1973).

Fish may have been an important component of the post-Medieval diet in England, as, for at least the earliest part of the period, many of the religious restrictions on eating meat were still in place (Müldner & Richards, 2005). A survey taken in the 1850s detailed the varieties of fish found in and around the Chichester harbour, which included: plaice, flounder, sole, whiting, bass, eel and cod, as well as trout and eel from the streams flowing into the harbour (Reger, 1996). In addition to fresh fish, shellfish also played a large part in the fishing economy of Chichester with lobster, prawn, and crab mentioned in a 1738 survey as being in abundance at the fish market (Green, 2011). There were numerous oyster fisheries in the surrounding area, but strangely these were not mentioned as being sold at the market, even though they had the reputation of being the best in the country at the time (Green, 2011). Herring was also eaten across the country, as it was cheap and often preserved (Serjeantson & Woolgar, 2006)

Alcohol was still a large contributor to the English diet and the 18th century saw improvements in brewing techniques that resulted in better quality and more diverse beers and ales (Wilson, 1973). Coffee and tea were new imports during this period that quickly caught on in the upper classes (Earle, 1989; Black, 1993). Because of the complicated preparation required and the fact that the coffee beans could not be reused, coffee was very much a drink enjoyed solely by those rich enough to buy such a luxury. However, by the end of the 18th century, the consumption of coffee declined and was replaced by tea, a drink that was consumed across the social ladder by rich and poor alike (Wilson, 1973; Black, 1993). The rich enjoyed sampling new luxury teas and entertaining guests with elegant tea services, while the poor drank tea as a stimulant to act as an energy boost. With the establishment of the sugar industries of the New World, sugar consumption increased progressively from the 16th to the 19th century (Deerr, 1950; Drummond & Wilbraham, 1957). A substantial proportion of this sugar was eaten in the form of treacle, jam and, in the later years, chocolate (Corbett & Moore 1976).

The accounts explored above show the disparity in dietary habits between the rich and the poor of society. The wealthy were accustomed to diverse and varied diets rich in meat, fish and luxuries such as fruit and refined breads (Drummond & Wilbraham, 1957; Dyer, 1988; Freeman, 1989; Razzell & Spence, 2006; Thirsk, 2007). The burgeoning middle class of the period - the town craftsmen, merchants, and small farmers - had greater access to a variety of meats, fish, vegetables, and fruits than the lower labouring classes, especially if they were living in or near to a market town. In contrast, the lower social classes, with their limited spending ability and varying access to quality food, often had to make do with the less desirable foodstuffs; these included salted herring, coarse breads, pottage, and meats such as mutton and the less desirable parts of animals usually eaten by the wealthy (Clayton & Rowbotham, 2009; Sykes, 2006; Thirsk, 2007). Additionally, it must be noted that there was a tendency for the lower classes to emulate the dietary choices of the upper classes, especially regarding the consumption of cheap carbohydrates such as sugar and fine white flour. However, this would have only been widespread towards the end of the post-Medieval period after the removal of import duties on sugar in 1845 and the repeal of the Corn Laws in 1846 (Corbett & Moore, 1976).

Stable isotope analysis

Since stable isotope analysis in archaeology was first pioneered in the 1970s (Vogel & van der Merwe, 1977; van der Merwe & Vogel, 1978) stable isotope analysis of skeletal remains has been widely used to reconstructing past diets (see reviews: Katzenberg, 2000; Sealy, 2001;

Schwarcz & Schoeninger, 2012; Makarewicz & Sealy 2015). Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope compositions of body tissue reflects those of the diet consumed, and in tissues that constantly remodel - such as bone collagen - reflect a dietary signal homogenised over years prior to death (Hedges, Clement, Thomas, & O'Connell, 2007). Tissue turnover rates vary by bone and decrease with age (Hedges et al. 2007; Hill & Orth, 1998). Therefore, the amount of time represented in a bone collagen sample will be influenced by the type of bone analysed and the age of the individual at death. While estimates of bone turnover rates range from around 2 to 30 years (e.g. Cox & Sealey, 1997; Hedges et al., 2007), cancellous and trabecular bones, such as ribs, have faster turnover rates than more compact bones, such as the femur, and their isotopic signal is likely to reflect the last few years of life. In this study analysis is restricted to ribs to minimise the potential effect of a residual childhood dietary signature in the bone collagen of adults.

$\delta^{13}C$ values of bone collagen primarily reflect dietary protein with some addition of lipids and carbohydrates (Ambrose & Norr, 1993; Tieszen & Fagre 1993; Hedges et al., 2007). $\delta^{13}C$ can be used to distinguish between plants using different photosynthetic pathways, between animals fed on these different types of plants, and between marine and terrestrial food webs (Vogel & van der Merwe, 1977; Schoeninger & De Niro, 1984). The majority of the plants found in Europe use the C_3 pathway and include wheat, barley, rice, legumes, tubers and nuts. Environmental factors that influence the $\delta^{13}C$ of C_3 plants include light intensity, temperature, soil nutrient levels and water availability (Heaton, 1999).

$\delta^{15}N$ values in bone collagen only reflect dietary protein. At the base of the food chain, the majority of plants obtain their nitrogen from the soil, although nitrogen fixing plants such as legumes can obtain nitrogen directly from the atmosphere. Soil and plant $\delta^{15}N$ values are influenced by environmental parameters including precipitation and temperature (Amundson et al., 2003), salinity (van Groenigen & van Kessel, 2002) and anthropogenic factors such as manuring (Bogaard, Poulton, & Merbach, 2007). With each succeeding trophic level in a food web, $\delta^{15}N$ is enriched by approximately 3-5‰ in comparison to the $\delta^{15}N$ of the dietary source (Bocherens & Drucker, 2003; Hedges & Reynard, 2007), although some studies suggest that diet to collagen enrichment may be larger, in the range of ~6‰ (O'Connell, Kneale, Tasevska, & Kuhnle., 2012). Nitrogen isotope measurements can be used to identify consumption of aquatic protein as freshwater and marine food chains are longer that terrestrial food chains, hence people with a high aquatic intake typically display higher $\delta^{15}N$ than those relying on terrestrial food resources (Schoeninger & De Niro, 1984). Nitrogen isotopes can also potentially inform about periods of nutritional stress as it results in small-scale increases in body tissue $\delta^{15}N$ values (Hobson, Alisauskas, & Clark, 1993; Fuller et al., 2005; Hertz, Trudel, Cox, & Mazumder 2015; Doi, Akamatsu, & González, 2017, Redfern, DeWitte, Beaumont, Millard, & Hamiln 2019).

Material and methods

St. Michael's Litten cemetery, Chichester

The city of Chichester, West Sussex has a long history of occupation, with its origin dating back to the Roman period; the city is a well-placed and strategic location on the south coast of England (CDC, 2005). Chichester has been continuously occupied since the Anglo-Saxon period (Willis, 1928) and played a predominant role in the region. By the late medieval period, Chichester became a religious centre and market town, and in 1353 was a staple port, giving it control over the local wool trade (CDC, 2005). There was a brief period of decline during the 17th century due to the English Civil War (Willis, 1928; Salzman, 1935), but the city again prospered, with the population doubling between 1670 and 1801 from some 2,400 people to 4,752, respectively (Reger, 1996). This revival was built upon increased trade with London and other cities in England, as well as from the products of farming and local industry (Reger, 1996; CDC, 2005).

Material selected for this study comes from the St. Michael's Litten, a cemetery located just outside the Roman walls of the city near the East Gate and was in use from the 11th century until its closure in 1859, although some of the earliest burials date to the Roman period (Hart, Doherty, Le Hefarat, & Sibun, 2012). The Litten is believed to be associated with the chapel and altar of St. Michael, which now no longer stands; its use preceded the building of the Chichester Cathedral, with which it was not connected (Willis, 1928). The cemetery itself was placed within St Pancras parish, a poor suburb outside the walls (Morgan, 1992); however, due to the extremely limited burial space within the city, it is thought that this cemetery was the primary burial ground for wealthy and poor alike, although the very rich would have likely been interred within the walls.

Excavations of the Litten site were carried out by Archaeology South East in 2011 (Site code: ESC11) and revealed a total of 1730 skeletons in 1727 burials from the Medieval and post-Medieval periods (Hart et al., 2012). All individuals were buried in a supine position with a roughly east to west orientation, with multiple burial types recorded (Figure 3). The most prominent of these being single shroud burials, which were common throughout the Medieval and post-Medieval periods. The two other burial types that represent a majority of the total inhumations were single coffin burials and brick tomb burials, which were only in use during the post-Medieval period (Hart et al., 2012). Of the 1730 skeletons, 420 are currently housed at the UCL Institute of Archaeology; these comprise the best-preserved skeletons and are thought to date predominantly to the post-Medieval period.

Forty adult skeletons were selected for this study. All skeletons selected had good preservation of the pelvic elements, such as the auricular surface and pubic symphysis, on at least one of the os coxae, so that age and sex of each individual could be established. The skeletal remains were generally well preserved, although many exhibited taphonomic damage and some fragmentation of the skeletal elements. Sex and age at death were determined from sexually dimorphic features of the pelvis and skull. Sex was estimated using standard methods as outlined in Buikstra and Ubelaker (1994), with age estimated through assessment of the auricular surface (Lovejoy et al., 1985) and the pubic symphysis (Brooks & Suchey, 1990) (Supplementary file 1). Only those skeletons considered 'adult' were used in this study; 'adultness' denotes an individual over the age of approximately 18 years. The range of ages was relatively evenly spread from the minimum of 25 to the maximum of 59 years (see supplementary file 1).

To denote social status in life, the sample size was divided into three groups based on burial type: shroud, coffin, or tomb burial. Individuals belonging to tomb burials were considered to be high status individuals, while those belonging to shroud burials were considered to be of low status. The wealthy and prosperous would have seen the investment in a family tomb and a funerary monument as an investment in cementing the family's social status in life. Moreover, the coffin itself was a symbol of status, "its finish and furniture indicative of the social standing of the deceased" (Litten, 1991: 86). The poor on the other hand, did not have the spending power to lavish on funerary expenses. Members of low social status would be given a shroud burial where the body was wrapped in a shroud and then transported to the burial ground in the communal parish coffin. The body would then be removed from the coffin and placed in the ground (Cherryson et al., 2012). Coffin burials were presumed to belong to the middle class; a portion of society that was of better means than the poor who could only afford a simple shroud, but not rich enough to be able to afford the investment of a family tomb. For some perspective, in the early 1800s, a funeral with a somewhat embellished coffin would have cost upwards of 60 pounds at the time; a 'laborer' or working-class person of the time would have made only around 25 pounds per annum (Chadwick, 1843), meaning this type of burial would have been outside of their means. Elaborate tomb burials would have been in the range of £150 – £1000 (Chadwick, 1843), or around £9000 - £60,000 in today's money.

Burial type was determined by examining the excavation paperwork and photos for each skeleton. The presence of distinct grave cuts and coffin fittings denoted a coffin burial while the absence of the above denoted a shroud burial; only a small percentage of burials were coffined before the beginning of the 1600s (Cherryson et al., 2012), and as such, are highly indicative of being from the post-Medieval period. Shroud burials were deemed contemporaneous to the coffined ones based on burial position (in rows with the coffin burials) and the position of the skeleton within the grave cut. Tomb burials were easily distinguished because of the intact preservation of the brick vaults and all would have dated to the post-Medieval period.

To represent sex and status groups equally, a similar number of individuals were sampled from each burial type: 13 skeletons were chosen from the single shroud burials, 14 from the single coffin burials, and 13 from the brick tomb burials. The three burial groups had a roughly equal number of males and females: a) shroud burials with 5 females and 8 males, b) coffin burials with 6 females and 8 males, and c) tomb burials with 7 females and 6 males.

Methods

Samples for stable isotope analyses were taken from the ribs of each skeleton. Collagen was extracted by a modified Longin method (Longin, 1971). Between 0.5 and 1 gram of intact bone was cut from each rib sample, cleaned, and demineralised in 8ml of 0.5M HCl at 4°C with the acid changed as needed every 2-4 days until all samples were demineralized. Samples were then rinsed in deionised water three times and then gelatinised in a pH 3.0 HCl solution at 75°C for 48 hours. The resulting supernatant liquid was decanted into plastic tubes using an Ezee filter, then frozen and lyophilised. Between 500 μg to 600 μg of dry collagen from each sample was analysed using a Thermo Flash EA linked to a Delta V continuous-flow isotope-ratio mass spectrometer at the Bloomsbury Environment Isotope Facility (BEIF) at University College London. All samples were initially run in duplicate and compared with laboratory and international standards that were interspersed through each run. A reproducibility of ±0.1‰ was reported for the standards and average reproducibility for the collagen 0.2‰ and 0.1‰ for the $\delta^{13}C$ and $\delta^{15}N$ values respectively. For twelve of the samples $\delta^{13}C$ values had differences of over 0.4‰ between the dual analyses; however, the $\delta^{15}N$ value differences were not similarly affected. As one result could not be ruled out over the other, a third aliquot of these 12 samples was analysed on the isotope ratio mass spectrometer and the average of all three runs were taken and included in this study. Results are expressed using the delta (δ) notation in parts per thousand (per mil or ‰) relative to the international reference standards: Vienna Pee Dee Belemnite (VPDB) for carbon and Ambient Inhalable Reservoir (AIR) for nitrogen isotope ratios.

Site-specific faunal remains were not available for sampling. Instead, this study relies on faunal baselines established from two previous studies (Table 1). The terrestrial faunal baseline comes from the post-Medieval sites of Queen's Chapel of the Savoy (c. AD 1510 to 1854) and Prescot Street (16^{th} to 19^{th} Century AD) (Bleasdale et al., 2019). As no marine or freshwater baselines were available for the Post-Medieval period we use data from the Medieval site of

Beverley (East Riding of Yorkshire), where marine and freshwater fish including eel, herring, flat fish, cyprinids, pike, ray, and whiting were sampled (Müldner & Richards, 2005).

Results

Collagen Preservation

All samples had collagen yields of over 1%, indicating adequate/good collagen preservation. Two samples (SK 3249 and SK 3772) had collagen yields between 1 and 2%. While the preferred minimum for collagen yields in dietary reconstruction is 2%, yields of 1% and greater are accepted when the other indicators of good collagen preservation are established (Ambrose, 1993; van Klinken, 1999). All samples fell within the accepted %C and %N ranges for bone collagen, except one analysis of sample SK 4799, which had a carbon content of 56.2%. This is above the accepted 50% cut off point for modern bone collagen values. The other analysis of sample SK 4799 had a carbon content of 42.6% and nitrogen content of 16.1%, which was within the accepted range and as such was kept in the study. Similarly, all the samples had acceptable atomic C:N ratios falling between 2.9-3.6 (DeNiro, 1985) except one analysis of sample SK 3643 (C:N ratio = 3.7). The other two analyses of this sample produced C:N ratios of 3.5 and 3.3, and as such were kept in the study. Full results are given in Supplementary Data Table 1.

Isotope Results for Dietary Reconstruction

$\delta^{13}C$ values range from -20.3‰ to -18.3‰ across all samples (median = -19.5‰, mean= -19.5 ± 0.4‰), while $\delta^{15}N$ values range from 10.7‰ to 12.8‰ (median = 12.1‰, mean = 12.0 ± 0.5‰). These values are somewhat elevated in comparison with what might be expected for an entirely C_3 terrestrial diet. For example, the mean/median $\delta^{13}C$ and $\delta^{15}N$ values are around

2-3‰ and 5-7‰ higher respectively, than those of the cattle, sheep and pig from the post-Medieval sites of Queen's Chapel of the Savoy and Prescot Street (Bleasdale et al., 2019). (Figure 4, Table 1). The elevated $\delta^{13}C$ and $\delta^{15}N$ values are consistent with a contribution of marine or freshwater resources to the diet of the people at Chichester. The small ranges in the $\delta^{13}C$ and $\delta^{15}N$ values across all analysed samples indicate a relatively homogenous diet across the assemblage, although this could still have consisted of a wide range of foods with differing isotopic compositions. There appears to be a slight positive correlation between $\delta^{13}C$ and $\delta^{15}N$, however the relationship is not statistically significant using Spearman's rank correlation coefficient ($r^2=0.29$ $p=0.07$).

Isotope Variation by Burial Type

Carbon and nitrogen isotope compositions for each burial type are summarized in Table 2 and Figure 5. As parametric assumptions were not met, non-parametric tests were used to analyse the data. Using a Kruskal-Wallis test, it is shown that $\delta^{13}C$ values do not vary between burial type ($H=2.33$ $p=0.311$), while $\delta^{15}N$ values do ($H=16.49$ $p<0.001$). Typically, $\delta^{15}N$ values for the tomb burials are higher than those for the shroud and coffin burials, with some tomb burials also having high $\delta^{13}C$ values, relative to the rest of the samples (Table 2; Figure 5). Mann-Whitney U tests were conducted to explore the difference in nitrogen isotope composition further. The $\delta^{15}N$ values differ most significantly between the shroud and tomb burials ($U=32.5$ $p=0.008$) and the coffin and tomb burials ($U=10$ $p<0.001$). No statistically significant difference between the $\delta^{15}N$ values of the coffin and shroud burials is identified ($U=63$ $p=0.174$).

Isotope Variation by Sex and Age

Carbon and nitrogen isotope compositions for each sex and burial type are presented in Figure 6 and summarised in Table 3. There is no significant difference between male and female $\delta^{15}N$ and $\delta^{13}C$ values, regardless of whether the data is compared within burial context or for the whole assemblage ($\delta^{13}C$ U=182 $p>0.05$, $\delta^{15}N$ U=196.5 $p>0.05$). No correlation is seen between age and $\delta^{15}N$ and $\delta^{13}C$ values.

Discussion

Diet Reconstruction

The carbon and nitrogen stable isotope signatures of the data indicate that the people of post-Medieval Chichester had a diet mainly consisting of C_3 terrestrial plants and meat and/or other animal products from terrestrial fauna fed on these plants. Results do not support aquatic resources as a primary source of protein, but they could have been included in the diet as a more minor component. This interpretation is consistent with historical records describing thriving beast markets in post-Medieval Chichester, as well as local and commercial fishing activities (Reger, 1996; Green, 2011). However, it is also possible that the observed isotopic values could be produced by a significant consumption of omnivores such as pig, rather than an aquatic dietary component, in addition to the dominant terrestrial herbivore and plant dietary components.

As there is no baseline isotope data available for local contemporary marine and terrestrial fauna, it is not possible to provide quantitative estimates of the proportion of these different resources in the diet. However, if a trophic enrichment in $\delta^{13}C$ of 1‰ is assumed, then the end point of an entirely C_3 terrestrial diet can be taken to be c. -19‰ based on the most enriched terrestrial faunal values from post-Medieval sites of Queen's Chapel of the Savoy (c. AD 1510 to 1854) and Prescot Street (16th to 19th Century AD) (Bleasdale et al., 2019). Carbon isotope values above this threshold would therefore likely indicate a marine contribution to the individual's diet. In the analysed samples, only three of the skeletons (SK 3115, SK 4600, SK 4576 – all high-status tomb burials) have $\delta^{13}C$ values above this end point, although this does not necessarily mean that other individuals did not also consume marine resources. It is possible that the Queen's Chapel of the Savoy and Prescot Street fauna provide an inadequate baseline for interpreting the Chichester values due to geographic and social differences between the sites. Further, it is possible that while marine resources did play a part in the diet of post-Medieval Chichester, they were not consumed in large enough quantities to be clearly detected isotopically in the bone collagen.

Estimating the potential contribution of different protein sources to the $\delta^{15}N$ signature is equally challenging (see discussion in Hedges, 2004; Prowse, Schwarcz, Saunders, Macchiarelli & Bondioli, 2004; Müldner & Richards, 2007b). In addition to the lack of baseline data local to Chichester, estimations are further limited by uncertainties in determining the entire range of fauna available for consumption, the digestible protein content of each based on different food preparation methods, and the precise magnitude of trophic level enrichment, estimates of which range from 3 to 6‰ (Bocherens & Drucker, 2003; Müldner & Richards, 2007b; O'Connell, Kneale, Tasevska, & Kuhnle, 2012). Median $\delta^{15}N$ for the Chichester humans is approximately 6‰ higher than the $\delta^{15}N$ cattle values from Queen's Chapel of the Savoy and Prescot Street, which could indicate either one or two trophic levels difference, depending on the enrichment factor considered. Moreover, as this faunal baseline comparison is derived from locations more distant than those most likely to be supplying post-Medieval Chichester, assessment of trophic level is further complicated by the role of local geography on environmental baseline $\delta^{15}N$ (Stevens, Lightfoot, Hamilton, Cunliffe, & Hedges, 2013).

While it is not possible to make quantitative estimates of the proportion of different protein sources in the diet, the combined $\delta^{13}C$ and $\delta^{15}N$ values clearly suggest that terrestrial herbivore protein was predominantly consumed, but was supplemented by dietary components that included marine and/or freshwater resources, and/or terrestrial omnivores. This is supported by historical accounts from the time period that emphasize the significance of meat and animal products from domesticated animal in the diets of individuals across the social strata (Dyer, 2005). The comparatively high $\delta^{15}N$ and lower $\delta^{13}C$ signal is most characteristic of either a contribution of freshwater fish and/or omnivore meat such as pork to the diet (Müldner & Richards, 2005), although stationary marine organisms, such as molluscs may also have $\delta^{13}C$ signatures that reflect terrestrial environments, especially if they inhabit estuarine settings influenced by pre-Quaternary carbonate sediments (Milner, Craig, Bailey, Pedersen, & Andersen, 2003). There is little evidence that the people of Chichester were consuming riverine species other than eel, but there is definite evidence that there was consumption of pig. Pigs, especially in towns, are known to have been kept in yards or roaming the streets and were fed on scraps and waste (Rixson, 2000), which would produce higher $\delta^{15}N$ than the herbivore species and could explain the higher values seen in the humans. Additionally, the area around Chichester had numerous oyster and other mollusc fisheries, which could explain why the human $\delta^{13}C$ signatures are not higher.

Although not obvious in the data, the contribution of C_3 plants in the diet should not be overlooked. Chichester had a thriving weekly "corn" market where barley, wheat, and oats were brought into the city by farmers to be sold to the local populace as well as to brewers and millers (Green, 2011). It is well attested that such cereal grains made up most of the diet of the poor, working classes (Stone, 2006). However, since cereals are largely made up of carbohydrates and lipids and a comparatively small proportion of protein, the isotope signature of a diet incorporating

C_3 terrestrial plants in addition to terrestrial animals or animal products will most strongly represent the animal rather than plant component of the diet (Ambrose & Norr, 1993).

Socioeconomic Status

The tomb burials have higher δ^{15}N values, and lower within-group variability, than the coffin and shroud burials (Table 2; Figure 5). This indicates differentiation based on socioeconomic status of the individual and is most likely the result of higher consumption of animal protein by high-status individuals. This is well evidenced in both the archaeological and historical records where higher meat consumption was a marker of the wealthy upper classes (Fox, 2013; Stone, 2006; Thirsk, 2006).

The lack of identifiable difference between coffin and shroud burials in δ^{15}N or δ^{13}C is interesting as coffin burials are assumed to have occupied a middle socioeconomic status, between high-status tomb burials and low-status shroud burials. While the difference in mean δ^{15}N values between the shroud and coffin groups is not significant, six individuals in the shroud group have δ^{15}N values that are greater than the highest δ^{15}N recorded for the coffin burial group. However, these higher values do not necessarily need to correspond to higher animal protein intake; it has been well documented that nutritional stress also leads to an increase in δ^{15}N values in bodily tissues (Hobson et al., 1993; Fuller et al., 2005; Hertz et al., 2015; Doi et al., 2017, Redfern et al., 2019). Nonetheless, most of these studies focused on the analysis of faunal tissues or human hair samples. Given that the rate of human bone collagen turnover is considerably longer, periods of nutritional stress would have needed to be prolonged in order to register in the bone collagen δ^{15}N signal. Extended famine is known during this period (Beaumont et al., 2013), so nutritional stress could result in these elevated δ^{15}N values. A further possibility is that low status individuals were making use of potentially free resources such as oysters and molluscs. A similar scenario was seen at the Anglo-Saxon site of Berinsfield, where ‘poor’ individuals consumed freshwater fish, but ‘wealthy’ individuals ate terrestrial animals (Privat, O’Connell & Richards, 2002). Further baseline faunal isotope data and the addition of sulphur isotopes to this dataset could in the future clarify the driver of the elevated $\delta^{15}N$ values. Interestingly, the Chichester tomb $\delta^{15}N$ values had a narrower range than the shroud and coffin $\delta^{15}N$ values, suggesting that individuals with higher socioeconomic status had more consistent diets within their class. However, the greater range in shroud and coffin burials could also be attributed to the inclusion of possible migrants in the dataset, which has been observed at a contemporary site in London, and might be expected given the population density at Chichester increased during this time (Beaumont et al., 2013). Further oxygen and strontium isotope analyses are needed to test this hypothesis.

Comparison of the Chichester results to other published data from post-Medieval sites in England shows a similar broad trend of relatively elevated $\delta^{15}N$ values, while not reflecting the expected associated increase in $\delta^{13}C$ values indicative of a significant marine dietary component (Figure 7). The elevated isotope signatures seen at the London sites of Chelsea (18-19th century AD), Spitalfields (18th and 19th century AD), St Barnabas (1831 to 1853 AD) and at All Saints York (17th to early 19th century AD) likely indicate more marine/freshwater resources in the diet than at Chichester, Queen’s Chapel of the Savoy London, Coventry (18-19th century AD) and St Martin’s Birmingham (late 18th to 19th century AD). Yet, despite the lowest $\delta^{13}C$ and ^{15}N values being observed for the shroud and coffin burials at Chichester, across all sites there is no clear-cut relationship between site socioeconomic status and $\delta^{13}C$ and $\delta^{15}N$ isotope signatures. Several sites considered to contain individuals of high socioeconomic status have elevated $\delta^{13}C$ and ^{15}N indicative of marine and/or freshwater resource consumption. St. Luke’s cemetery in Chelsea is thought to have served individuals of high socioeconomic status based on the recovery of high quality funerary artefacts and historical documentation regarding individuals buried there (Trickett, 2006). The crypt of Christ Church in Spitalfields housed affluent members of the surrounding area, e.g. wealthy wholesalers, professionals, and the independently wealthy who had the economic resources to be interred within the crypt of the church (Molleson & Cox, 1993; Nitsch et al., 2010). The cemetery at St. Barnabas served individuals from the relatively affluent district of Kensington (Bleasdale et al., 2019). All Saints York is also considered to contain individuals of relatively high socioeconomic status from a wealthy parish (Müldner & Richards, 2007b). Yet elevated δ^{13}C and ^{15}N values are also observed at the lower socioeconomic status site of Lukin Street cemetery in East London (Figure 7, Beaumont et al., 2013). Beaumont *et al.*, argue these elevated δ^{15}N values in post-Medieval samples from Lukin Street reflect local agricultural practices rather than marine or freshwater resource consumption linked to higher socioeconomic status. While fauna grazing in salt marshes or estuarine environments can lead to enriched δ^{15}N values (Britton et al., 2008), this explanation would not hold true across the other assemblages such as Chelsea, which showed higher δ^{15}N values for individuals described as 'gentlemen' while lower δ^{15}N values for bricklayer's wives (Trickett, 2006). It should also be noted that a considerable number of the individuals recovered from Lukin Street may have been first- or second-generation Irish immigrants of which some may have been survivors of the Great Irish Famine (Beaumont et al., 2013). As previously discussed, such extended nutritional stress may have influenced their bone isotope signatures.

The populations with isotope signatures most like those observed for the Chichester burials are from Coventry and Queen's Chapel of the Savoy London (Figure 7). The Coventry burials were considered to be low socio-economic status both in terms of the populations they served and the artefacts within the graves (Trickett, 2006). Based on historical and burial records, the Queen's Chapel of the Savoy population are thought to be of diverse socioeconomic status and included parishioners, hospital patients, military personnel and criminals. The high-status brick-lined tombs burials at St Martin's Birmingham also had similar nitrogen isotope values to those seen at Chichester (Figure 7) (Richards, 2006). It is clear that further local baselines from across the British Isles are required to resolve how dietary compositions relate to socioeconomic status. Nevertheless, despite the lack of local faunal baseline, within the Chichester cemetery there is a clear relationship between burial wealth and diet.

Sex

Based on the isotope results, there appears to be no difference in diet linked to the sex of the individual (Table 3, Figure 6). This is in accordance with bone stable isotope data from sites across England from the post-Medieval period, which similarly do not show statistically significant variation in carbon and nitrogen isotope signatures based on sex (Trickett, 2006; Nitsch et al., 2010). By contrast a difference between male and female isotope values was seen in the dentine samples of humans from St Saviour's Almshouse burial ground in Southwark, London (18th-19th Century). This was attributed to a difference in the diet between sexes early in life, or alternatively, a greater susceptibility of males to nutritional deprivation compared to females (Henderson, Lee Thorpe & Loe 2014). It may be that childhood sex-based dietary difference existed more widely in post-Medieval England, but that this are not visible in bone collagen its isotope signatures represent diet over a period of several years. Some studies on earlier Medieval assemblages have found sex-based dietary differences, such as from Newark Bay, Orkney and Fishergate in York (Richards et al., 2006; Müldner & Richards, 2007a), while others have not, for example from

Hartpoole and Newcastle (Mays, 1997). However, these examples represent very different populations and the differences between the assemblages could represent other aspects of differential access to food stuffs, such as religious status, societal role or economic circumstance. Therefore, the evidence to support sex-based differences in diet are not clear cut.

Whilst sex-based dietary differences are not seen in the Chichester assemblage, given the small sample size for this study, sex-based diet variation cannot be entirely ruled out. Moreover, isotope analysis of bone collagen cannot give more nuanced details about diet beyond differentiating between terrestrial and marine resources, amount of protein consumed, and C_3 or C_4 plants. As such, differential access to different cuts of meat or the body parts of the animal (e.g. females ate flesh, while males ate dairy) or the quality of the food being consumed (e.g. females ate preserved meat, while males ate fresh meat). would not be seen isotopically in the body tissues.

Conclusion

The diet revealed by stable isotope analysis of the bone collagen from the three burial types in the Chichester assemblage suggests a largely terrestrial diet with the possibility of a small marine resource contribution. This is somewhat different from what would have been expected based on historical and archaeological information of the post-Medieval period. There is no clear indication that marine resources made up a significant portion of the dietary protein of the individuals in post-Medieval Chichester, yet it is likely that small marine components were part of a high protein diet. However, this study shows clear variation in diet based on socioeconomic status. Individuals of higher status were buried in family tombs and were a visible representation of the family’s wealth and power. When analysed, these individuals have noticeably higher carbon and nitrogen isotope values compared to individuals in the lower status shroud and middle status coffin burials. This signifies that higher status individuals were consuming considerably more animal protein in their diet. Conversely, there was no isotope evidence for sex-based variation in the diet of post-Medieval Chichester, either between sexes within burial groups or within the entire dataset. This is consistent with similar studies within England; however, sex-based variation in diet cannot simply be ruled out and this must be taken into account with the limitations that accompany isotope analysis. Although it is too early to definitively say whether this reflects a true representation of dietary patterns in post-Medieval England, the evidence is compelling and more research needs to be done on similar sites for definitive conclusions to be drawn.

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Data availability statement:

All data are available in the supplementary online dataset.

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Table captions:

Tables:

Table 1: Table 1: Mean and median faunal baselines from Queen's Chapel of the Savoy (QCS) and Prescot Street (PS) London, and Beverley (BV)Yorkshire (Müldner & Richards, 2005; Bleasdale et al., 2019).

Species	Site	n	δ^{13}C (‰)			δ^{15}N (‰)		
			Mean	± σ	Median	Mean	± σ	Median
QCS &PS	Sheep/ goat	17	-21.9	0.4	-21.9	6.3	1.4	5.9
	Goose	1	-20.3			8.5	-20.3	
	Pig	10	-21.2	0.4	-21.3	6.7	1.8	6
	Cattle	13	-22.0	0.2	-21.9	5.8	1.6	5.7
	Fallow deer	1	-22.1			4.6		

	Domestic fowl	4	-20.2	0.2	-20.2	8.5	1.9	9.2
BV	Cyprinid	1	-18.6			10.2		
	Eel	6	-22.2	2.3	-22.8	11.6	0.7	11.75
	Flatfish	2	-12.8			12.7		
	Gadidae sp.	5	-12.8	0.7	-12.7	14.2	1.8	14.4
	Haddock	2	-13.1			13.0		
	Herring	3	-15.2	0.8	-15.4	10.7	0.6	10.4
	Ling	1	-12.4			17.2		
	Pike	2	-24.0			20.1		
	Ray	1	-12.0			14.7		
	Whiting	5	-12.7	0.5	-12.4	14.0	0.7	14.3

Table 2: δ^{13}C and δ^{15}N isotope values by burial type.

Burial Type	**n**	**δ^{13}C (‰)**					**δ^{15}N (‰)**				
		Mean	**± σ**	**Median**	**Max**	**Min**	**Mean**	**± σ**	**Median**	**Max**	**Min**
Shroud	13	-19.5	0.4	-19.7	-18.6	-20.0	11.9	0.6	12.0	12.6	10.7
Coffin	14	-19.7	0.4	-19.6	-19.0	-20.3	11.6	0.5	11.7	12.2	10.8
Tomb	13	-19.4	0.5	-19.4	-18.3	-20.0	12.4	0.3	12.4	12.8	12.0
Total	40	-19.5	0.4	-19.5	-18.3	-20.3	12.0	0.5	12.1	12.8	10.7

: δ^{13}C and δ^{15}N isotope values of males and females by burial type.

Sex	**Burial Type**	**n**	**δ^{13}C (‰)**					**δ^{15}N (‰)**				
			Mean	**± σ**	**Median**	**Max**	**Min**	**Mean**	**± σ**	**Median**	**Max**	**Min**
Female	Shroud	5	-19.7	0.2	-19.9	-19.4	-20.0	11.7	0.7	12.2	12.4	10.7
	Coffin	6	-19.5	0.4	-19.4	-19.0	-20.3	11.5	0.5	11.6	12.1	10.8
	Tomb	7	-19.4	0.5	-19.6	-18.7	-20.0	12.4	0.3	12.4	12.9	12.0
	Total	18	-19.5	0.4	-19.5	-18.7	-20.2	11.9	0.6	12.1	12.8	10.7
Male	Shroud	8	-19.4	0.4	-19.6	-17.8	-19.9	11.9	0.4	11.9	12.6	11.2
	Coffin	8	-19.8	0.4	-19.6	-19.2	-20.3	11.7	0.4	11.9	12.1	11.2
	Tomb	6	-19.3	0.6	-19.5	-18.3	-20.0	12.4	0.3	12.5	12.8	12.1
	Total	22	-19.5	0.5	-19.6	-18.3	-20.3	12.0	0.5	12.0	12.8	11.2

Figure captions:

Figure 1: Map of England showing the location of Chichester in relation to other sites discussed.

Figure 2: Excerpt of the 1880 map of Chichester with the site of the Litten cemetery outlined in red (Sussex LXI Ordnance Surveys, 1880). Note that by the time this map was drawn, the cemetery was already closed.

Figure 3: Examples of the three main burial types found at the site of St Michael's Litten (ESC11) Chichester observed in the post-Medieval period: A) typical 'shroud' burial; B) typical 'coffin' burial; and C) typical 'tomb' burial. (All images: Archaeology South East.)

Figure 4: Human $\delta^{15}N$ and $\delta^{13}C$ values from the Chichester assemblage plotted with the mean faunal values from Queen's Chapel of the Savoy (c. AD 1510 to 1854) and Prescot Street and Beverley (16th to 19th Century AD) (East Riding of Yorkshire (Müldner & Richards, 2005; Bleasdale et al., 2019). All means ± one standard deviation.

Figure 5: Graph of the isotope values for all samples in this assemblage: coffin n=14, shroud n=13, tomb n=13, with mean isotope values for each burial type (all means ± one standard deviation). Note the clustering of tomb burial $\delta^{15}N$ values.

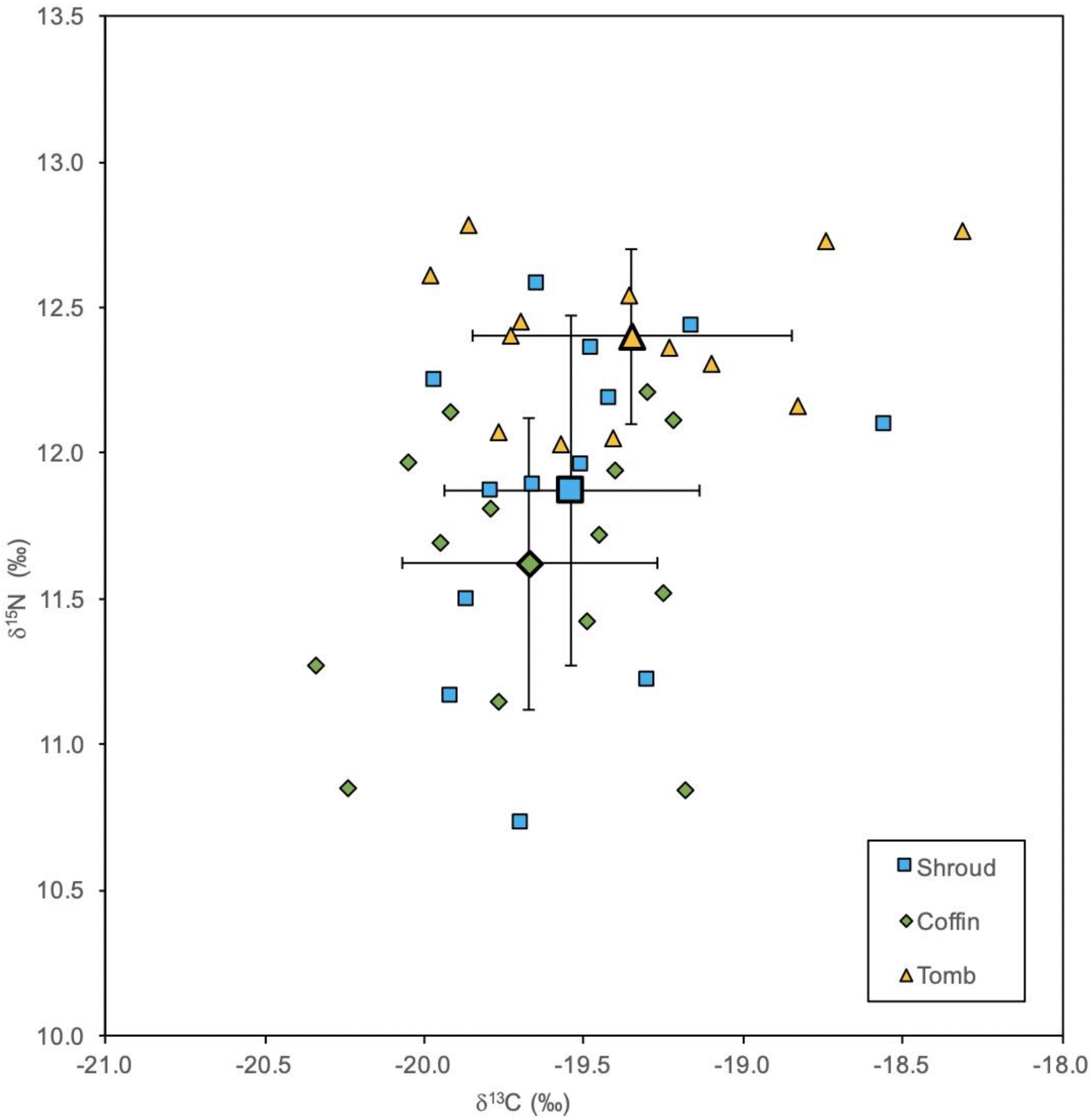

Figure 6: $\delta^{15}N$ and $\delta^{13}C$ values for males and females for all burial types (a), tomb burials (b), coffin burials (c) and shroud burials (d).

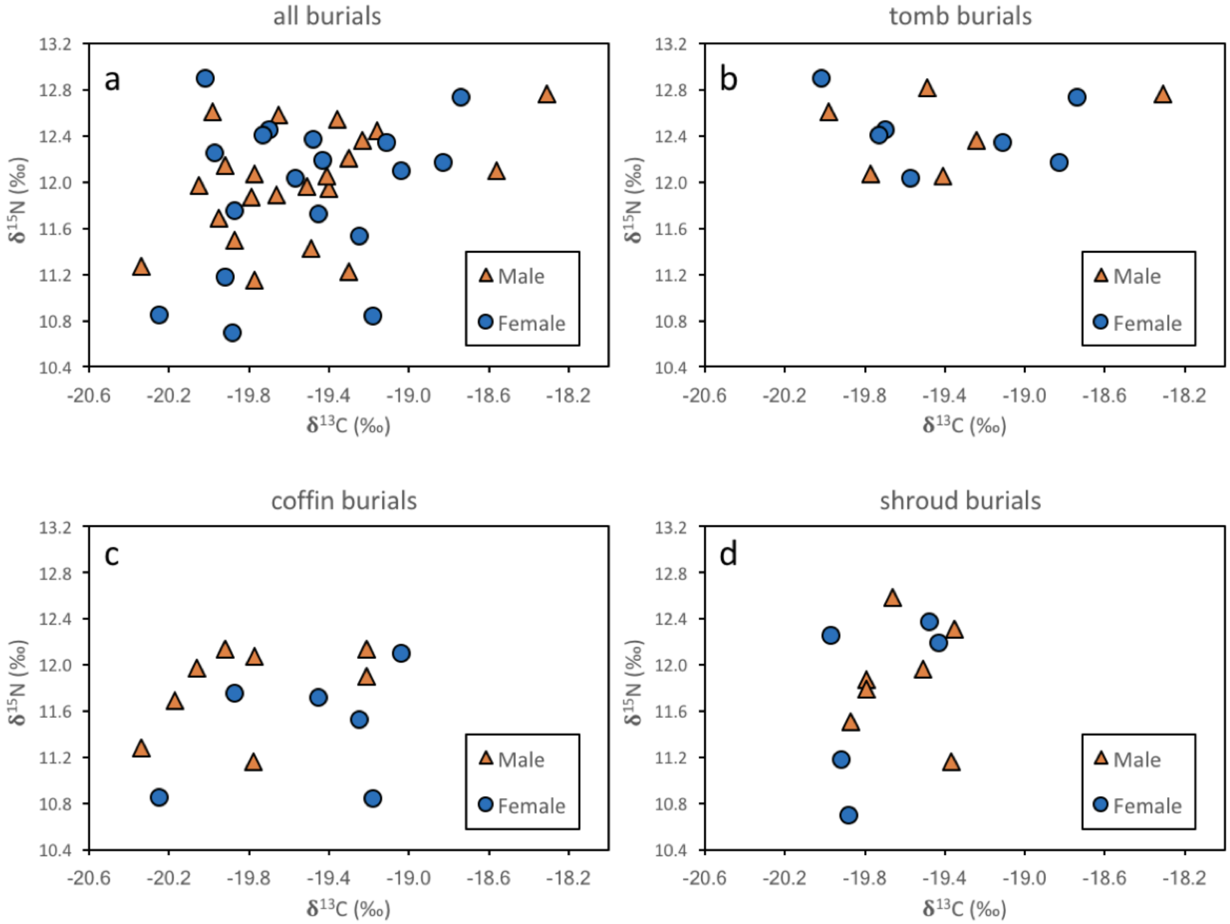

Figure 7: Mean isotope values of shroud, coffin, and tomb burials from the Chichester assemblage in comparison with isotope data from Coventry (18-19th century AD) (Trickett, 2006), Chelsea, London (18-19th century AD) (Trickett, 2006), St Martins, Birmingham (late 18th to 19th century AD) (Richards 2006), All Saints, York (17th to early 19th century AD) (Müldner & Richards, 2007a), Lukin Street, London (19th century AD) (Beaumont et al., 2013), Spitalfields, London (18th and 19th century AD) (Nitsch et al., 2010), Queen's Chapel of the Savoy, London (c. AD 1510 to 1854) (Bleasdale et al., 2019), St Barnabas, London (1831 to 1853 AD) (Bleasdale et al., 2019). All means ± 1 standard deviation.