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ORIGINAL PAPER

# High status diet and health in Medieval Lisbon: a combined isotopic and osteological analysis of the Islamic population from São Jorge Castle, Portugal

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## Abstract

This paper presents the first bioarchaeological study of Islamic diet and lifeways in medieval Portugal. Stable isotopes of $\delta^{13}C$ and $\delta^{15}N$ and osteological and paleopathological analyses are combined to explore the diet and health status of 27 humans buried within São Jorge Castle, Lisbon (eleventh to twelfth century), interpreted as a high status population. Human isotopic data are considered alongside an animal baseline comprised of 30 specimens sampled from nearby Praça da Figueira, including the main domesticates and fish. Isotopic data indicate an age- and sex-related difference in diet among the population, suggesting a difference in food access between females and children compared to males. Palaeopathological analysis indicates a low prevalence of non-specific stress indicators such as Harris lines (HL), linear enamel hypoplasia (LEH) and cribra orbitalia (CO) in this population in comparison to other medieval populations. LEH is only present in adults. These results suggest the presence of socio-cultural patterning relating to the organisation of the Islamic family, where women and men occupied different places in the household and society. This paper demonstrates the utility of a combined osteological and isotopic approach to understand the lifeways of Islamic populations in Medieval Iberia, as well as illuminates the lifeways of understudied segments of the population.


**Keywords** Muslim, diet · Medieval, Portugal · Stable isotopes · Paleopathology

## Introduction

This study applies a combination of bioarchaeological techniques to explore a human skeletal assemblage from São Jorge Castle, Lisbon, dating to the time of Islamic rule (eighth to thirteenth century). Osteological and paleopathological analysis, together with carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopic analysis of human and animal bone collagen are employed to explore the diet and lifeways of this high status population (Fig. 1). The standard Muslim burial custom entails the use of dedicated areas for burial, usually located outside the city walls with no discrimination based on social status (Insoll 1999, p. 169). The unusual location of these interments, within the Castle itself, suggests these individuals might have had a privileged treatment at death and therefore belonged to an elevated social status, with possible links to the ruling Islamic family. The archaeological excavation and associated finds provide a chronology for the use of this site between the tenth and eleventh century, at the height of Islamic rule in Lisbon. This assemblage thus provides a unique opportunity to explore the dietary habits and overall health status of a specific group of individuals within Lisbon's Medieval Muslim community.

Isotopic research into medieval diet among Islamic populations in Iberia is growing, specifically in Spain. Research has been undertaken on individuals from Valencia and Aragon (Alexander et al. 2015; Guede et al. 2015; Salazar-García et al. 2014, 2016), a small assemblage from Granada (Jiménez-Brobeil et al. 2016) and the Balearic Islands of Mallorca (Cau Ontiveros et al. 2016; Garcia et al. 2004),

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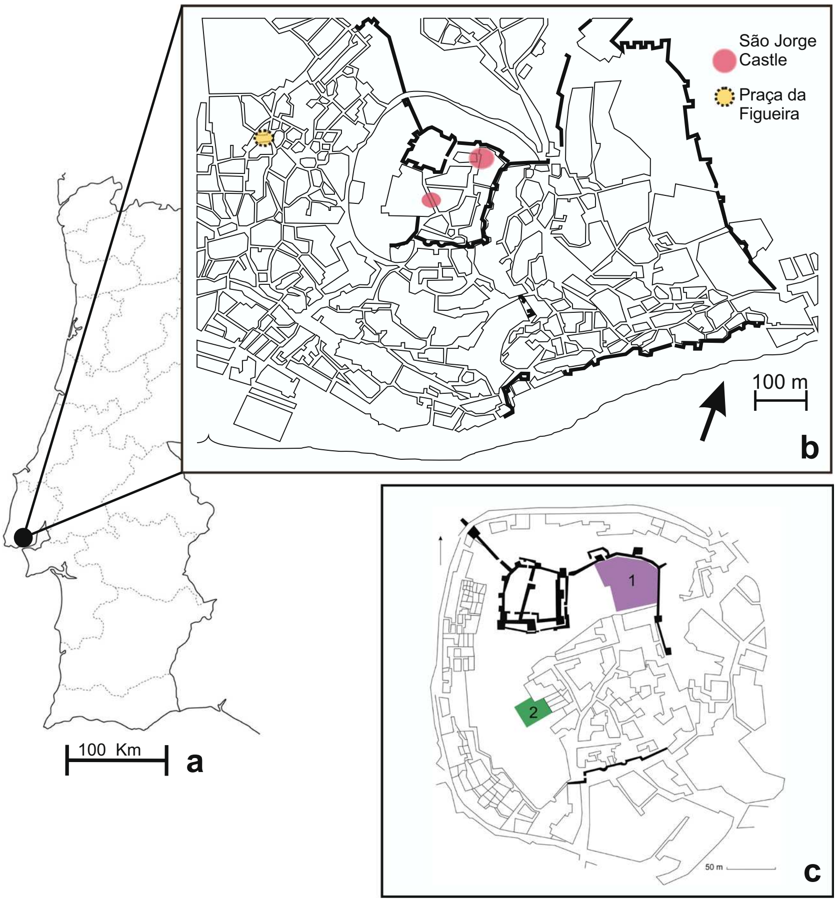



**Fig. 1** **a** Location of Lisbon in Portugal; **b** location of São Jorge Castle (human remains) and Praça da Figueira (animal remains) (adapted from Planta da cidade de Lisboa 1650, copia de Carvalho Jr. in Silva, 1884); **c** sites of Praça Nova (1) and Palácio das Cozinhas (2) (adapted from drawing by Rita Nobre Neto da Silva (2014) based on municipal open-source cartography Câmara Municipal de Lisboa, 2012)

Ibiza and Formentera (Fuller et al. 2010; Nehlich et al. 2012; Pickard et al. 2017). Regarding Portuguese material, a recent article explored the diet of a group of Late Antique Christian individuals from Monte da Cegonha (Saragoça et al. 2016). However, to date no research has been published on Portuguese Islamic material.

## Osteology, lifeways and diet

The combination of osteology and stable isotopes analysis offers different but complimentary data sets, which allow us to investigate medieval lifeways more holistically in terms of diet and health. Pathological alterations such as dental enamel hypoplasia, cribra orbitalia, Harris lines and periostitis are the bone/teeth insults commonly investigated in non-adults and adults in past populations. These lesions are considered signs of non-specific stress and are used to produce an overall, but approximate idea of community health, to reconstruct the health profile of the population (Mays 2013).

This study aims to identify potential variations in dietary habits and lifeways within the Muslim social elite. Notably, this represents the first application of stable isotope analysis to examine diet for an Islamic population in Portugal, adding a new body of data to the understanding of medieval diet on the Western edge of the Iberian Peninsula. This paper demonstrates the potential of a combined bioarchaeological approach to understand medieval lifeways, and to shed light onto specific segments of the society that were traditionally understudied or misrepresented in the historical sources (i.e. women and children).

## Site context

This study is primarily focused on skeletal materials from Islamic burials from São Jorge Castle (SJC), located on a hilltop in the centre of present day Lisbon (Fig. 1). A settlement with defensive walls was established here in the Roman period (Bugalhão 2009, p. 385), commanding a strategic location at the confluence of the River Tagus and the Atlantic Ocean. The area is surrounded by fertile territory and has convenient access to the interior by river, making this site particularly appealing to Muslim settlers in 714 CE (Picard 2000, p. 25). However, the role of Lisbon in the first years of Islamic rule was marginal until the ninth century. Its major expansion, testified by the construction of later defensive walls, took place between the eleventh and twelfth centuries

(Torres 1994). The castle is mentioned in Christian sources that describe Lisbon immediately after the conquest; however, its foundation is yet to be attributed to a specific date. The building that stands today has undergone vast restoration and is, in fact, a Medieval Christian fortress, with later sixteenth and seventeenth century additions (Melo 2014, p. 46).

Archaeological excavation undertaken within the Castle site recovered several stratified structures pertaining to different chronologies, indicating a long-lasting occupation from the Iron Age to the post-medieval period. However, the publication of data from the excavation focuses mainly on the later medieval period under Christian rule (Gaspar and Gomes 2001; Gomes et al. 2003).

The faunal remains included in this study were excavated from the nearby site of Praça da Figueira in Lisbon. Praça da Figueira has a notable place in the history of Lisbon's archaeology. Excavations of the Modern Age Royal Hospital of All Saints between 1960 and 1971 and more recent works between 1999 and 2001 revealed a long diachronic use of the site, from a Late Bronze Age small settlement (circa 10th–9th BCE) to the modern day. Late Antique/post-Roman occupation was recorded and other structures dated to the Islamic period (eleventh to twelfth century) were identified, along with later medieval activity associated with a nearby Dominican convent (thirteenth century onwards). Archaeological evidence for the seventh to mid-eleventh century is scarce but significant evidence was found for the second half of the eleventh century, consistent with agricultural use of the land. However, during the early twelfth century, a swift change occurred in the eastern part of the area where blocks of houses and roads were built. This suburban expansion attests to the enlargement of Muslim Lisbon in the few decades that preceded the Christian conquest by the coalition of Northern European Crusaders and the Portuguese king (1147 CE). Some of the excavated suburban Muslim houses were kept in use after the Christian conquest, while others were abandoned. By the early thirteenth century, only two of them were still occupied, and most of the area regained its previous agricultural vocation.

## Archaeological evidence for diet in Medieval Iberia and Lisbon

Much of what is known about medieval diet comes from historical accounts that usually focus on Christian Europe. While a handful of cookbooks and health treatises survived from the late medieval period concerning Islamic Spain, no information is given on the territories of modern day Portugal (Rosenberger 1999, p. 222; Adamson 2004, p. 117). Variety appears to be the basic feature of early medieval diet at all social levels; however, qualitative and quantitative differences existed between various social groups, and food played an important role in reinforcing group identities at the time (Montanari 1999, p. 169). Arab cuisine focused mostly on meat from domestic animals, fowl and game, accompanied by vegetables and a variety of flat breads in the East or semolina flour couscous in the Maghreb. Animal fat, especially from mutton, was widely used (Rosenberger 1999, p. 214). Although the principles of Arab cuisine can be generally applied to the Islamic west, the Iberian Peninsula developed its own variations due to the assimilation of previous culinary traditions, namely those imported by Phoenicians, Greeks and Romans (Adamson 2004, pp. 115–116). In the absence of specific historical sources for the Portuguese territories, archaeological research plays a crucial role in shedding light onto dietary habits and food preferences shown by the Islamic community of the West.

The use of plants in the diet of medieval Muslims and Christians, including imports, is widely documented in historical sources. Although they describe the main products consumed in Medieval Christian Portugal, these can be applied, with some approximation, to the late Islamic period. In a few cases, the link between the persistence of Islamic customs orcelery, common vervain and cumin were recorded especially in Praça D. Pedro IV with ruderal species including goosefoot, annual mercury, purslane and common nettle (Bugalhão and Queiroz 2006; Queiroz 1999; Queiroz and Mateus 2012). Surprisingly, in both Lisbon contexts, there was no trace of leguminous plants or cereals, although they are widely mentioned in historical sources (Rei 2017, pp. 70–71). This misrepresentation, especially in comparison to other Islamic sites in Southern Portugal, is linked to the nature of the sites that, especially for NARC, was linked to a possible fruit processing and transformation industry (Bugalhão and Queiroz 2006). Since stable isotope analysis of collagen cannot inform on the fruits and vegetables consumed, these findings are a valuable contribution to explore variety in the medieval diet, although in this case they do not reveal the cereal staples, which are usually found as charred cereal remains in silos.

Historical sources mention a high reliance on herbivores such as cattle, sheep and goat and also birds such as chickens and partridge (Catarino 1998, p. 126; Gonçalves 1989, p. 294). Dairy and eggs would also have been widely consumed, and were a substantial part of the protein intake of the lower classes (Catarino 1998, pp. 130–131). Wild animals like rabbits and hares were consumed by all social classes as they were very abundant in Portugal (Gonçalves 2004). Fish consumption was common (e.g. sardines and tuna): inshore and coastal fishes are an easy catch and may have supplemented the diet of the lower classes in those areas (Catarino 1998, p. 142; Gonçalves 2004). In terms of zooarchaeological evidence for diet, animal bones from five sites in Lisbon have been studied, four of which have been published and include material of Islamic chronology: Sé (Moreno-García and Davis 2001); São Jorge Castle (Moreno-García 2008 unpublished); NARC (Bugalhão et al. 2008; Moreno-García and Gabriel 2001); Lisbon western quarter (Bugalhão et al. 2008) and Largo da Severa (Valente and Marques 2017). Four of these sites date between the ninth to twelfth century and resulted from different waste activities in Islamic Lisbon. The consumption pattern portrayed at these sites adheres to other Islamic cities in Portugal such as Santarém (Davis 2006; Moreno-García and Davis 2001), Alcácer do Sal (Moreno-García and Davis 2001), Mértola (Antunes 1996; Morales Muñiz 1993; Moreno-García and Pimenta 2012), Mesas do Castelinho (Cardoso 1993), Évora (Costa and Lopes 2012), and Silves (Davis et al. 2008) with a predominance of sheep/goat, followed by cattle and rabbit.

Zooarchaeological studies of faunal assemblages from Islamic sites showed a high predominance of ovicaprids as the most represented species, followed by rabbit. Only two sites show different species as being the most common: pig in Torre Vedras (Gabriel 2003) and cow in Conimbriga (Detry et al. 2014). The presence of pig is quite surprising though somehow common in Islamic sites (Detry et al. 2014, p. 101). This is usually explained as pig breeding for Christian consumption or wild boar hunting, a practice that was permitted in case of need, and still exists in modern Maghreb tribes (Simoons 1961). Cattle is common and is usually the second or third most represented species across all sites. The assemblage from São Jorge Castle itself is rather small and therefore it is hard to judge how representative it is. It is interesting to note, however, that unlike other Islamic fortresses in Portugal, there is no trace of larger hunted animals such as deer that are considered a sign of high status diet and found at similar sites elsewhere, e.g. Paderne, Palmela, Salir and Sintra (Cardoso and Fernandes 2012; Coelho 2012; Fernandes et al. 2015; Martins 2013; Pereira 2013). In terms of age at death, evidence indicates that sheep/goat were slaughtered for consumption at a younger age whereas cattle were older, perhaps consumed after their agricultural use as draught animals was over, in accordance with the suggestions of Arabic culinary treatises (Nasrallah 2007).

## Materials

Within São Jorge Castle, 35 individuals were excavated from two sites: Praça Nova (PN) and Palácio das Cozinhas (PC). Each individual was assessed for sex and age and the recurrence of three non-specific stress markers were recorded: linear enamel hypoplasia (LEH), Harris lines (HL) and cribra orbitalia (CO) as outlined below. Samples of 27 individuals were taken for stable isotope analysis of collagen $\delta^{13}C$ and $\delta^{15}N$, with preference to more complete skeletons with well-preserved ribs (Table 1). Five Islamic individuals excavated from Calçadinha do Tijolo (CDT), Alfama and Lisbon, were also analysed using stable isotope analysis to provide a low status comparison to the high status individuals from SJC. A full report of the excavation, dietary and anthropological study has been published elsewhere (Filipe et al. 2018).

Animal bone samples from a range of taxa ($n = 38$) were collected from waste pits associated with domestic contexts

**Table 1** List of analysed individuals from São Jorge Castle (SJC)

| Individual codes | Age (y.o.) | Sex | LEH | HL | CO | SAI |
|---|---|---|---|---|---|---|
| CSJ.PC.1 | IA | M | | | | x |
| CSJ.PN.1 | 30–49 | M | ✓ | | ✓ | ✓ |
| CSJ.PN.2 | 18–29 | F | ✓ | | ✓ | ✓ |
| CSJ.PC.2 | 18–29 | I | | | | ✓ |
| CSJ.PC.3 | 6–11 | NA | ✓ | ✓ | ✓ | ✓ |
| CSJ.PC.4 | 0.16–5 | NA | | ✓ | | ✓ |
| CSJ.PN.4 | 0.16–5 | NA | ✓ | | | ✓ |
| CSJ.PC.5 | 12–17 | NA | ✓ | | | ✓ |
| CSJ.PN.5 | 12–17 | NA | ✓ | | | ✓ |
| CSJ.PC.6 | IA | M | | | | |
| CSJ.PN.6 | 0.16–5 | NA | ✓ | ✓ | ✓ | ✓ |
| CSJ.PC.7 | 18–29 | F | ✓ | | | ✓ |
| CSJ.PN.7 | 0.16–5 | NA | | | | ✓ |
| CSJ.PC.8 | 18–29 | M | ✓ | | ✓ | ✓ |
| CSJ.PN.8 | 0.16–5 | NA | ✓ | | ✓ | ✓ |
| CSJ.PC.9 | IA | M | | ✓ | | |
| CSJ.PN.9 | Foetus | NA | | ✓ | | |
| CSJ.PN.10 | NB | NA | ✓ | | | ✓ |
| CSJ.PC.11 | 12–17 | NA | ✓ | | ✓ | ✓ |
| CSJ.PN.11 | NB | NA | | | | ✓ |
| CSJ.PC.12 | 18–29 | F | | | | ✓ |
| CSJ.PN.12 | NB | NA | | | | ✓ |
| CSJ.PC.13 | 0.16–5 | NA | | | ✓ | ✓ |
| CSJ.PN.13 | 0.16–5 | NA | | | | ✓ |
| CSJ.PC.14 | > 50 | F | | ✓ | | ✓ |
| CSJ.PN.14 | NB | NA | | ✓ | | ✓ |
| CSJ.PC.15 | Foetus | NA | | ✓ | | |
| CSJ.PN.15 | NB | NA | | | | ✓ |
| CSJ.PC.16 | 30–49 | F | | | | ✓ |
| CSJ.PC.17 | 0.17–5 | NA | ✓ | | ✓ | ✓ |
| CSJ.PC.18 | INA | NA | | | | |
| CSJ.PC.19 | 30–49 | F | | | | ✓ |
| CSJ.PC.20 | NB | NA | | ✓ | | ✓ |
| CSJ.PC.21 | IA | I | | | | |
| CSJ.PC.22 | IA | F | | | | |

Codes: *I* indeterminate, *IA* indeterminate adult, *INA* indeterminate non-adult, *NB* newborn, *LEH* linear enamel hypoplasia, *HL* Harris lines, *CO* cribra orbitalia, *SIA* stable isotopes analysis excavated in Praça da Figueira under the direction of Dr. Rodrigo Banha da Silva. To increase sample size, animals were sampled from layers dating from the Roman to the late medieval period (first to fourteenth centuries).

## Methods

### Preservation, paleodemographic and paleopathological assessment

The anatomical preservation index (API) and the bone representation index (BRI) were calculated for all individuals, following Dutour (1989) and Garcia (2005/2006), in order to assess if there were differences in preservation regarding sex and age, which could bias the demographic profile of the sample. The skeleton was divided in 44 anatomical parts classified between 0 (bone not preserved) and 1 (bone present and complete). For the vertebral column, pelvic girdle, ribs, hands and feet, a ratio between the number of preserved bones and the bones that should have been present was computed (BRI). The quality of the periosteum was not quantified.

Paleodemographic data were collected by standard methods as outlined below. Individuals were assembled in age groups according to the following categories: foetus (under 39 weeks); newborns (40 weeks to < 1 month); infants (1 month to 5 years); children (6 to 11 years); juveniles (12 to 17 years); young adults (18 to 29 years); middle-aged adults (30 to 49 years) and old adults (> 50 years).

For non-adults, age at death was estimated primarily through dental development (Liversidge et al. 1993; Liversidge and Molleson 1999). In the absence of teeth, the length of long bones shafts and skeleton maturation were used to provide an age estimation (Cardoso 2005; Scheuer et al. 2009). Adult age estimation was performed following multiple methods such as the evaluation of the pubic symphysis (Brooks and Suchey 1990), the auricular surface (Lovejoy et al. 1985) and the sternal end of the ribs (İşcan et al. 1984, 1985). In younger adults, the medial epiphysis of the clavicle was analysed to provide a more specific age according to the state of fusion observed (Cardoso 2008). For sex estimation, the method proposed by Bruzek (2002) was used. In the absence of the pelvic girdle, the skull and post-cranial bones were used (Cardoso 2000; Silva 1995; Walrath et al. 2004).

Macroscopic assessment of all skeletons was undertaken by Sara Gaspar and Susana Garcia to detect abnormal bone formations that could be related to a pathological process. All bones were systematically analysed to detect signs of infectious diseases like tuberculosis or leprosy, and metabolic diseases (e.g. scurvy, osteoporosis or vitamin D deficiency) according to Ortner (2003), Matos and Santos (2006), and Matos (2009). The presence of periostitis on the anterior tibia was investigated. Caries were recorded in all erupted deciduous and permanent teeth according to Hillson (2001). The assessment of HL was performed on adults and non-adult tibiae. Data were collected by x-ray analysis with consideration of the indications listed by Mays (1995). Distal ends of left tibiae were classified in relation to the presence/absence of HL and in reference of the total number of lines observed: (1) tibia with one line; (2) tibia with two or three lines; (3) tibia with four or more lines. The right tibia was used in the absence of the left one.

LEH is represented by a transverse line or groove across the tooth enamel (King et al. 2005) and was recorded in the anterior permanent dentition, from both adults and non-adults. Each anterior tooth was macroscopically observed under a strong light and was classified in relation to the presence/absence of LEH and the number of lines was counted. Only teeth with dental wear less than stage 6 were analysed (Smith 1984). Individuals with two or more anterior teeth with observable defects were considered LEH positive. The codes were as follows: (1) tooth without hypoplasia; (2) tooth with one line; (3) tooth with two or more lines. Signs of haematological disorders (e.g. anaemia) were searched in all available orbits in adults and non-adults older than 6 months. Orbital lesions were classified according to Stuart-Macadam (1985) as: (1) light; (2) moderate; (3) severe.

Statistical analyses were carried out using SPSS version 20 and 22. Due to the small sample size, non-parametric tests were used to assess associations between variables. The differences in the prevalence of the stress markers between age and sex groups were assessed with $X^2$ test and the Yate's correction was applied.

### Collagen extraction and stable isotope analysis

Ribs were sampled from each adult skeleton. In the non-adult skeletons, ribs were not always present or were fragmented; therefore, long bones such as tibia, femur and humerus were preferred. The bones were only collected if they were incomplete and whenever the antimere was present and in a good state of preservation. Collagen was extracted following a modified Longin (1971) method including an ultrafiltration step (Brown et al. 1988). The samples (~ 0.4 g) were mechanically cleaned with a scalpel blade and demineralised in acid (0.6 M HCl at 5 °C for up to 7 days). The resulting demineralised bone was gelatinised in HCl at pH 3 for 48 h at 80 °C. The gelatinised fraction was ultrafiltered to isolate the higher molecular weight collagen (> 30 kDa) which was then frozen (~ − 20 °C) and lyophilized. The collagen samples were analysed in duplicate using isotope ratio mass spectrometry (IRMS) with a Sercon 20-22 at the BioArCh facilities, University of York. Isotopic values are reported following standard practice as the ratio of the heavier isotope to the lighter one ($\delta$ values in parts per mille, ‰) relative to internationally defined standards for carbon $^{13}C/^{12}C$ (VPDB, Vienna Pee Dee Belemnite) and nitrogen $^{15}N/^{14}N$ (AIR) following the equation [$\delta = (R_{sample} - R_{standard}) / R_{standard} \times 1000$]. The analytical error for $\delta^{13}C$ and $\delta^{15}N$ was ± 0.2‰ as determined by analysis of internal laboratory standards coupled with every run. The accuracy of measurements was monitored using international and in-house standards with well-known isotopic composition (in-house fish gelatine: $\delta^{13}C$ − 15.5 ± 0.1, $\delta^{15}N$ 14.3 ± 0.2; cane sugar IA-R006: $\delta^{13}C$ − 11.8 ± 0.1; caffeine IAEA 600: $\delta^{13}C$ − 27.8 ± 0.1, $\delta^{15}N$ 0.8 ± 0.1; ammonium sulfate IAEA N2: $\delta^{15}N$ 20.4 ± 0.2).

Statistical analyses of the isotopic data were conducted using SPSS with $p$ values < 0.05 considered significant. Due to the small sample size, only the non-parametric Mann-Whitney $U$ test for equal median was used to compare groups.

## Results

### Preservation, paleodemographic and paleopathological profile

This collection presents a moderate API; on average, 38% of the bones were present to be analysed. Non-adults were better preserved (43%) than adults (31%), and males (53%) were better preserved than females (42%).

Figure 2 illustrates the demographic profile of the population. The sample is composed of 35 individuals, 21 non-adults and 14 adults. Of the non-adults, 13 were less than 2 years at the time of death, 3 were between 2 and 6 years and 5 were older than 6 years.

The adult sample is composed of five young adults, three middle-aged adults and one old adult. The age-at-death was undetermined in five adults. Fifty percent of the adults are female ($n = 7$) and 36% are male ($n = 5$). However, sex was not estimated in two individuals due to poor preservation.

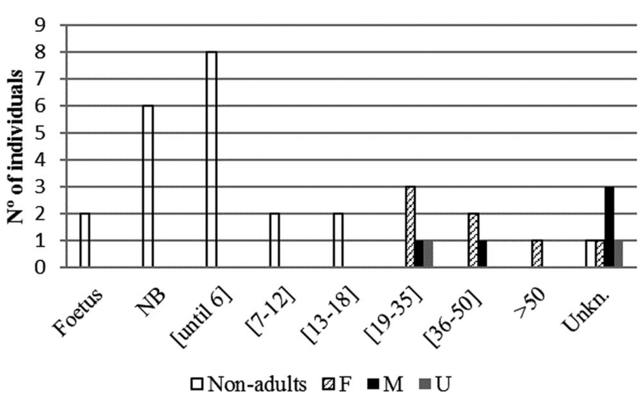



**Fig. 2** Demographic profile of the population

The non-adults present more stress indicators than the adults (Table 2), although the difference is not significant ($p >$ 0.05). The exception is the prevalence of LEH, which affected 33.3% of the non-adults ($n = 3$) and 75% of the adults ($n = 3$). Harris lines were scored in seven non-adults and two adults. Observable orbits included six that belonged to non-adults (older than 6 months) and three to adults. Half of the non-adults exhibit CO, while it was absent in the adult sample.

No cases of infectious disease such as tuberculosis or leprosy were identified and no sign of non-specific osteitis or periostitis was also found. Signs of scurvy, osteoporosis or vitamin D deficiency (rickets and osteomalacia) were also not observed. From the nine non-adults with erupted permanent teeth, three exhibited caries (33%), while in the adult population only one male individual had caries. It is worth mentioning that in the São Jorge Castle sample, only four adults have teeth preserved and ante-mortem tooth loss was not found. The sample size is too small to warrant statistical comparison.

### Stable isotope analysis

All samples passed collagen quality criteria (%C, %N, C/N; De Niro 1985; van Klinken 1999) and sufficient collagen was extracted in all samples (> 1% yield) apart from one case (CSJ.PC.20). This sample was not included in the analysis. It should be noted that the use of ultrafilters is known to substantially decrease collagen yields (Jørkov et al. 2007).

A summary of the stable isotope data including mean and standard deviation of the main species, adult and non-adult individuals is provided in Table 3. The human and animal stable isotope data are listed in Tables 4 and 5 and plotted together in Fig. 3.

Despite the wide chronology for the animal samples, there is no chronological pattern to the data. All domestic animals exhibit a diet based on $C_3$ plants with no trace of $C_4$ plants.

**Table 2** Prevalence of stress indicators by age and sex including LEH (linear enamel hypoplasia), HL (Harris lines), CO (cribra orbitalia)

| | Non-adults | | | Adults | | | | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Females | | | Males | | | | | |
| | *N* | *n* | % | *N* | *n* | % | *N* | *n* | % | *N* | *n* | % |
| LEH | 9 | 3 | 33 | 2 | 1 | 50 | 2 | 2 | 100 | 12 | 6 | 50 |
| HL | 7 | 1 | 14 | 1 | 0 | 0 | 1 | 0 | 0 | 9 | 1 | 11 |
| CO | 6 | 3 | 50 | 1 | 0 | 0 | 2 | 0 | 0 | 8 | 2 | 25 |

*N*, number of total individuals available; *n*, number of individuals with the stress markers

**Table 3** Summary of isotopic data for adults (> 18 years) and non-adults (≤ 18 years) from São Jorge Castle (tenth to eleventh centuries) and animals from Praça da Figueira (first to fourteenth centuries)

| Site/species | *n* | $\delta^{13}C_{VPDB}$ (‰) | | | | $\delta^{15}N_{AIR}$ (‰) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Range | Mean ± 1σ | Min | Max | Range | Mean ± 1σ |
| SJC adults | 10 | − 19.4 | − 18.5 | 0.9 | − 18.9 ± 0.3 | 8.6 | 11.2 | 2.6 | 9.9 ± 0.8 |
| SJC non-adults | 17 | − 18.8 | − 16.5 | 2.2 | − 18.1 ± 0.6 | 8.4 | 13.1 | 4.3 | 10.9 ± 1.2 |
| *B. taurus* (cattle) | 10 | − 21.8 | − 20.2 | 1.6 | − 21.1 ± 0.5 | 4.9 | 11.1 | 6.2 | 6.3 ± 1.9 |
| *O. aries* (sheep) | 5 | − 21.6 | − 20.0 | 1.6 | − 20.8 ± 0.6 | 4.5 | 9.9 | 5.4 | 6.6 ± 2.4 |
| *C. hircus* (goat) | 3 | − 20.6 | − 20.0 | 0.6 | − 20.2 ± 0.6 | 4.0 | 10.6 | 6.7 | 6.5 ± 3.6 |
| *Sus* (pig/wild boar) | 6 | − 21.0 | − 18.9 | 2.1 | − 20.0 ± 0.8 | 4.9 | 7.7 | 2.8 | 6.6 ± 1.0 |
| *Gallus* (chicken) | 5 | − 19.9 | − 18.4 | 1.4 | − 19.0 ± 0.6 | 8.0 | 10.7 | 2.7 | 9.4 ± 1.3 |

Notably, herbivores from all periods exhibit widely ranging $\delta^{15}$N values (4.0 to 11.1‰, range 7.1‰). Omnivores, as expected, have variable diets. Chickens and the one dog specimen possess similar values to humans, whereas pigs tend to have lower $\delta^{15}$N values, placing them among the herbivores.

The trophic level offset between humans and herbivores is within the expected range of 3–5‰ (Bocherens and Drucker 2003). Male values are on average 1.8‰ higher in $\delta^{13}$C and 4.5‰ in $\delta^{15}$N compared to the herbivores, while female values are 1.9‰ higher in $\delta^{13}$C and 3.1‰ in $\delta^{15}$N. Although males were consuming higher trophic level protein, females were

**Table 4** Values of $\delta^{13}$C and $\delta^{15}$N of the humans with indication of sex and age at death

| Site | Sample | Sex | Age (years) | $\delta^{13}C_{VPDB}$ (‰) | $\delta^{15}N_{AIR}$ (‰) | C/N | %Col |
|---|---|---|---|---|---|---|---|
| Praça Nova | 1 | M | 30–49 | − 18.8 | 11.2 | 3.23 | 0.74 |
| | 2 | F | 18–29 | − 18.7 | 9.4 | 3.22 | 2.91 |
| | 4 | I | 0.1–5 | − 18.4 | 9.4 | 3.20 | 4.79 |
| | 5 | I | 12–17 | − 17.3 | 10.4 | 3.2 | 2.52 |
| | 6 | I | 0.1–5 | − 18.1 | 12.2 | 3.18 | 39.40 |
| | 7 | I | 0.1–5 | − 16.5 | 11.5 | 3.27 | 2.72 |
| | 8 | I | 0.1–5 | − 17.8 | 12.5 | 3.26 | 8.8 |
| | 10 | I | NB | − 18.7 | 10.1 | 3.22 | 1.43 |
| | 11 | I | NB | − 18.6 | 11.3 | 3.38 | 2.14 |
| | 12 | I | NB | − 17.6 | 10.4 | 3.31 | 1.23 |
| | 13 | I | NB | − 18.2 | 11.8 | 3.23 | 1.51 |
| | 14 | I | NB | − 17.8 | 11.0 | 3.18 | 3.10 |
| | 15 | I | NB | − 17.9 | 10.5 | 3.29 | 1.30 |
| Palácio das Cozinhas | 1 | M | IA | − 18.7 | 11.2 | 3.16 | 3.98 |
| | 2 | I | 18–29 | − 18.8 | 9.9 | 3.29 | 0.12 |
| | 3 | I | 6–11 | − 18.1 | 10.5 | 3.21 | 3.75 |
| | 4 | I | 0.1–5 | − 18.2 | 10.8 | 3.20 | 4.10 |
| | 5 | I | 12–17 | − 18.8 | 9.2 | 3.17 | 7.78 |
| | 7 | F | 18–29 | − 19.1 | 9.2 | 3.15 | 0.99 |
| | 8 | M | 18–29 | − 19.4 | 10.0 | 3.22 | 1.90 |
| | 11 | I | 12–17 | − 18.4 | 8.8 | 3.17 | 7.41 |
| | 12 | F | 18–29 | − 18.9 | 9.9 | 3.19 | 0.64 |
| | 13 | I | 0.1–5 | − 17.9 | 13.1 | 3.25 | 2.96 |
| | 14 | F | > 50 | − 18.5 | 9.6 | 3.33 | 1.33 |
| | 16 | F | 30–49 | − 18.9 | 9.4 | 3.2 | 5.59 |
| | 17 | I | 0.1–5 | − 18.4 | 10.9 | 3.19 | 3.56 |
| | 19 | F | 30–49 | − 18.9 | 8.6 | 3.21 | 1.91 |

**Table 5** Values of $\delta^{13}C$ and $\delta^{15}N$ of the faunal remains (Praça da Figueira)

| Site | Sample | Period | Taxon | $\delta^{13}C_{VPDB}$ (‰) | $\delta^{15}N_{AIR}$ (‰) | C/N | %Col |
|---|---|---|---|---|---|---|---|
| Praça da Figueira | 8605C | 1st to 3rd | *B. taurus* | − 20.3 | 5.4 | 3.31 | 1.09 |
| | 8584C | 1st to 3rd | *B. taurus* | − 21.4 | 6.5 | 3.21 | 5.22 |
| | 8521C | 1st to 3rd | *B. taurus* | − 21.3 | 5.7 | 3.21 | 3.04 |
| | 8204C | 1st to 3rd | *B. taurus* | − 21.5 | 5.0 | 3.18 | 4.51 |
| | 7500C | 1st to 3rd | *B. taurus* | − 20.9 | 6.0 | 3.26 | 4.66 |
| | 4179C | 1st to 3rd | *B. taurus* | − 21.8 | 5.8 | 3.20 | 1.73 |
| | 3602C | 12th | *B. taurus* | − 20.2 | 5.3 | 3.19 | 8.74 |
| | 1227C | 14th | *B. taurus* | − 21.7 | 4.9 | 3.20 | 7.34 |
| | 1184C | 14th | *B. taurus* | − 20.8 | 4.9 | 3.19 | 7.32 |
| | 1177C | 14th | *B. taurus* | − 21.3 | 8.3 | 3.20 | 6.42 |
| | 1164S | 14th | *B. taurus* | − 20.9 | 11.1 | 3.23 | 4.12 |
| | 8584S | 1st to 3rd | *C. hircus* | − 19.9 | 4.7 | 3.21 | 2.49 |
| | 8541S | 1st to 3rd | *C. hircus* | − 20.0 | 4.0 | 3.20 | 9.26 |
| | 8521S2 | 1st to 3rd | *C. hircus* | − 20.6 | 10.6 | 3.24 | 4.71 |
| | 4311S | 1st to 3rd | *O. aries* | − 21.3 | 4.5 | 3.29 | 3.13 |
| | 8504S | 1st to 3rd | *O. aries* | − 20.8 | 5.1 | 3.20 | 4.35 |
| | 8507S | 1st to 3rd | *O. aries* | − 20.5 | 9.9 | 3.19 | 7.99 |
| | 8513S | 1st to 3rd | *O. aries* | − 21.6 | 8.3 | 3.23 | 3.57 |
| | 1173S | 14th | *O. aries* | − 20.0 | 5.0 | 3.20 | 4.10 |
| | 8211B | 1st to 3rd | *G. gallus* | − 19.1 | 10.6 | 3.31 | 5.61 |
| | 8504B2 | 1st to 3rd | *G. gallus* | − 19.8 | 9.6 | 3.23 | 3.34 |
| | 8504B | 1st to 3rd | *G. gallus* | − 18.5 | 10.7 | 3.32 | 14.27 |
| | 8507B | 1st to 3rd | *G. gallus* | − 18.4 | 8.0 | 3.23 | 4.61 |
| | 8503B | 1st to 3rd | *G. gallus* | − 19.3 | 8.0 | 3.25 | 2.65 |
| | 8541P | 1st to 3rd | *Sus domesticus* | − 18.9 | 6.3 | 3.20 | 2.25 |
| | 8581P | 1st to 3rd | *Sus domesticus* | − 20.4 | 7.2 | 3.18 | 3.75 |
| | 8659P | 1st to 3rd | *Sus domesticus* | − 21.0 | 6.5 | 3.26 | 1.44 |
| | 1269P | 12th | *Sus domesticus* | − 20.2 | 7.1 | 3.25 | 3.86 |
| | 1374P | 12th | *Sus domesticus* | − 19.1 | 4.9 | 3.43 | 4.14 |
| | 1177P | 14th | *Sus domesticus* | − 20.3 | 7.7 | 3.19 | 6.13 |
| | 8510M | 1st to 3rd | *C. familiaris* | − 15.6 | 14.1 | 3.17 | 0.49 |
| | 3833D | 1st to 3rd | *C. familiaris* | − 18.4 | 9.4 | 3.22 | 0.85 |
| | 1254B | 12th | *F. catus* | − 18.5 | 8.9 | 3.17 | 7.5 |
| | 1173BB | 14th | *F. catus* | − 18.9 | 6.9 | 3.25 | 9.4 |
| | 8299H | 1st to 3rd | *Equus sp.* | − 18.3 | 6.0 | 3.23 | 1.26 |
| | 1173B | 14th | *O. cuniculus* | − 21.6 | 5.2 | 3.23 | 2.02 |
| | 8521B | 1st to 3rd | *Corvus corax* | − 19.4 | 8.6 | 3.19 | 8.75 |
| | 9106F | 1st to 3rd | *M. merluccius* | − 12.0 | 14.4 | 3.16 | 4.42 |
| | 2076F | 12th | *G. galeus* | − 11.9 | 11.9 | 3.32 | 1.33 |

still eating animal products. When the population is divided by sex, males are enriched in $^{15}N$ compared to the females (Fig. 4). The difference is significant for $\delta^{15}N$ but not for $\delta^{13}C$ (Mann-Whitney *U* test, $p = 0.02$ and $p = 0.89$, respectively). In contrast, Muslim individuals from the Lisbon suburb (Calçadinha do Tijolo, CDT), do not show a sex difference in diet. Males and females from CDT have similar values of both $\delta^{13}C$ and $\delta^{15}N$ and plot with the females from the SJC.

A second clear trend is shown by adult and non-adult individuals that display a significant difference in both their $\delta^{13}C$ and $\delta^{15}N$ values (Mann-Whitney *U* test, $p = 0.00$ and $p = 0.04$, respectively). The non-adults show a typical breastfeeding signal (Millard 2000; Jay et al. 2008) with individuals of less than 3 years of age enriched in $^{13}C$ and $^{15}N$ (Fig. 4). The individuals older than 3 years seem to have a similar diet to the females.

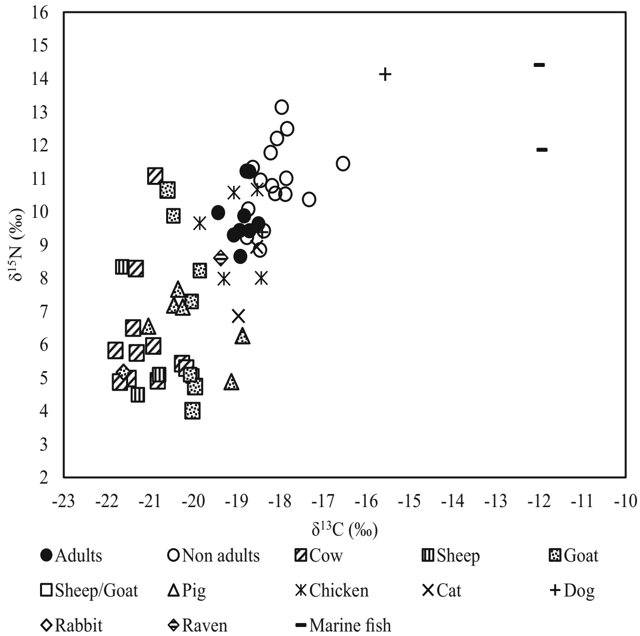



**Fig. 3** Plot of $\delta^{13}$C and $\delta^{15}$N values for the Muslim individuals from São Jorge Castle (tenth to eleventh centuries) and animals from Praça da Figueira (tenth to eleventh centuries)

## Discussion

### Paleopathological assessment

The São Jorge Castle collection presents low frequencies of stress markers. As observed in other collections, the frequency

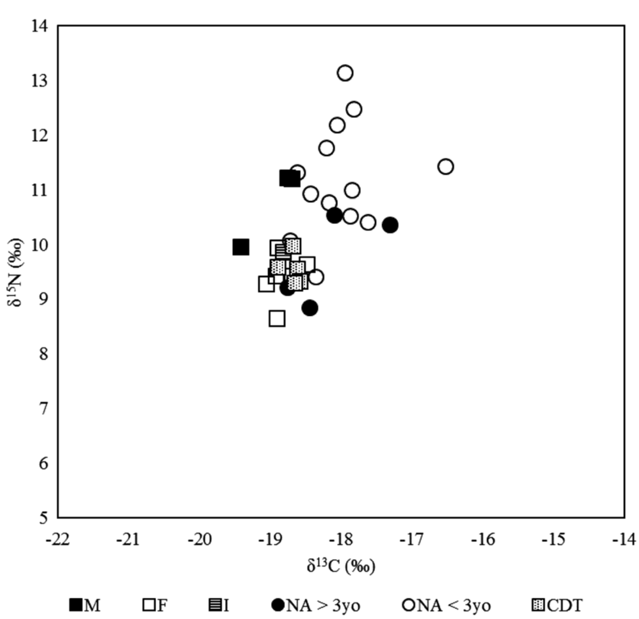



**Fig. 4** Plot of $\delta^{13}$C and $\delta^{15}$N values of the SJC individuals divided by sex and age groups: males (M), females (F), indeterminate sex (I), non-adults (NA). A comparative sample of Muslim individuals from urban Lisbon (Calçadinha do Tijolo) is included

of LEH in the SJC collection is higher in the adults and the CO frequency is higher in the non-adult sample (Garcia 2007; Herrscher 2001; Robles et al. 1996). LEH is interpreted in bioarchaeology as an indicator of temporary growth disruption associated with a state of illness, undernutrition or both (Goodman 1991; King et al. 2005; Ritzman et al. 2008). Although the frequency of LEH is higher in the adult sample, it reflects the first 6 years of development of an individual. Thus, any event that could explain the formation of LEH had to occur in this timeframe. The non-adults with LEH were older than the ones without, but the small size of the samples demands that the results of the LEH and also of the other stress markers be interpreted with caution.

For instance, as previously mentioned, the frequency of CO is higher in the non-adult sample in comparison with the adult sample. There are many possible causes associated with CO. The traditional explanation linked the occurrence of CO with iron deficiency anaemia (Stuart-Macadam 1985) derived either from a deficient intake of iron, a difficulty in its absorption or significant loss. Other explanations are based in the hereditary transmission of haemolytic diseases as sickle cell anaemia or thalassaemia. Although recent discussion had questioned the validity of iron deficiency explanations (Walker 2009), many authors have advocated the importance of not excluding them (Blau 2001; Facchini et al. 2004; McIlvaine 2015; Oxenham and Cavill 2010; Walker 1986). The funerary context of this sample indicates that these individuals were privileged in Islamic society since they were buried inside the walls of the Lisbon castle. The results of the stable isotope analysis indicated that two individuals with CO showed a breast-feeding pattern (enrichment in $^{15}$N) and women and older children exhibited a diet that incorporated lower trophic level protein than males.

The lack of evidence of any infectious disease (including non-specific types), and the low frequencies of stress markers are in keeping with the high status nature of the population. Poor nutrition which may be expected in low status populations is often linked to elevated levels of infectious disease and stress (Larsen 2002). Nevertheless, this collection is characterised by being greatly represented by young non-adults that, although simulate a 'disease-free' population, died before adulthood. The problem of a selective mortality (Wood et al. 1992) should be considered, at least as a theoretical concern. However, studies have been consistent in demonstrating that LEH are more frequent in populations with a lower socio-economic status (Geber 2014; Goodman 1993; Goodman and Roe 1991). In populations with high fertility and high mortality, it is expected to find that around 40% of the archaeological cemetery are non-adults, but in the Lisbon sample, 60% of the individuals are under 18 years of age. This pattern emerges when there is an excess of mortality triggered by starvation or other acute health crisis (Geber 2016). However, interpretation of this biased mortality profile is hampered by the small number of individuals in this population.

Only one adult individual with erupted permanent teeth had caries. However, other historical populations present much higher frequencies such as Later Medieval Christians from Portugal and Muslims from Spain. For instance, in São Martinho, Leiria, the prevalence of carious lesions in individuals with permanent erupted teeth was 56%. Adults from São Martinho had a prevalence of caries of 84% (Garcia 2007). The same is observed comparing the values with the Islamic collection of Xarea, where the prevalence of caries in adults is 73% (Robledo and Trancho 2003). The relationship between caries and diet has long been investigated and there are many studies that agree that there is a relationship between the ingestion of fermentable carbohydrates and an increase in the metabolic activity of cariogenic bacteria (Powell 1985; Moynihan and Petersen 2004). On the other hand, proteins and dietary fats seem to have a protective effect against caries (Mundorff-Shrestha et al. 1994) due to their basic nature (opposed to the acidic nature of carbohydrates) that slows the bacterial activity (Powell 1995). The low prevalence of caries in the population from the Castle may be the result of consumption of moderate amounts of carbohydrates alongside regular consumption of animal proteins and dietary fats which complements the results of the stable isotope analysis which indicates a reliance on animal products in the diet.

## Dietary patterns: stable isotope analysis

Despite the uncertainty related to the long chronology of the faunal remains, feeding practices for the main domestic species seem to be constant in Lisbon throughout time. The majority of the domestic species show an herbivorous diet based on $C_3$ plants. Notably, a few individuals (two cows, two sheep and one goat) have enriched $\delta^{15}N$ values. This wide range in $\delta^{15}N$ values for herbivores can occur for a number of reasons. Among these are environmental factors such as temperature, aridity and coastal proximity that vary the isotopic composition of plants (Amundson et al. 2003; Hartman 2011). Specific human land use practices such as manuring can shift the baseline values (Fraser et al. 2011), and animals that are reared near urban centres are more likely to show enriched $\delta^{15}N$ values (Hedges et al. 2005; Reitz et al. 2016). Metabolic and physiological pathways between different species could also affect $\delta^{15}N$ values; however, this is not the case in Lisbon, since a wide range of values is exhibited among individuals of the same species (Itahashi et al. 2014). The variation in herbivore values can also indicate a wider provisioning area. From historical sources, it is known that animals consumed in urban areas were not always reared near the settlements (Catarino 1998, p. 39). Toponyms in the surrounding of Lisbon, with particular mention of the areas upstream of the river Tagus for the Muslim and Christian period, suggest the existence of pastures (Catarino 1998, p. 34; Gomes Barbosa 1994, p. 20). Thus, these differences in herbivore diet suggest distinct management strategies and/or provenance for these individuals.

Nitrogen isotope signatures for chickens are very close to the human individuals from SJC which indicates that they were fed on domestic food waste. Both food scraps and insects, typically included in the chicken diet, have enriched nitrogen isotope values (Reitz et al. 2016) and a similar pattern of human and chicken values have been found at a late medieval Muslim site (Alexander et al. 2015). The two pigs of Islamic chronology plot similarly to the herbivores and pigs from other periods, therefore indicating that they may possibly be wild; however, we cannot be certain since pigs have shown very variable isotope values in previously analysed medieval assemblages (Halley and Rosvold 2014). The single dog exhibits surprising enrichment in both $^{13}C$ and $^{15}N$ in comparison to both animals and humans. The isotopic values suggest a diet based on marine resources, which is unique among the individuals sampled here. However, this is a juvenile (unfused femur) and therefore may retain a nursing signal; furthermore, the dog derives from Roman contexts and so may not be indicative of Medieval subsistence or husbandry in the city.

Turning to the human diet, in terms of animal protein, given the aforementioned wide range in nitrogen isotope values for animals, it is difficult to pin down specific species that were consumed. It is likely that herbivores played a significant part in the diet of these individuals, with omnivores such as chickens supplementing the diet of some, particularly those with higher nitrogen isotope values. Perhaps the most notable feature of the human results is that despite the coastal location of Lisbon, marine resources do not appear to play a major role in the human diet, with humans possessing carbon and nitrogen isotope values indicative of a terrestrial, $C_3$-based diet. This is surprising given the location of Lisbon and its intrinsic relationship with both the sea and the river Tagus. However, limited consumption of low trophic level fish that typically live near the coast would not be detected by isotopic analysis. As well, dietary models indicate that a terrestrial-based diet could include up to 20% marine protein without raising bone collagen $\delta^{13}C$ values, therefore underrepresenting marine food unless consumed in substantial amounts (Hedges 2004; Milner et al. 2004). Freshwater fish, although a plausible and abundant resource in the Tagus River, was probably not widely consumed. In this regard, cultural and religious preferences should also be considered. The Quran does not prohibit the consumption of fish; however, some sections of Islam did consider it unlawful, mainly in the Eastern Shia tradition (Pellat et al. 2012). Arab authors, following their Greek predecessors, had different opinions on the benefit of fish; however, it was commonly believed that fish were less nutritious than meat and generally not as good for human consumption (García-Sánchez 1986, p. 259).

Fish recipes are also very scarce in medieval Andalusian cookbooks, usually accounting for 4–10% of the presented recipes (García-Sánchez 1986, pp. 264–265). The only medieval Portuguese cookbook available unfortunately dates to the late medieval Christian period (Manuppella 1987). A lack of zooarchaeological data also hinders the assessment of the consumption of marine resources in Islamic Lisbon. Sieving is not routinely carried out due to the time constraints that recovery processes imposed on rescue and commercial archaeology in the city.

There is no indication of $C_4$ plants in the diet of the humans or animals from Lisbon. This is despite historical records indicating that they were available. $C_4$ plant consumption has been found in isotopic studies of medieval Muslim populations from Valencia (Alexander et al. 2015; Salazar-García et al. 2014) and in late antique and medieval populations in Galicia (López-Costas 2012; López-Costas and Müldner 2016). Crops such as millet and sorghum may have been considered to be low status crops (Alexander et al. 2015; García-Sánchez 1996, p. 223), and the lack of evidence for them in the diet, especially among the SJC individuals, may reflect the privileged status of this population.

## Sex-related trends in diet

When considering the diet of this population in relation to sex, women and men display a different diet (Fig. 4), with males generally possessing higher $\delta^{15}$N than females. This could indicate that males derived a greater proportion of their dietary protein from animal rather than plant sources in comparison to females or that they consumed higher trophic level protein from chickens or potentially freshwater fish, which would also serve to enrich $\delta^{15}$N values (Hedges and Reynard 2007). This sex difference in food consumption could be an expression of family organisation and use of domestic space where men, women and children may not have necessarily eaten together. This connection between family and domestic architecture has been studied in medieval Morocco. The centralised structure of the houses in Maghreb with equal cells surrounding a central space is said to reflect the family structure of its inhabitants: wives and children are relatively equal to each other but subordinate to the male head of the household (Fentress 2000). Historical sources from as early as the eleventh century describe specific spaces for women within a household or palace in Al-Andalus (Díez Jorge 2002, p. 159). In the household, the man was required to provide a separate room for his wife and a separate house if he married a second wife (Pérez Ordóñez 2009, p. 5). A series of such norms and regulations about the use of domestic space are reported (Marín 2000, p. 237), but these regulations were more feasible in large, high status household with many rooms. In high status contexts, the Arab-Islamic table was dominated by men; women could watch the banquet from a shielded area or eat separately in their part of the house (Lewicka 2011, p. 401; Visser 2012, p. 279).

When the high status population from the castle is compared with a contemporaneous Muslim urban population from CDT, female individuals from the castle have a very similar diet to these lower status individuals that include both females and males (Fig. 4), who, in this context, show no sex-related differences in diet. In the case of the nuclear, one-room houses common for those of lower status across Islamic settlements, such as those excavated in Praça da Figueira (Díez Jorge 2002, p. 161), it is probable that men and women were more likely to share space and food. In a similar vein, medium and lower-status women were less restricted in their daily activity, being free to wander in public spaces and use the public baths, unlike women of high status (Coope 2013; Lachiri 1993). This may be why there is no sex difference detected among low status individuals.

Therefore, it appears that high status males are more distinctive in their eating habits compared to the rest of the urban population of the time. This difference for the high status male individuals could be linked to their activities taking place outside the home and them potentially having access to a wider range of foodstuffs, including sources enriched in $^{15}$N as mentioned above. In terms of a typical high status male diet, one could infer that the entirety of etiquette manuals and cookery books were actually intended for higher-status male individuals and are therefore a reliable source of information, i.e. a diet rich in animal products. The fact that the low status population and the high status females have similar diets might be a reflection of the consumption of comparatively less meat by both these social groups.

Similar patterns in isotopic data in relation to sex, with males consuming higher trophic level proteins, have been recorded elsewhere in Muslim Spain, at Tauste, for example (Guede et al. 2017a, b), where males were hypothesised to consume more freshwater fish. However, the evidence from this study and other published populations from Spain indicates that a sex difference in diet is not a consistent trend among isotopic datasets for Muslim populations (Alexander et al. 2015; Fuller et al. 2010; Salazar-García et al. 2014, 2016). The small sample sizes from Lisbon hamper any definite conclusions regarding diet and sex, although the role of status in a possible male/female differentiation in food consumption is hypothesised.

## Age-related trends in diet

The weaned non-adults of this population share a similar diet to the females. There are few explicit references in historic literature for culinary products shared by women and children. Women and children were considered of different physiological nature (children were hot and humid, while women were colder and drier); therefore, this similar food consumption is not associated with the humoral theories (Oliveira 2007, p. 31). However, childcare is traditionally entrusted to women and it is likely that physical proximity would have prompted the consumption of similar meals. To the best of our knowledge, it is the first time a similar trend is shown by isotopic data in an Islamic population and further exploration of non-adult diet is needed to assess the prevalence of this practice.

Breastfeeding, although sometimes performed by wet-nurses among high status families, was considered by Christian and Muslim medieval societies of vital importance to child development and health (Giladi 1998, p. 108; Shahar 1990, p. 57; Winer 2008). Our results show that the majority of the non-adults under the age of three were still breastfed in accordance with medical and historical sources from both the Muslim and Christian world, which suggested breastfeeding to at least until 2 years of age (Baumgarten 2004; Fildes 1986). When compared to other archaeological medieval populations, the individuals from SJC appear to follow a similar pattern of enriched nitrogen isotope values compared to the females' mean value of their respective populations (Fig. 5). This is the expected signature for breastfeeding and weaning and can be observed across all sites. The nitrogen isotope ratios start to decrease at SJC around 2 years of age, as would be expected from historical sources, while at other sites such as Grenoble, Fishergate, Raunds and Tauste, the weaning period seems to occur slightly later. However, a lack of individuals between the age of 2 and 6 years old at SJC could mask a similar pattern and prevent a more precise estimate of the weaning age of this Muslim population. Incremental dentine layers analysis may have served to pinpoint weaning times with greater precision (King et al. 2018); however, sampling restrictions did not permit destructive analysis of dentition. It should also be borne in mind that due to the 'osteological paradox' (Beaumont et al. 2015; Wood et al. 1992), the non-adults here are non-survivors that may not reflect the dietary practice of the 'healthy' population (Beaumont et al. 2015).

## Diet and status

Status played an important role in food access, both in terms of quantity, quality and variety of the available resources. High status people not only had easier access to a greater quantity of food but also to a wider selection of products. Previous studies on medieval population in Sweden (Bäckström et al. 2017; Linderholm et al. 2008), UK (Müldner and Richards 2007, Müldner et al. 2009), Italy (Reitsema and Vercellotti 2012) and France (Colleter et al. 2017) have explored the influence of status on diet, examining the correlation between isotopic values and graves goods or burial type. In these previous examples, more high status individuals consumed marine protein and/or higher trophic level terrestrial protein. Although the small sample size constitutes a limitation in the SJC assemblage, the sex-related difference in diet that was found in this population may be an expression of its social status, further supported by the lack of any sex-related difference in diet in the urban population of Calçadinha do Tijolo.

Contemporaneous (tenth to thirteenth centuries) medieval high status individuals have been recently analysed from the Royal Houses of Castile and Aragon (Jiménez-Brobeil et al. 2016; Martínez-Jarreta et al. 2017). The Royal members showed higher $\delta^{15}$N compared to other medieval Spanish populations suggesting the inclusion of higher trophic level protein such as pig and freshwater fish. Although the difference between female and male $\delta^{15}$N values is not significant, males have higher $\delta^{15}$N mean (12.8‰ ± 1.3) than females (11.3‰ ± 1.7). While the Spanish royal members, both females and males, showed higher $\delta^{15}$N values compared to contemporaneous populations; in

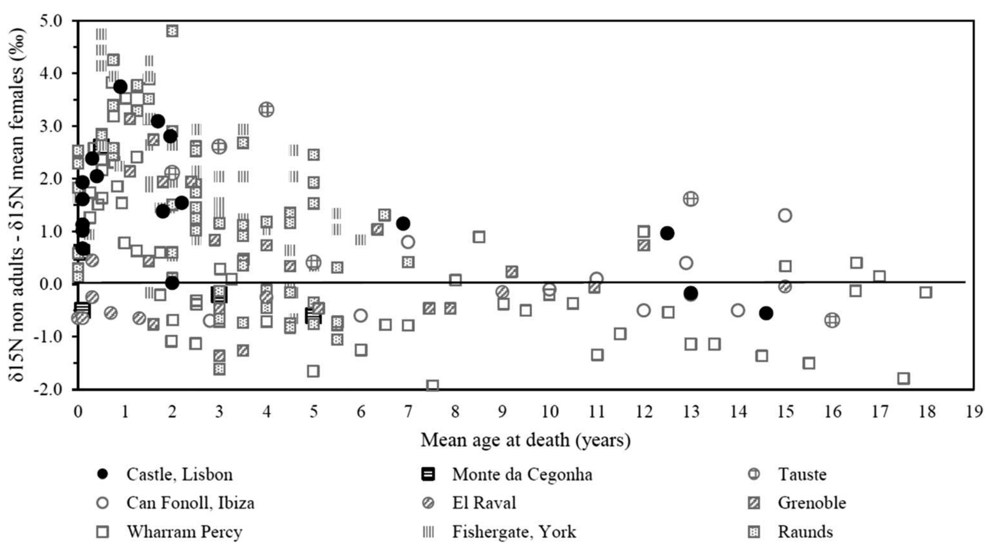



**Fig. 5** Breastfeeding and weaning pattern of non-adult individuals from SJC, Lisbon and Monte da Cegonha compared to other Muslim and Christian populations from Spain, France and UK. The comparative sites are Monte da Cegonha, Portugal (Saragoça et al. 2016), Tauste, Spain (Guede et al. 2017a, b), Can Fonoll, Ibiza, Spain (Pickard et al. 2017), El Raval, Spain (Salazar-García et al. 2014), Grenoble, France (Herrscher 2003), Wharram Percy, UK (Richards et al. 2002), York, UK (Burt 2013), and Raunds, UK (Haydock et al. 2013)

Lisbon, this status-related difference can be seen in males only, similarly to what was found at Whithorn Cathedral Piory (Müldner et al. 2009), Fishergate, York (Müldner and Richards 2007) and Brittany (Colleter et al. 2017).

### Wider comparison with the Iberian dataset

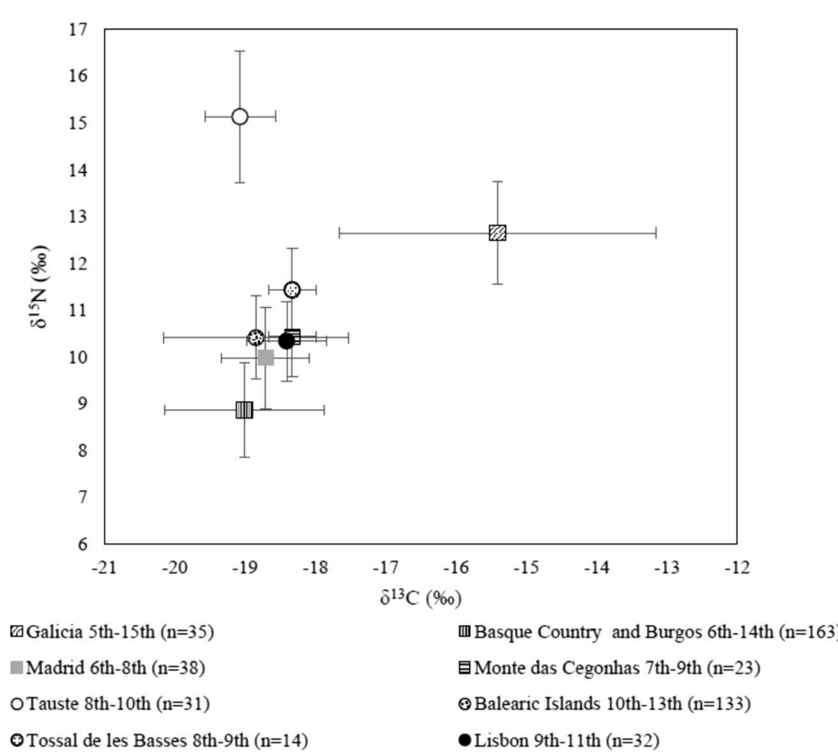
The two Lisbon populations (SJC and Calçadinha do Tijolo) were compared to contemporaneous populations from the Iberian Peninsula (Fig. 6). The comparison indicates that there is an extremely similar diet shared by the ninth to eleventh century Lisbon and the Portuguese Late Antique individuals from Monte das Cegonhas, suggesting the continuation of dietary practice between the Late Antique and the Islamic period. More widely, similar mean isotopic values are exhibited by contemporaneous Muslim populations from Tossal de les Basses (Alicante), the Balearic Islands, and a Late Antique population from Madrid (Cau Ontiveros et al. 2016; Lubritto et al. 2017; Nehlich et al. 2012; Pickard et al. 2017; Salazar-García et al. 2016). The stark difference between Portuguese sites and data from Galicia is notable (López-Costas and Müldner 2016), with the latter exhibiting higher $\delta^{13}$C values despite the fact that both geographic areas overlook the Atlantic coast and may be assumed to have similar diets, or at least more similar than populations from the Mediterranean coast of Iberia. Isotopic data have indicated that $C_4$ crops and marine resources were heavily relied upon at least from the Roman period which would both serve to increase $\delta^{13}$C values; however, this cannot be seen along the Portuguese coast during the early medieval period (López-Costas and Müldner 2016). It should be borne in mind that some of the differences here will be not only be related to cultural preferences but will also be linked to the environment and climate in each region and any differences may reflect baseline rather than dietary shifts. This is particularly relevant for Tauste, where the consumption of freshwater resources and/or the presence of individuals from more arid climates might have affected the nitrogen isotope values.

The $^{15}$N enrichment exhibited by two males (CAS1PN, CAS1PC) may alternatively be explained by a possible different geographical origin. Individuals from arid climates tend to possess higher $\delta^{15}$N values (e.g. Dupras and Schwarcz 2001; Schwarcz et al. 1999). During this period of Islamic rule in Iberia, it is highly likely that people were moving from North Africa to the Iberian Peninsula, facilitated by their shared political (and cultural) systems. However, available historical sources lack specific information on this issue. Further analysis of isotopes such as strontium, oxygen or possibly ancient DNA would be needed to explore the theme of mobility at a deeper level.

## Conclusion

In the São Jorge Castle, the frequencies of stress indicators were found to be low and followed a common pattern of age

**Fig. 6** Comparison of Lisbon populations (SJC and Calçadinha do Tijolo) with other medieval Iberian populations. The values are presented as a mean, error bars represent ± 1σ



distribution in respect to LEH and CO. LEH is more common in older individuals, and CO and HL in young individuals. The absence of evidence of infectious diseases (including non-specific) and the low frequency of stress markers may reflect the high status nature of the population. However, the small samples size demands caution.

The isotopic results indicate a terrestrial, $C_3$-based subsistence economy. The isotopic signature of the animals, although representing a long chronology, does not show significant changes over time, suggesting a certain degree of continuity in economy and animal husbandry practices between the Roman and Medieval periods in Lisbon. Again, however, the sample size is small and further analyses could explore this observation more fully. All domestic animals were fed or grazed on $C_3$ plants, although some variation due to climate, environmental and physiological factors might have affected the nitrogen isotope values of certain individuals. Results for humans suggested a sex-based difference in diet, with females and non-adults relying on lower trophic level proteins compared to males. In addition, females and non-adults showed a very similar diet, implying that the close proximity of these two groups may have prompted communal consumption practices. These patterns, absent in other Islamic urban populations published from Iberia thus far, may reflect the strict division of sex and age groups in the Islamic household predominantly followed by the higher classes. There is no difference, however, between the privileged females analysed from the castle and males and females from the general population buried outside the castle at Calçadinha do Tijolo. Although the sample size is small, a tentative shift towards high status males exhibiting enrichment in $^{15}N$ is proposed, following a trend seen among other sites in Medieval Europe. The combined bioarchaeological approach used here offers the first detailed insight into the lifeways of high status Islamic populations from Iberia. A major investment in similar studies of other Islamic collections will provide valuable information to allow a better understanding of life and death across Islamic society in Al-Andalus.

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