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Bone stable isotope data of the Late Roman population (4^{th}–7^{th} centuries CE) from Mondragones (Granada): A dietary reconstruction in a Roman villa context of south-eastern Spain

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Abstract

The aim of this study is to examine the diet, using bone stable isotope analysis ($\delta^{13}C$ and $\delta^{15}N$), of a Late Roman population (4^{th}–7^{th} centuries CE) from the Roman villa of Mondragones (Granada, Spain). This archaeological site presents an exceptionally high number (n = 121) of well-preserved skeletal remains (adults and non-adults), giving the opportunity to study for the first time the nutritional and health conditions of a Late Roman population by the analysis of stable isotopes and pathologies in the context of the south-eastern Iberian Peninsula. Stable isotopes ratios of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) were analysed in 46 individuals (21 adults and 25 non-adults) as well as in 7 faunal samples (2 *cows/ox,* 2 *goats/sheep,* and 3 *large mammals)*. Frequencies of cariogenic lesions, dental calculus, dental enamel hypoplasia, porotic hyperostosis, and cribra orbitalia were also explored. The anthropological study revealed a high presence of dental caries and calculus in adults, which are related to a diet rich in starch and carbohydrates, and non-specific stress markers in non-adults, probably pointing to the weaning process or childhood diseases. Collagen isotope ratios suggested that the population of Mondragones had a diet rich in C_3 plants, with some meat intake from terrestrial herbivores. There were significant differences between non-adults and adults, but no differences were detected by sex. The youngest non-adults (aged 1 year ± 4 months) showed the $\delta^{15}N$ mean value almost 4‰ above the adult female one, which could reflect the breastfeeding period.

Keywords: paleodiet, isotopes, collagen, breastfeeding, Late Antiquity, Spain.

1. Introduction

The study of stable isotopes in skeletal remains has gained importance in recent years in the context of the Iberian Peninsula. While there are a lot of paleodietary data in Spain from prehistoric (Salazar García, 2011; Fontanals-Coll et al., 2016; Villalba-Mouco et al., 2018) and medieval sites (Inskip et al., 2019; Guede et al., 2017; Jiménez-Bobreil et al., 2020), there is a deep gap for the Roman and Late Roman period, except for some works such as López-Costas (2012). There is a lack of studies in Spain for this specific period in comparison with near geographical areas as Italy (Rutgers et al., 2009; Tafuri et al., 2018; Milella et al., 2019), maybe because it is usually very difficult to find many skeletal remains from the Late Roman period with good conservation conditions in the Iberian Peninsula as a result of cremation practices and taphonomic processes (Polo Cerdá and Garcia-Prosper, 2005; Heras Martínez et al., 2011; López-Costas, 2012; Diéguez Ramírez, 2015). This paleodiet study is focused on a sample of the Late Roman and Late Antiquity population (5th to 7th century CE [Common Era]) buried at the Roman villa of Mondragones, located in south-eastern Spain. Therefore, it represents a great opportunity to know more about the nutritional conditions of this period on the Iberian Peninsula.

The study of stable isotopes in humans provides good quality data for the reconstruction of ancient populations' diets (Reitsema, 2013; Ma et al., 2016). Specifically, with this analytical technique it is possible to assess the type of vegetables that were consumed, as well as the sources of the dietary proteins (animal or vegetal). This knowledge provides direct information on aspects that otherwise could only be inferred by indirect evidence, such as food preparation utensils, storage vessels, or wall and vase paintings (Keenleyside et al., 2009). The stable isotope technique is based on the principle that the isotopic composition of tissues in both humans and animals is determined by the diet. Therefore, analysis of $\delta^{13}C$ and $\delta^{15}N$ can provide information about the diet of past populations (Budd et al., 2013; Müldner and Richards, 2007).

In C_3 plants, the $\delta^{13}C$ value ranges between -20‰ and -35‰, while in C_4 plants the values vary between -7‰ and -17‰ (Pate, 2001). Consequently, carbon isotope values can be used to distinguish between C_3 and C_4 plants. These differences in carbon isotope values are transferred along the food chain to animals and humans, making it possible to determine the kind of plant ingested (Van der Merve and Vogel, 1978). Furthermore, carbon isotope composition in the atmosphere reaches an average $\delta^{13}C$ value of -7‰, while in the sea, dissolved carbonates display a value of 0‰ (Rullkötter, 2006).

Therefore, carbon isotope values can differentiate the consumption of marine and terrestrial food sources (Craig et al., 2009; Reitsema et al., 2010).

Nitrogen isotope in bone collagen provides information about trophic level (increase by 3–5‰ with increasing trophic level), distinguishing among herbivores, omnivores, and carnivores (Hedges and Reynard, 2007; Keenleyside et al., 2009). Moreover, an increase in $\delta^{15}N$ bone collagen values is observed for individuals with significant ingestion of marine products, either direct or indirect (i.e., sea spray) (Schoeninger and DeNiro, 1984; Schoeninger, 1995). Indeed, atmospheric N_2 dissolved in water is converted into ^{15}N-enriched nitrates and ammonia, leading to generally more positive $\delta^{15}N$ values in the marine food web compared to terrestrial vertebrates (Pate, 1994). The nitrogen isotope ratios can also be used to estimate the duration of breastfeeding and the timing of the weaning process (Fuller et al., 2006), which are very important because these processes have an impact on the health condition of a population and on its demography. The relation between nitrogen isotope ratios and the breastfeeding/weaning period has been analysed in many studies (Dupras et al., 2001; Turner et al., 2007; Prowse et al., 2008; Keenleyside et al., 2009; Bourbou et al., 2013), but it has limitations associated with the cross-sectional method applied. These studies are based on sampling non-survivors, which may not be representative for inferring population norms, and they do not consider the population and individual variation (Kendall, 2016), so such studies require caution.

In addition, combining the stable isotope ratios with an osteological analysis of skeletal remains can provide information on health conditions and complement the dietary patterns (Toso et al., 2019). Pathological conditions caused by interruptions in growth are especially interesting in the paleodiet context, because they could suggest periods of malnutrition or lack of specific essential nutrients (Katzenberg, 2012). Caries, dental calculus, and non-specific stress markers (such as cribra orbitalia, porotic hyperostosis, and dental enamel hypoplasia) are frequently considered in paleodiet studies (Buzon et al., 2012; Laffranchi et al., 2019), as well as in this research.

Dental caries is considered one of the most important tools to reconstruct the diet of past populations, because its aetiology is related to fermentable carbohydrates from the diet (Hillson, 2001; Svyatko, 2014). It is an oral pathology characterized by demineralization and progressive destruction of calcified dental tissues by bacterial fermentation of carbohydrates (Hillson, 2019), although it is also affected by other factors such as salivary glycoproteins, dental plaque, or deficient oral hygiene (Lopez et al., 2012).

Dental calculus is produced from the accumulation of plaque that, if not removed, becomes mineralized (Scott and Poulson, 2012). Plaque accumulates faster in an alkaline oral environment, which occurs when the diet is rich in proteins and/or carbohydrates (Roberts and Manchester, 2010). Calculus is also influenced by salivary flow, genetic factors, and dental care (Hardy et al., 2009).

Cribra orbitalia and porotic hyperostosis are non-specific stress markers identified macroscopically as porous lesions of the orbital roof and cranial vault, respectively (Suby, 2014). While iron-deficiency anaemia is the most accepted aetiological factor for these pathologies (Oxenham and Cavill, 2010; Rivera and Mirazón, 2017), other studies suggest that cribra orbitalia and porotic hyperostosis could be linked to megaloblastic anaemias, which are associated with deficiencies of vitamin B_{12} and vitamin B_9 (Walker et al., 2009). However, they are also related to multiple aetiologies like inflammatory, haemorrhagic, or tumoral processes (Ortner, 2003). Finally, dental enamel hypoplasia is another non-specific stress marker characterized by the formation of lines, pits, or grooves on the enamel surface (Roberts and Manchester, 2010). It can be related to dietary deficiencies, childhood fevers, and infectious diseases (Hillson, 2019), and it can provide information about lifestyle and living conditions (Goodman and Rose, 1991; Laffranchi et al., 2019). These defects are formed only during enamel development, so they can record the stress periods of childhood (Mays, 1998).

The analysis of stable isotopes and the paleopathological variables from this particularly well-preserved Late Roman population from southern Spain provides the opportunity to assess the nutritional conditions of this little-known period and to compare it with chronologically contemporary populations.

2. Material and methods

2.1 Archaeological site

The Roman villa of Mondragones is located in the city of Granada (Fig. 1), Andalusian region, Spain (37°11'26.46"N; 3°36'41.16"W), and it was first discovered and investigated in 2013 by Rodríguez Aguilera et al. (2014). This villa was built in the middle of the 1st century CE, and the period of occupation was documented until the 7th century CE. It was a periurban villa, located 1.7 km from the urban nucleus of the *Municipium Florentinum Iliberritanum*, which is the Roman name of Granada. It showed the typical roman structures of agrarian villas, which have a productive function: the *pars rustica*, the *pars frumentaria*, and the *pars urbana* (Fornell-Muñoz, 1999). These villas were owned by the *dominus*, who lived in the *pars urbana* with his family and the service, while the labour force lived in the *pars rustica*, where the stables were also located (Joly, 2003). The *pars frumentaria* was the centre of the agricultural production, and in Mondragones it was formed by an oil mill. It seems that Mondragones belonged to a group of villas dedicated to the agricultural exploitation of the fertile plain of Granada, mainly centred on agriculture, whose objective was to supply the area and probably export the excess production (Sánchez López, 2013). From the 5th century CE, the villa was restructured with successive modifications, such as the reduction of space for oil production. In the second half of the 6th century CE, a religious building and a cemetery were built. A total of 85 graves have been uncovered: 23 belong to the Imperial Roman time (1st century CE) and 62 belong to the Late Roman and Late Antiquity time. These 62 graves are divided into 2 phases: [1] 23 graves dated from the 4th to 5th century CE, and [2] 39 graves dated from the 5th to 7th century CE (Fig. 2). Most individuals were inhumed in a *decubitus supinus* position with an East–West orientation (Rodríguez Aguilera et al., 2014).

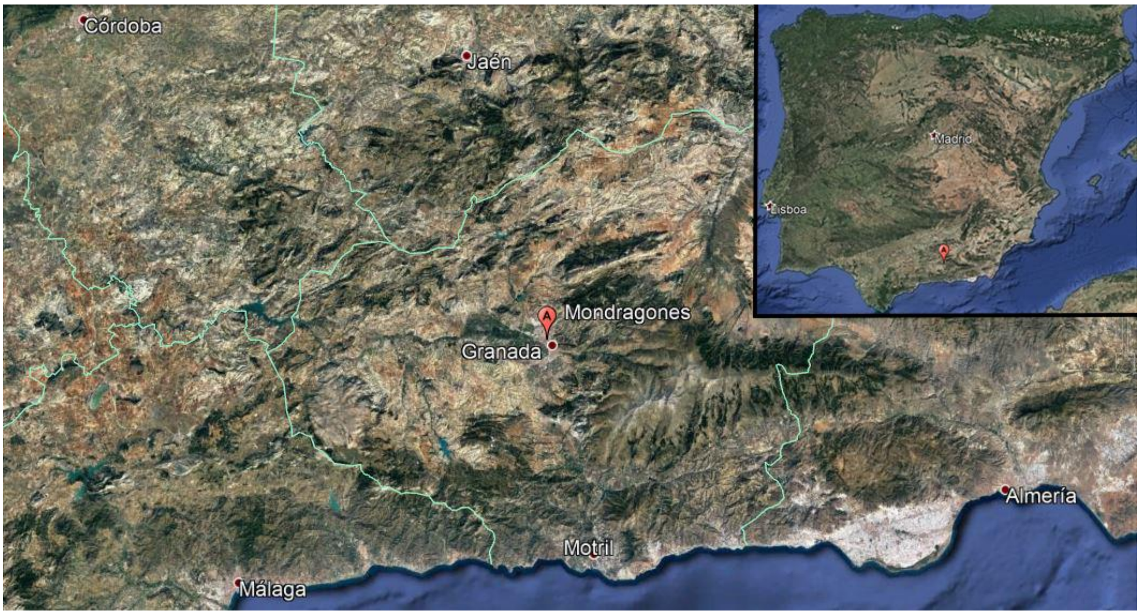

Fig. 1. Map showing the location of Mondragones (Google Earth V 7.3.2.5776 (64-bit) (May 17, 2018). Andalusian region, Granada, Spain. 37°11'26.46"N; 3°36'41.16"W, eye alt 247.03 km. Google 2018).

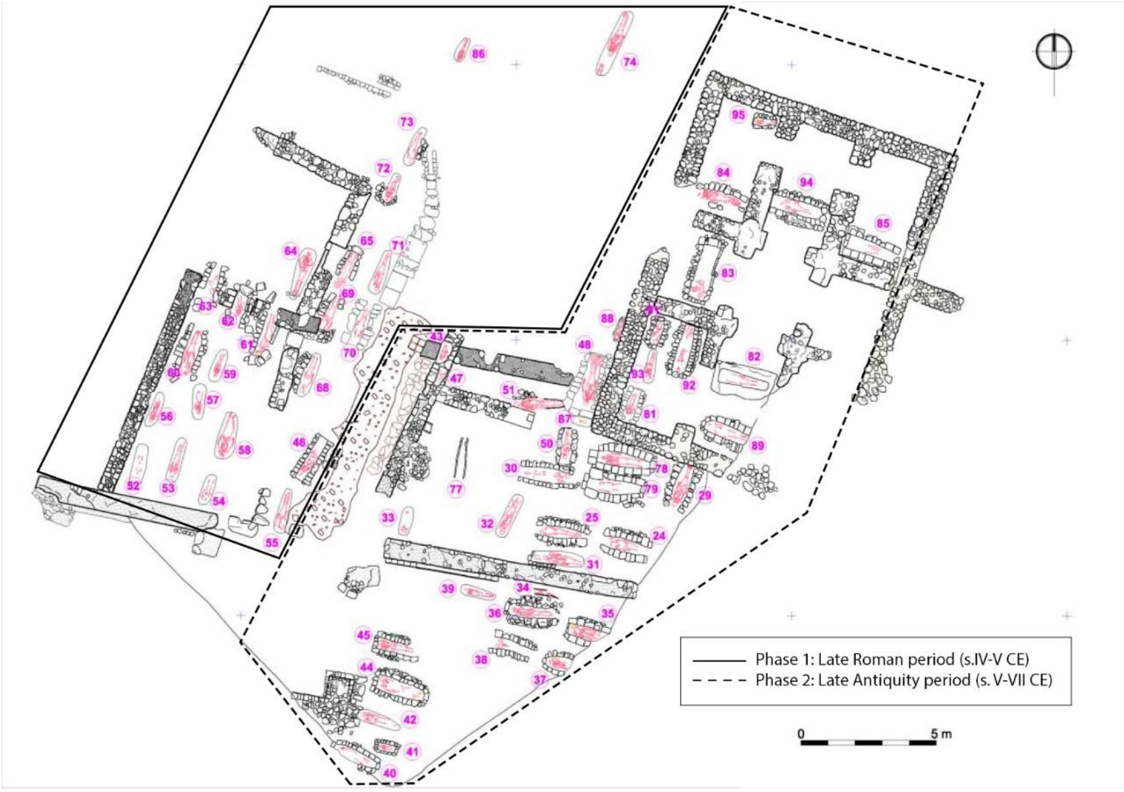

Fig. 2. Plan of the Late Roman cemetery of Mondragones (adapted from Rodríguez Aguilera et al., 2014).

2.2 Archaeological samples

Although the site was used from the 1st to the 7th century CE, only Late Roman and Late Antiquity (4th to 7th century CE) individuals were selected to reduce cultural variability. The collagen turnover rate of sampled bones is an important key in the interpretation of paleodiet (Hedges et al., 2007). Ribs and femurs are usually chosen for this kind of study owing to their faster turnover rates, which reflects diet from a recent period prior to death (Fahy et al., 2017). As many samples as possible were selected to make a representative analysis. Ribs from 46 individuals buried in Mondragones were sampled, including 21 adults (9 females, 3 males, 9 undetermined) and 25 non-adults (7 from 1 to 3 years old, 11 from 4 to 8 years old, and 6 from 10 to 18 years old). None of the selected ribs showed any signs of pathology or fractures. Of these 46 samples, 20 belong to phase 1 and 26 to phase 2.

Seven samples of faunal remains recovered from the site were analysed for the baseline. Zooarchaeological characterization identified 2 different species: 2 samples of cow/ox (*Bos taurus*) and 2 samples of goat/sheep (*Capra hircus/Ovis aries*). The other remains (all ribs) were classified as large mammals (perhaps cattle).

2.3 Anthropological and paleopathological methods

Human sex and age estimations were carried out using various standard methods based on cranium, mandible, and hip bones to increase the determination accuracy. Age estimation methods in adults included the morphology of the pubic symphysis (Todd, 1920, in White et al., 2012) and the alterations of the auricular surface of the ilium (Schwartz, 1995). In non-adults, age estimation methods included dental development (Ubelaker, 1978, in Scheuer and Black, 2000) and long bone length (Maresh, 1970, in Scheuer and Black, 2000). Biological sex was determined only in adults using the morphology of the pelvis and different cranial and mandible features, including the nuchal crest, mastoid process, supraorbital margin, prominence of the glabella, and mental eminence (Buikstra and Ubelaker, 1994). Stature was estimated using the formulae developed by De Mendonça (2000) in a Portuguese adult population. This method measures the maximum and physiological length of the humeri and femora to determine stature in centimetres (cm).

To consider all variables that could affect the dietary interpretation, a paleopathological study of the individuals was carried out. Pathological conditions were analysed macroscopically using multiple descriptions. For this study, mainly pathologies related to diet were considered, such as dental (cariogenic lesions and dental calculus) and non-specific stress markers (cribra orbitalia*,* porotic hyperostosis, and dental enamel hypoplasia). Dental caries was analysed using the system of Moore and Corbett (1971), modified by Buikstra and Ubelaker (1994). Dental calculus was measured according to Brothwell's (1981) description. As for cribra orbitalia, porotic hyperostosis, and dental enamel hypoplasia, only the presence or absence of pathology was measured, with the limitation of not having radiographic data. Aufderheide and Rodríguez-Martín (1998), Baxarias and Herrerin (2008), and Roberts and Manchester (2010) were followed in the description of these non-specific stress markers.

2.4 Bone collagen extraction

Collagen was extracted using a modification of the method originally developed by Longin (1971) (Britton et al., 2008; Knipper et al., 2013; Salesse et al., 2014; Saragoça et al., 2016). In brief, around 0.5 g of human and faunal bone samples were collected and cleaned with a Dremel Rotary Tool. Bone samples were demineralized in 10 mL 0.5 M HCl at 4 °C for 14 days, with regular vortex and changing the acid after 1 week. To oxidize fulvic and humic acids, samples were rinsed to neutrality with Milli-Q water and soaked in 0.125 M NaOH for 20 h at room temperature. Samples were rinsed again to neutrality with Milli-Q water and gelatinized in 0.01 M HCl at 70 °C for 48 h, with regular vortex. The liquid fraction containing solubilized collagen was filtered using Ezee-Filter separators (Elkay Laboratory Products), frozen with liquid nitrogen, lyophilized for 48 h, and analysed. Collagen extraction was performed in the HERCULES Laboratory (Évora, Portugal).

2.5 Stable isotope analysis

The carbon and nitrogen isotope composition ($^{13}C/^{12}C$ and $^{15}N/^{14}N$, respectively) of the collagen samples were determined by elemental analysis/isotope ratio mass spectrometry (EA/IRMS). The EA/IRMS system consisted of a Flash 2000 HT elemental analyser (Thermo Scientific, Bremen, Germany) with 2 reactors: i) combustion (C, N, and S) and ii) pyrolysis (H and O). The elemental analyser was coupled with a ConFlo IV (Thermo Scientific) continuous flow open split interface to a Delta V Advantage isotope ratio mass spectrometer (Thermo Scientific).

Carbon and nitrogen isotope analysis used a helium carrier gas at a flow rate of 95 mL/min. Aliquots of collagen samples (between 0.5 and 0.6 mg) together with the calibration standards (approx. 0.6 mg) were weighed in tin cups (IVA Analysentechnik GmbH & Co. KG, Meerbusch, Germany). The cups were closed, folded, pressed to a small size, and loaded in a MAS 200R (Thermo Scientific).

The stable isotope standard for carbon is Vienna Pee Dee Belemnite limestone (VPDB), and it is Vienna air (V-Air) for nitrogen. The standards used (IAEA 600, IAEA CH_6, and IAEA N_2) are recognized by the International Atomic Energy Agency (IAEA) (Valkiers et al., 2007). The standard deviations of bulk $\delta^{13}C$ and $\delta^{15}N$ were ± 0.1‰ and 0.2‰, respectively. Carbon and nitrogen isotope composition was measured in duplicate for each sample.

2.6 Statistical analysis

Statistical analysis was performed using SPSS v.24.0 for Windows and Microsoft Excel for Windows. Stable isotope results were compared by age, sex, phase, population, and pathological condition using a non-parametric Mann–Whitney *U* test because the data do not follow a normal distribution.

3. Results and discussion

3.1 Anthropological and paleopathological results

A total of 21 adults (9 females, 3 males, and 9 undetermined) aged between 18.5 years and 41.5 years were analysed (Table 1). Stature was estimated for 8 individuals whose sex determination was possible, using the physiological length of the femur. The male average was 164.44 ± 6.90 cm (n = 3), while the female average was 154.16 ± 5.92 cm (n = 5). Furthermore, stature was also estimated in females using the maximum length of the humerus, because this measure could be taken in more individuals of this sex (n = 7), obtaining an average of 154.96 ± 7.70 cm. These values are consistent with the results of other populations of the same timeline that used the De Mendonça (2000) method (López-Costas, 2012; Saragoça et al., 2016).

Nine adults (out of 21) showed cariogenic lesions, and 12 displayed dental calculus (Table 1). Four individuals presented non-specific stress markers. Specifically, one (MON-045A) shows cribra orbitalia, two (MON-059A and MON-059B) present dental enamel hypoplasia, and one (MON-051A) shows both enamel hypoplasia and porotic hyperostosis.

Among the 25 non-adults analysed, 5 presented cariogenic lesions and 3 showed dental calculus. Seven non-adults displayed cribra orbitalia, and one non-adult showed porotic hyperostosis. Furthermore, 2 cases of dental enamel hypoplasia were detected.

All these pathologies have been observed in similar contemporary populations from Iberian and Italian Peninsulas (i.e., Ortega Pérez and De Miguel Ibáñez, 1997; Facchini et al., 2004; Belcastro et al., 2007; Cardona López, 2009).

Table 1. Anthropological (age-at-death, sex, and stature) and paleopathological data of the individuals from Mondragones. n.d.: not determined; n.a.: not assessable; -: feature absent; LR: Late Roman; LA: Late Antiquity.

Sample	Age	Sex	Stature (cm)	Period	Pathologies
MO-041A	1 year ± 4 months	n.d.	n.a.	LA	n.a.
MO-043B	1 year ± 4 months	n.d.	n.a.	LA	n.a.
MO-056B	1 year ± 4 months	n.d.	n.a.	LR	Cribra orbitalia
MO-086B	1 year ± 4 months	n.d.	n.a.	LR	Cribra orbitalia
MO-093A	1 year ± 4 months	n.d.	n.a.	LA	Cribra orbitalia
MO-081A	2 years ± 8 months	n.d.	n.a.	LA	-
MO-095A	2 years ± 8 months	n.d.	n.a.	LA	Cribra orbitalia
MO-047A	4 years ± 12 months	n.d.	n.a.	LA	-
MO-050A	4 years ± 12 months	n.d.	n.a.	LA	Dental calculus
MO-062A	4 years ± 12 months	n.d.	n.a.	LR	Cribra orbitalia
MO-072A	4 years ± 12 months	n.d.	n.a.	LR	Cariogenic lesions
MO-088A	4 years ± 12 months	n.d.	n.a.	LA	-
MO-033B	6 years ± 24 months	n.d.	n.a.	LA	Dental enamel hypoplasia, cariogenic lesions
MO-056A	6 years ± 24 months	n.d.	n.a.	LR	Cribra orbitalia, cariogenic lesions, porotic hyperostosis
MO-057A	6 years ± 24 months	n.d.	n.a.	LR	Cariogenic lesions
MO-060A	6 years ± 24 months	n.d.	n.a.	LR	-
MO-086A	6 years ± 24 months	n.d.	n.a.	LR	-
MO-091A	8 years ± 24 months	n.d.	n.a.	LA	Cribra orbitalia
MO-039A	10 years ± 30 months	n.d.	n.a.	LA	Dental enamel hypoplasia, cariogenic lesions
MO-054A	<12 years	n.d.	n.a.	LR	n.a.
MO-042A	12 years ± 30 months	n.d.	n.a.	LA	Dental calculus
MO-037A	15 years ± 30 months	n.d.	n.a.	LA	n.a.
MO-053A	15 years ± 30 months	n.d.	n.a.	LR	Dental calculus
MO-074A	15 years ± 30 months	n.d.	n.a.	LR	-
MO-047B	<18	n.d.	n.a.	LA	n.a.
MO-044A	17–20 years	n.d.	n.a.	LA	Dental calculus
MO-045A	17–25 years	n.d.	n.a.	LA	Cariogenic lesions, dental calculus, cribra orbitalia
MO-059B	20–21 years	Female	168.6	LR	Dental calculus, dental enamel hypoplasia
MO-084B	20–21 years	Female	150.9	LA	Cariogenic lesions, dental calculus
MO-063A	25–29 years	Female	150.6	LR	Cariogenic lesions, dental calculus
MO-064A	30–34 years	Female	147.7	LR	n.a.
MO-071A	30–34 years	Female	n.a.	LR	Cariogenic lesions, dental calculus
MO-051A	35–39 years	Male	154.9	LA	Cariogenic lesions, dental calculus, dental enamel hypoplasia, porotic hyperostosis
MO-078A	35–39 years	Female	162.2	LA	Cariogenic lesions, dental calculus
MO-059A	39–44 years	Female	155.7	LR	Dental enamel hypoplasia, cariogenic lesions, dental calculus, periodontal disease
MO-029A	40–44 years	Male	169.4	LA	Cariogenic lesions, dental calculus
MO-069A	40–44 years	Female	n.a.	LR	n.a.
MO-031A	>18	Male	166.2	LA	Cariogenic lesions, dental calculus

MO-032	>18	n.d.	n.a.	LA	n.a.
MO-035	>18	n.d.	n.a.	LA	n.a.
MO-040A	>18	n.d.	n.a.	LA	n.a.
MO-046	>18	n.d.	n.a.	LR	n.a.
MO-048	>18	n.d.	n.a.	LA	n.a.
MO-058A	>18	Female	154.5	LR	Dental calculus
MO-068A	>18	n.d.	n.a.	LR	n.a.
MO-083	>18	n.d.	n.a.	LA	n.a.

3.2 Collagen quality

According to well established criteria, collagen extraction was successful for human and faunal bone samples: collagen yields >1%, (van Klinken, 1999); carbon content between 15.3% and 47.0% (Ambrose, 1990); nitrogen content between 5.5% and 17.3% (Ambrose, 1990); and C/N ratios between 2.9 and 3.6 (DeNiro, 1985). All samples displayed collagen content ranging from 5% to 15%. The carbon and nitrogen content in the bone collagen showed ranges between 37.1% and 43.8%, and between 13.6% and 16.1%, respectively. The atomic C/N ratios of bone collagen ranged between 3.0 and 3.3. Consequently, all the samples analysed in this study were considered well preserved (Table 2).

Table 2. Carbon and nitrogen stable isotope results and collagen quality indicators for human and faunal samples.

Individual category	Sample	$\delta^{15}N$ (‰, V-Air)	$\delta^{13}C$ (‰, VPDB)	N (%)	C (%)	C/N	Collagen yield (%)
Non-adults	MO-033B	9.6	-18.9	15.6	43.1	3.2	11.2
	MO-037A	8.8	-19.0	15.6	42.9	3.2	11.3
	MO-039A	9.4	-19.1	15.7	43.0	3.2	13.3
	MO-041A	12.8	-17.4	15.2	41.5	3.2	9.1
	MO-042A	8.9	-19.2	15.5	42.3	3.2	8.5
	MO-043B	13.5	-17.4	15.4	42.2	3.2	8.8
	MO-047A	10.8	-18.4	14.1	37.1	3.1	3.8
	MO-047B	9.7	-19.3	15.4	42.7	3.2	9.4
	MO-050A	10.4	-17.6	14.5	39.7	3.2	3.3
	MO-053A	10.0	-18.5	15.8	41.1	3.0	11.9
	MO-054A	10.0	-18.6	15.3	42.1	3.2	9.1
	MO-056A	10.7	-18.8	15.3	41.6	3.2	10.3
	MO-056B	14.6	-18.4	15.8	43.2	3.2	11.4
	MO-057A	9.9	-18.9	14.9	41.3	3.2	6.1
	MO-060A	9.4	-18.9	15.1	40.9	3.1	5.9
	MO-062A	10.5	-18.1	16.0	43.4	3.2	10.8
	MO-072A	9.7	-18.6	16.1	42.0	3.1	9.2
	MO-074A	9.5	-18.7	15.9	42.3	3.1	8.1
	MO-081A	10.0	-18.5	14.8	40.6	3.2	8.8
	MO-086A	10.0	-19.0	15.5	42.3	3.2	11.4
	MO-086B	13.2	-17.5	16.0	43.3	3.2	13.6
	MO-088A	10.6	-18.5	16.0	42.0	3.1	5.9
	MO-091A	9.8	-18.5	14.6	39.7	3.2	5.1
	MO-093A	14.6	-17.6	15.7	43.0	3.2	9.7
	MO-095A	10.8	-18.5	16.0	43.2	3.1	10.0
Male Adults	MO-029A	10.2	-18.6	15.4	41.8	3.2	4.5
	MO-031A	9.9	-19.1	14.2	39.6	3.2	7.0
	MO-051A	9.7	-18.6	14.2	39.0	3.2	3.7
Female Adults	MO-058A	9.5	-18.7	15.0	40.8	3.2	8.1
	MO-059A	10.2	-18.7	15.3	41.8	3.2	10.4
	MO-059B	10.4	-18.6	15.7	41.5	3.1	3.1
	MO-063A	9.4	-19.2	16.1	43.8	3.2	7.5
	MO-064A	9.8	-18.8	16.0	41.9	3.1	6.4
	MO-069A	9.3	-19.2	13.9	38.2	3.2	5.5
	MO-071A	10.6	-18.7	15.3	41.2	3.1	12.6

	MO-078A	9.2	-19.4	13.5	37.4	3.2	3.9
	MO-084B	10.8	-18.5	16.0	43.6	3.2	17.7
Adults (n.d.)	MO-032	10.2	-18.7	15.0	40.8	3.2	5.5
	MO-035	9.5	-18.4	16.0	41.9	3.0	11.3
	MO-040A	8.6	-18.7	14.5	37.3	3.0	5.0
	MO-044A	9.6	-18.9	15.1	39.8	3.1	4.9
	MO-045A	9.7	-18.4	14.9	38.6	3.0	7.7
	MO-046	10.4	-19.0	14.5	39.9	3.2	8.2
	MO-048	10.3	-18.7	15.4	42.1	3.2	5.9
	MO-068A	9.1	-18.4	14.4	40.0	3.3	5.8
	MO-083	11.2	-18.0	14.5	39.3	3.2	5.7
Bos taurus	MO-UE1194A	7.5	-20.4	15.6	42.5	3.2	8.2
	MO-UE1194B	7.1	-20.4	15.7	42.1	3.1	7.4
Capra hircus/ Ovis aries	MO-UE651	6.4	-19.7	15.5	42.9	3.2	10.5
	MO-UE1272	6.4	-21.0	15.0	40.8	3.2	6.8
Large mammal	MO-UE6093	7.8	-19.7	15.8	42.8	3.2	9.4
	MO-UE6098	8.1	-20.7	15.9	42.8	3.1	14.7
	MO-UE750	8.6	-19.0	15.5	41.5	3.1	7.9

3.3 Dietary patterns

The isotopic composition ($\delta^{13}C$ and $\delta^{15}N$) of human and faunal samples are listed in Table 2 and represented in Fig. 3.

$\delta^{13}C$ data from animal samples ranged from -21.0‰ to -19.1‰ and thus related to a diet based predominantly on C_3 plants. Most of the faunal samples displayed more depleted $\delta^{13}C$ values ($\delta^{13}C_{average}$ = -20.1 ± 0.7‰) than the human ones ($\delta^{13}C_{average}$ = -18.6 ± 0.5‰), reflecting a $\delta^{13}C$ increase for one trophic level. However, there was one outlier (UE-750, a large mammal) with a $\delta^{13}C$ value of -19.0‰ (Fig. 3). The $\delta^{13}C$ value of this sample may be due either to the consumption of C_4 plants, such as millet, or to the type of plant tissue consumed, because there are organs more enriched with $\delta^{13}C$ than others (Dungait et al., 2011). Another possibility may be that this sample was incorrectly classified as a large mammal when it could belong to a species like domestic pig, which is normally clustered with human data (Ren et al., 2017). According to evidence from the literature, these animals had a conspicuous importance in the Roman economy and diet (Prowse et al., 2004). Although the identification of this rib was not possible, the presence of pigs in the Iberian Peninsula has been recorded for the Roman period (Grau-Sologestoa, 2015), so this may support the idea that in Mondragones there were domesticated pigs. Concerning the ^{15}N composition, the values recorded in the collagen of the faunal samples ranged from 6.4‰ to 8.6‰ ($\delta^{15}N_{average}$ = 7.4 ± 0.8‰), where the highest $\delta^{15}N$ values belonged to large mammals (7.8–8.6‰). If it is assumed that these faunae were cattle, these results may be linked to the manuring practices. The application of animal dung to fields where domesticated animals were kept would generate a $\delta^{15}N$ enrichment in the soil and plants (Bogaard et al., 2007) as well as in the bone of animals and human consumers (van Klinken et al., 2002; Bogaard et al., 2007). However, the highest nitrogen value of these large mammals belonged to the outlier UE-750 (8.6‰), so these results must be interpreted cautiously, as species determination for these samples was not possible.

A diachronically isotopic study was realized to establish whether there were differences among individuals from the 2 chronological phases. The *U* test showed that there were no significant differences between Late Roman and Late Antiquity individuals (P_{carbon} = 0.367, $P_{nitrogen}$ = 0.929), so both phases were analysed together. The lack of significant differences between phases could be related to continuities of dietary and/or farming practices since the population of Mondragones lived mainly from their agriculture production.

The δ^{13}C values of non-adults ranged from -19.3‰ to -17.4‰ ($\delta^{13}C_{average}$ = -18.5 ± 0.6‰), while their δ^{15}N values ranged from 8.8‰ to 14.6‰ ($\delta^{15}N_{average}$ = 10.7 ± 1.7‰). The averages of carbon and nitrogen isotope composition, respectively, in non-adults by age groups were: [1] -17.9 ± 0.5‰ and 12.8 ± 1.8‰ for non-adults from 0 to 3 years (*n* = 7), [2] -18.6 ± 0.4‰ and 10.1 ± 0.5‰ for non-adults from 4 to 8 years (*n* = 11), and [3] -18.9 ± 0.3‰ and 9.4 ± 0.5‰ for non-adults from 9 to 18 years (*n* = 6). The δ^{13}C values for adults (males and females) ranged from -19.4‰ to -18.0‰ ($\delta^{13}C_{average}$ = -18.7 ± 0.3‰), and their δ^{15}N values ranged from 8.6‰ to 11.2‰ ($\delta^{15}N_{average}$ = 9.9 ± 0.6‰) (Table 3).

The δ^{13}C and δ^{15}N values were significantly different between adults and non-adults between 0 and 3 years (P_{carbon} = 0.000; $P_{nitrogen}$ = 0.000), but there were no differences between adults and the other groups of non-adults ($P > 0.05$). These results show that as the age of the non-adults increases, the results become more similar to those obtained in adults. Furthermore, the δ^{13}C and δ^{15}N values of human samples showed no significant differences in the diets of different sex (P_{carbon} = 0.482, $P_{nitrogen}$ = 0.864).

Table 3. Average stable carbon and nitrogen isotope values by age group and sex.

		N	δ^{15}N (‰, V-Air)	δ^{13}C (‰, VPDB)
Non-adults		24	10.7 ± 1.7	-18.5 ± 0.6
	Group 1 (0–3 years)	7	12.8 ± 1.8	-17.9 ± 0.5
	Group 2 (4–8 years)	11	10.1 ± 0.5	-18.6 ± 0.4
	Group 3 (9–18 years)	6	9.4 ± 0.5	-18.9 ± 0.3
Adults		21	9.9 ± 0.6	-18.7 ± 0.3
	Males	3	9.9 ± 0.2	18.8 ± 0.3
	Females	9	9.9 ± 0.6	-18.9 ± 0.3

Human samples displayed relatively higher δ^{13}C and δ^{15}N values in comparison to the fauna (P_{carbon} = 0.000; $P_{nitrogen}$ = 0.000), approximately 1.4‰ and 2.5‰ for C and N, respectively (Fig. 3). This is indicative of an increase of one trophic level between fauna and humans (Katzenberg, 2008), which suggests that animal meat may be a prominent protein resource in the diet of the population of Mondragones. In Roman culture, domesticated animals were kept not only for food provision but also as important beasts of burden, for example in the case of cattle (Cool, 2006). The meat component of the diet in this period came primarily from pigs, with a minor component of sheep and goats (approximately 25% to 35%), whose main function was to produce wool, milk, and cheese (Prowse et al., 2004). However, in the Iberian Peninsula, there is a good degree of variability that suggests that a local pattern persisted (King, 1999). This pattern, in most of the studied sites, consisted in a relatively low pig percentage (20% or less) and a higher percentage of sheep/goat and ox (King, 1999). In any case, the meat influence on the Roman diet is well documented (Alcock, 2006; Cool, 2006; Faas, 2013) and illustrated by the stable isotopic composition of the population from Mondragones.

The collagen average $\delta^{13}C$ values of individuals with a diet based on C_3 plants are around -20‰, while for individuals who consume a diet rich in C_4 plants this average is around -10‰ (Keenleyside et al., 2009). Taking this into account, the $\delta^{13}C$ values in adult humans ($\delta^{13}C_{average}$ = -18.7 ± 0.3‰) could be indicative of C_3 consumption with some contribution of C_4 plants, possibly millet. Although there is no archaeobotanical evidence of millet cultivation in Mondragones, there is evidence of its cultivation in the south-eastern Iberian Peninsula during the Bronze Age in locations close to Mondragones (Moreno-Larrazabal et al., 2015). Moreover, its presence is widely documented in most of the archaeological sites from the Bronze Age in Mediterranean geography (Peña-Chocarro, 1999; Rovira Buendía, 2007; Buxó and Piqué, 2008). Nevertheless, in Mondragones an increase in $\delta^{13}C$ values was observed along with the $\delta^{15}N$ values (see Fig. 3). C_4 consumption increases the collagen $\delta^{13}C$ values, while $\delta^{15}N$ values should not be affected, so this allows distinguishing between the consumption of C_4 plants and aquatic resources, which are usually also enriched with ^{15}N (Schoeninger and DeNiro, 1984; López-Costas et al., 2015). The pattern observed in Mondragones, of concomitant and significant increase in human bone $\delta^{13}C$ and $\delta^{15}N$ values (R^2 = 0.2801, P = 0.0005), can be due to fish consumption, which is consistent with its proximity to the Mediterranean Sea. The inclusion of other isotopes (e.g. sulphur, $\delta^{34}S$) could clarify the effective presence of a marine contribution in the diet of this population (Nehlich et al., 2010, Curto et al., 2019).

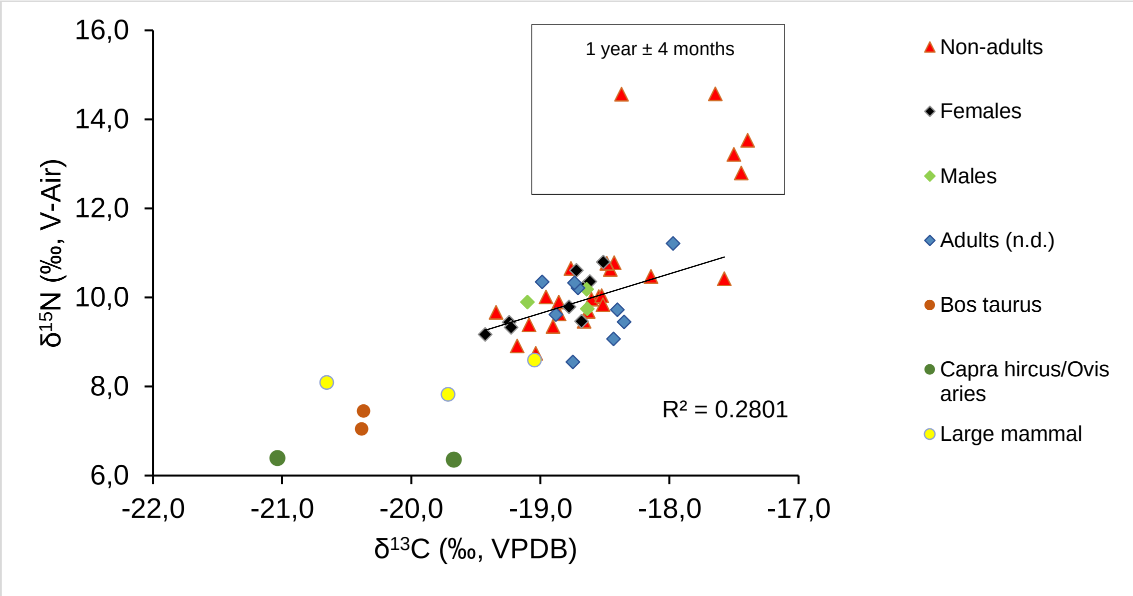

Fig. 3. Carbon and nitrogen isotope data from humans and faunal remains recovered at Mondragones.

Most of the human collagen δ^{13}C and δ^{15}N values were closely clustered, with the exception of 5 outliers (MO-041A, MO-043B, MO-056B, MO-086B, and MO-093A) associated with an enriched δ^{15}N value (Fig. 3). All of them were non-adults (1 year ± 4 months), whose average δ^{15}N value of 13.7 ± 0.8‰ was almost 4‰ above the average δ^{15}N value for the adult female population of Mondragones (9.9 ± 0.6‰) (P = 0.000). This high average δ^{15}N is probably indicating the period of breastfeeding. Values for δ^{15}N have been used to study breastfeeding and weaning patterns, because when infants are at breastfeeding age, their trophic level is one unit above their mothers. This is due to they are basically consuming their mother's tissue by the breast milk (Fuller et al., 2006). But the association between isotope data and the breastfeeding/weaning process involves the assumption that the bone collagen isotopes are representative of diet at approximately the time of death and that non-adults who died are representative of their age group (Beaumont et al., 2015). This is not considering the "Osteological Paradox" (Wood et al., 1992), which suggests that non-adults who have died may not be representative of the health conditions of the whole population. Increased nitrogen ratio could also reflect other conditions than the period of breastfeeding, such as a metabolic disorders or maternal stress episodes during pregnancy (Siebke et al., 2019). Moreover, a negative nitrogen balance could also produce an increase in δ^{15}N values (Laffranchi et al., 2018). It is caused by an imbalance between nitrogen intake and excretion (more catabolic than anabolic processes), which could be related to starvation, protein malnutrition or disease (Long et al., 1979; Fuller et al., 2005). An individual with some of these stress conditions loses tissue due to an excessive catabolic activity to maintain protein synthesis in other parts of the body, which could lead to increased δ^{15}N ratios

(D'Ortenzio et al., 2015). Henceforth, although an increase in nitrogen levels is generally observed in non-adults between 0 and 1 years of age, and it subsequently drops to the adult average, the observed increase does not allow us to conclude definitively that it is due to the breastfeeding period. Other techniques are recommended to complement the information obtained by analysing stable isotope ratios from bone, such as the application of incremental dentine micro-samples from teeth (Burt, 2015) and the investigation of other stable isotopes ratios e.g. oxygen (Reynard and Tuross, 2015; Britton et al. 2015).

On the other hand, there is another outlier (MO-050A) that displays a similar $\delta^{13}C$ value to non-adults and a similar $\delta^{15}N$ value to adults (-17.6‰ and 10.4‰, respectively) (Fig. 3). This individual was 4 years ± 12 months in age, and its $\delta^{13}C$ value could be due to the weaning process, assuming the limitations explained above. Its nitrogen and carbon isotope values were intermediate between non-adults and adults. This could be related to, in some cases, the transition to an adult diet, which goes through the introduction of supplementary foods enriched in ^{13}C (Dupras et al., 2001). This is consonant with the description of weaning practices of the Roman Era realized by Soranus and Galen (Greek and Roman physicians, respectively). They described it as a gradual process based on the introduction of supplementary foods (such as boiled honey or a mixture of honey and goat's milk) from 6 months of age to 3 years of age, when the weaning was completed (Dupras et al., 2001; Fuller et al., 2006; Saragoça et al., 2016).

Furthermore, a comparison of Mondragones dietary patterns with other Roman and Late Roman sites from the Iberian and Italian Peninsulas was also realized (Table 4). The adult results have been compared with the sites of Joan Planells (Ibiza, Spain) (Alaica et al., 2019), Tossal de les Basses (Valencia, Spain) (Salazar-García et al., 2016), Monte da Cegonha (Alentejo region, in southern Portugal) (Saragoça et al., 2016), and Port of Velia (Velia, Italy) (Craig et al., 2009). For the comparison of non-adult results, the sites of Isola Sacra (on the coast near Rome) (Prowse et al., 2008) and Monte da Cegonha (Saragoça et al., 2016) were selected. Dietary patterns from these populations are based predominantly on C_3 plants, with variable meat or dairy consumption. There are also differences in the consumption of C_4 plants and marine resources. In addition, the population from Port of Velia can be divided into 2 groups: [I] with a diet rich in cereals and relatively poor in meat and marine resources and [II] with much more meat and fish intake, and a consequent $\delta^{15}N$ increase. These populations have similar faunal isotope values to those obtained in this study, which enables a comparison of the human values. Even though there are significant differences between the $\delta^{15}N$ and $\delta^{13}C$ values in most adult populations ($P < 0.05$), the variation is more pronounced in nitrogen values (Fig. 4), especially in coastal populations. This variation appears to be associated with the availability of marine resources, because the only population that does not show significant differences is Monte da Cegonha, which is also located inland. Related to this, there are significant differences between nitrogen values of non-adults from Mondragones and non-adults from Isola Sacra (P = 0.000) (Table 4), who present higher values of $\delta^{15}N$. However, there are no differences between carbon values, so the nitrogen increase is probably due to seafood intake detected in their mothers (Prowse et al., 2008).

Table 4. Comparison of stable isotope results in different European sites.

		N	$\delta^{15}N$ (‰, V-Air)	*P*	$\delta^{13}C$ (‰, VPDB)	*P*
Adults	Mondragones	21	9.9 ± 0.6		-18.7 ± 0.3	
	Joan Planells (Alaica et al., 2019)	36	11.2 ± 1.5	0.000	-18.7 ± 0.5	0.768
	Monte da Cegonha (Saragoça et al., 2016)	18	10.3 ± 0.6	0.083	-18.4 ± 0.3	0.000
	Port of Velia I (Craig et al., 2009)	100	8.2 ± 0.7	0.000	-19.5 ± 0.2	0.000
	Port of Velia II (Craig et al., 2009)	17	11.2 ± 1.3	0.000	-19.3 ± 0.3	0.000
	Tossal de les Basses (Salazar-García et al., 2016)	23	10.8 ± 0.9	0.000	-18.2 ± 0.3	0.000
Non-adults	Mondragones	25	10.7 ± 1.7		-18.5 ± 0.6	
	Isola Sacra (Prowse et al., 2008)	37	12.5 ± 1.9	0.000	-18.7 ± 0.5	0.741
	Monte da Cegonha (Saragoça et al., 2016)	5	11.0 ± 1.3	0.300	-18.2 ± 0.6	0.416

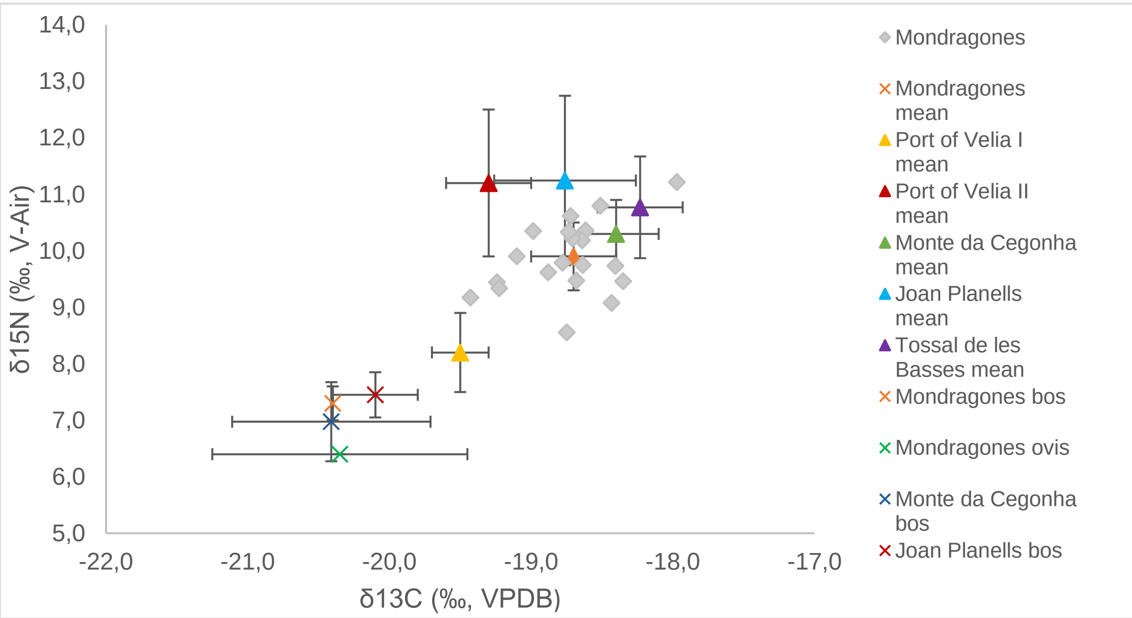

Fig. 4. Plot of $\delta^{15}N$ versus $\delta^{13}C$ values of the adult human (and faunal) samples from Mondragones compared with the mean values from other published Roman populations.

3.4 Pathological conditions and diet

An attempt to establish a relationship between the different pathologies detected and dietary patterns at the population level was realized. It was possible to infer the influence of diet in some pathologies attending to the detected cases (Table 5). However, a limitation of these analysis is that not all individuals had a complete skeleton, so only individuals with good skeletal representation (mainly cranium and teeth well-preserved) were considered. Therefore, these results are only an approximation of the relation between diet and pathological conditions.

Cariogenic lesions, dental calculus, dental enamel hypoplasia, and cribra orbitalia were analysed. Porotic hyperostosis could not be included in the statistical study because it was observed macroscopically in only 2 individuals and this result was not be confirmed by a further radiographical analysis. Caries was observed in at least 14 individuals (5 non-adults, 5 females, 3 males, and 1 undetermined), as well as dental calculus, which was observed in 12 individuals (3 non-adults, 7 females, 3 males, and 2 undetermined) (Table 5). Significant differences in carbon ratios between individuals with and without caries were observed (P = 0.018). Even though with this result and the dental calculus (P > 0.05) it was not possible to assume a relation between diet and this kind of dental lesions, the presence of caries and dental calculus in several individuals was indicative of starchy food and/or carbohydrate consumption (Lieverse, 1999; Featherstone, 2000).

Regarding non-specific stress markers, these conditions were found more frequently in non-adults (7 non-adults and 1 undetermined) (Table 5). Significant differences in terms of cribra orbitalia were observed (P_{carbon} = 0.001; $P_{nitrogen}$ = 0.006). In this case, individuals affected show higher nitrogen and less negative carbon averages than individuals without cribra, which may be related to the fact that most individuals affected by this condition are non-adults (all aged: 1 year ± 4 months). Cribra orbitalia and porotic hyperostosis have been traditionally related to anaemic conditions (Ortner, 2003), among others also, and the high prevalence of these pathologies in non-adults could be related to the Infant weaning transition described by Roman authors as Galen and Soranus, who suggest the introduction in the diet of infants of a mixture of goat's milk and honey (Fairgrieve and Molto, 2000). Goat’s milk has a lower content of folate than human milk (Chanarin, 1990), which has a direct impact on iron absorption and may lead to megaloblastic anaemia (Dupras et al., 2001). Dental enamel hypoplasia was observed in only 5 individuals (2 non-adults, 2 females, and 1 male). However, the relation between diet and presence/absence of dental enamel hypoplasia did not show significant differences (P > 0.05). None of these 5 individuals showed signs of cribra orbitalia or porotic hyperostosis, so this condition may be related to other dietary deficiencies or childhood diseases (Roberts and Manchester, 2010). In fact, enamel hypoplasia has also been linked to trauma to the developing tooth, genetic conditions, and specific environmental factors (Towle and Irish, 2020), so all these issues should be considered.

Table 5. Association between $\delta^{13}C$ and $\delta^{15}N$ values and pathologies.

		Non-adults	Adults			$\delta^{13}C$		$\delta^{15}N$	
			♀	♂	nd	x̄±SD	P	x̄±SD	P
Caries	Absence	15	2	0	1	-18.5 ± 0.5	0.018	10.7 ± 1.7	0.220
	Presence	5	5	3	1	-18.8 ± 0.3		9.9 ± 0.5	
Dental calculus	Absence	17	0	0	0	-18.5 ± 0.4	0.216	10.8 ± 1.7	0.165

	Presence	3	7	3	2	-18.7 ± 0.4		9.9 ± 0.5	
Dental enamel hypoplasia	Absence	18	5	2	2	-18.6 ± 0.5	0.285	10.5 ± 1.4	0.361
	Presence	2	2	1	0	-18.8 ± 0.2		9.9 ± 0.4	
Cribra orbitalia	Absence	2	7	2	1	-18.7 ± 0.4	0.001	9.9 ± 0.5	0.006
	Presence	7	0	0	1	-18.2 ± 0.5		11.7 ± 2.1	

4. Conclusions

This study provided the first paleodietary information on a Late Roman population from the south-eastern of the Iberian Peninsula. The results indicated a diet rich in C_3 plants supplemented with meat from terrestrial herbivores, although it is possible that this population had minimum C_4 plant or fish intake.

Dietary differences were not observed according to sex, but these differences were observed in age where the youngest non-adults in the breastfeeding period formed a well-defined group and showed significant differences with adults.

The palaeopathological study revealed the presence of diet-related diseases and non-specific stress markers. The high presence of caries and dental calculus are indicative of a diet rich in starch and carbohydrates, while cribra orbitalia, porotic hyperostosis, and dental enamel hypoplasia seem to be more related to dietary deficiencies (e.g. effect of supplementary food during the weaning period, malnutrition, diarrhea…).

Finally, considering the dietary variation and the geographical location of different Roman populations, although it is possible to establish similarities among all of them (for example, C_3 plants are common to all), it seems that the diet depended more on the environment and the local availability of food than on cultural habits.

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References

Alaica, A.K., Schalburg-Clayton, J., Dalton, A., Kranioti, E., Graziani Echávarri, G., Pickard, C., 2019. Variability along the frontier: stable carbon and nitrogen isotope ratio analysis of human remains from the Late Roman–Early Byzantine cemetery site of Joan Planells, Ibiza, Spain. Archaeol Anthropol Sci, 11(8), 3783–3796. https://doi.org/10.1007/s12520-018-0656-0

Alcock, J.P., 2006. Food in the Ancient World. Greenwood Press, Westport, CT.

Ambrose, S.H., 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis. J. Archaeol. Sci. 17, 431–451. https://doi.org/10.1016/0305-4403(90)90007-R

Aufderheide, A.C., Rodríguez-Martín., 1998. The Cambridge Encyclopedia of Human Paleopathology. Cambridge University Press.

Baxarias, J., Herrerín, J., 2008. The Handbook Atlas of Paleopathology. Libros Pórtico.

Beaumont, J., Montgomery, J., Buckberry, J., Jay, M., 2015. Infant mortality and isotopic complexity: New approaches to stress, maternal health, and weaning. Am. J. Phys. Anthropol. 157(3), 441–457. https://doi.org/10.1002/ajpa.22736

Belcastro, G., Rastelli, E., Mariotti, V., Consiglio, C., Facchini, F., Bonfiglioli, B., 2007. Continuity or discontinuity of the life-style in central Italy during the Roman imperial age-early middle ages transition: Diet, health, and behavior. Am. J. Phys. Anthropol. 132(3), 381–394. https://doi.org/10.1002/ajpa.20530

Bogaard, A., Heaton, T.H.E., Poulton, P., Merbach, I., 2007. The impact of manuring on nitrogen isotope ratios in cereals: Archaeological implications for reconstruction of diet and crop management practices. J. Archaeol. Sci. 34, 335–343. https://doi.org/10.1016/j.jas.2006.04.009

Bourbou, C., Fuller, B.T., Garvie-Lok, S.J., Richards, M.P., 2013. Nursing mothers and feeding bottles: Reconstructing breastfeeding and weaning patterns in Greek Byzantine populations (6th-15th centuries AD) using carbon and nitrogen stable isotope ratios. J. Archaeol. Sci. 40(11), 3903–3913. https://doi.org/10.1016/j.jas.2013.04.020

Britton, K., Müldner, G., Bell, M., 2008. Stable isotope evidence for salt-marsh grazing in the Bronze Age Severn Estuary, UK: Implications for palaeodietary analysis at coastal sites. J. Archaeol. Sci. 35, 2111–2118. https://doi.org/10.1016/J.JAS.2008.01.012

Britton, K., Fuller, B.T., Tütken, T., Mays, S. and Richards, M.P. (2015), Oxygen isotope analysis of human bone phosphate evidences weaning age in archaeological populations. Am. J. Phys. Anthropol., 157: 226-241. https://doi.org/10.1002/ajpa.22704

Brothwell, D.R., 1981. Digging Up Bones: The Excavation, Treatment, and Study of Human Skeletal Remains. Cornell University Press.

Budd, C., Lillie, M., Alpaslan-Roodenberg, S., Karul, N., Pinhasi, R., 2013. Stable isotope analysis of Neolithic and Chalcolithic populations from Aktopraklik, Northern Anatolia. J. Archaeol. Sci. 40, 860–867. https://doi.org/10.1016/j.jas.2012.09.011

Buikstra, J., Ubelaker, D. (Eds.), 1994. Standards for Data Collection from Human Skeletal Remains. Arkansas Archeological Survey, Fayetteville, AR.

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

Buxó, R., Piqué, R., 2008. Arqueobotánica: Los Usos De Las Plantas en La Península Ibérica. Grupo Planeta, Madrid, Spain.

Buzon, M.R., Conlee, C.A., Simonetti, A., Bowen, G.J., 2012. The consequences of Wari contact in the Nasca region during the Middle Horizon: archaeological, skeletal, and isotopic evidence. J. Archaeol. Sci. 39, 2627–2636. https://doi.org/10.1016/j.jas.2012.04.003

Cardona López, F., 2009. Resultados Del Estudio Antropológico De La Necrópolis Del Foro De Pollentia (Alcudia, Mallorca). Campañas 2004-2008. CPAG, 19, 429–447.

Chanarin I., 1990. The Megaloblastic Anemias, 3rd ed. Blackwell Scientific Publications, Oxford.

Cool, H.E.M., 2006. Eating and Drinking in Roman Britain. Cambridge University Press, Cambridge.

Craig, O.E., Biazzo, M., O'Connell, T.C., Garnsey, P., Martinez-Labarga, C., Lelli, R., … Bondioli, L., 2009. Stable isotopic evidence for diet at the imperial roman coastal site of Velia (1st and 2nd centuries AD) in Southern Italy. Am. J. Phys. Anthropol. 139, 572–583. https://doi.org/10.1002/ajpa.21021

Curto, A., Maurer, A., Barrocas-dias, C., Mahoney, P., Fernandes, T., Fahy, G.E., 2019. Did military orders influence the general population diet? Stable isotope analysis from Medieval Tomar, Portugal. Archaeol Anthropol Sci. 11, 3797-3809. https://doi.org/https://doi.org/10.1007/s12520-018-0637-3

De Mendonça, M.C., 2000. Estimation of height from the length of long bones in a Portuguese adult population. Am. J. Phys. Anthropol. 112, 39–48. https://doi.org/10.1002/(SICI)1096-8644(200005)112:1<39::AID-AJPA5>3.0.CO;2-%23

DeNiro, M.J., 1985. Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. Nature. 317, 806–809. https://doi.org/10.1038/317806a0

Diéguez Ramírez, J.P., 2015. Estudio Bioantropológico comparado de tres necrópolis históricas excavadas en el Término Municipal de Lucena (Córdoba) (thesis). University of Granada.

D'Ortenzio, L., Brickley, M., Schwarcz, H., Prowse, T., 2015. You are not what you eat during physiological stress: isotopic evaluation of human air. Am. J. Phys. Anthropol. 157, 374–388. https://doi.org/10.1002/ajpa.22722

Dungait, J.A.J., Docherty, G., Straker, V., Evershed, R.P., 2011. Variation in bulk tissue, fatty acid and monosaccharide δ13C values between autotrophic and heterotrophic plant organs. Phytochemistry. 72, 2130–2138. https://doi.org/10.1016/j.phytochem.2011.07.010

Dupras, T.L., Schwarcz, H.P., Fairgrieve, S.I., 2001. Infant feeding and weaning practices in Roman Egypt. Am. J. Phys. Anthropol. 115, 204–212. https://doi.org/10.1002/ajpa.1075

Faas, P., 2013. Around the Roman Table. Pan Macmillan, Chicago, IL.

Facchini, F., Rastelli, E., Brasili, P., 2004. Cribra orbitalia and cribra cranii in Roman skeletal remains from the Ravenna area and Rimini (I-IV century AD). Int J Osteoarchaeol, 14(2), 126–136. https://doi.org/10.1002/oa.717

Fahy, G.E., Deter, C., Pitfield, R., Miszkiewicz, J.J., Mahoney, P., 2017. Bone deep: Variation in stable isotope ratios and histomorphometric measurements of bone remodelling within adult humans. J. Archaeol. Sci. 87, 10–16. https://doi.org/10.1016/j.jas.2017.09.009

Fairgrieve S.I., Molto J.E., 2000. Cribra orbitalia in two temporally disjunct population samples from the Dakhleh Oasis, Egypt. Am. J. Phys. Anthropol. 111, 319–331. https://doi.org/10.1002/(SICI)1096-8644(200003)111:3<319::AID-AJPA3>3.0.CO;2-N

Featherstone, J.D.B., 2000. The science and practice of caries prevention. J. Am. Dent. Assoc. 131, 887–899. https://doi.org/10.14219/jada.archive.2000.0307

Fontanals-Coll, M., Díaz-Zorita Bonilla, M., Subirà, M.E., 2016. A palaeodietary study of stable isotope analysis from a high-status burial in the Copper Age: The Montelirio megalithic structure at Valencina de la Concepción-Castilleja de Guzmán, Spain. Int. J. Osteoarchaeol. 26(3), 447–459. https://doi.org/10.1002/oa.2435

Fornell-Muñoz, A., 1999. Las “villae” romanas en la Andalucía Mediterránea y del Estrecho (thesis). University of Jaén.

Fuller, B.T., Fuller, J.L., Sage, N.E., 2005. Nitrogen balance and $\delta^{15}N$: why you're not what you eat during nutritional stress. Rapid Commun. Mass Spectrom. 19, 2497–2506. https://doi.org/10.1002/rcm.2090

Fuller, B.T., Molleson, T.I., Harris, D.A., Gilmour, L.T., Hedges, R.E.M., 2006. Isotopic evidence for breastfeeding and possible adult dietary differences from Late/Sub-Roman Britain. Am. J. Phys. Anthropol. 129, 45–54. https://doi.org/10.1002/ajpa.20244

Goodman, A.H., Rose, J.C., 1991. Dental enamel hypoplasias as indicators of nutritional status. In: Kelley, M., Larsen, C. (Eds), Advances in Dental Anthropology. Wiley-Liss, New York, pp. 279-293.

Grau-Sologestoa, I., 2015. Livestock management in Spain from Roman to post-medieval times: A biometrical analysis of cattle, sheep/goat and pig. J. Archaeol. Sci. 54, 123–134. https://doi.org/10.1016/j.jas.2014.11.038

Guede, I., Ortega, L.A., Zuluaga, M.C., Alonso-Olazabal, A., Murelaga, X., Pina, M., Gutierrez, F.J., Iacumin, P., 2017. Isotope analyses to explore diet and mobility in a medieval Muslim population at Tauste (NE Spain). PLoS ONE. 12(5), 1–27. https://doi.org/10.1371/journal.pone.0176572

Hardy, K., Blakeney, T., Copeland, L., Kirkham, J., Wrangham, R., Collins, M., 2009. Starch granules, dental calculus and new perspectives on ancient diet. J. Archaeol. Sci. 36(2), 248–255. https://doi.org/10.1016/j.jas.2008.09.015

Hedges, R.E.M., Clement, J.G., Thomas, C.D.L., O'Connell, T.C., 2007. Collagen turnover in the adult femoral mid-shaft: Modeled from anthropogenic radiocarbon tracer measurements. Am. J. Phys. Anthropol. 133, 808–816. https://doi.org/10.1002/ajpa.20598

Hedges, R.E.M., Reynard, L.M., 2007. Nitrogen isotopes and the trophic level of humans in archaeology. J. Archaeol. Sci. 34, 1240–1251. https://doi.org/10.1016/j.jas.2006.10.015

Heras Martínez, C.M., Galera Olmo, V., Batista Ramírez, A.B., Corrales Pevida, R., 2011. Necrópolis bajoimperial y tardorromana de "La Magdalena III-IV" (Alcalá de Henares): contextualización arqueológica. Actas de las octavas jornadas de Patrimonio Arqueológico en la Comunidad de Madrid, pp. 79–92.

Hillson, S., 2001. Recording dental caries in archaeological human remains. Int. J. Osteoarchaeol. 11(4), 249–289. https://doi.org/10.1002/oa.538

Hillson, S., 2019. Dental pathology, in: Katzenberg, M. A., Grauer, A. L. (Eds.), Biological Anthropology of the Human Skeleton, third ed. John Wiley & Sons, pp. 293–333. https://doi.org/10.1002/9781119151647

Inskip, S., Carroll, G., Waters-Rist, A., López-Costas, O., 2019. Diet and food strategies in a southern al-Andalusian urban environment during Caliphal period, Écija, Sevilla. Archaeol Anthropol Sci. 11(8), 3857–3874. https://doi.org/10.1007/s12520-018-0694-7

Jiménez-Brobeil, S.A., Maroto, R.M., Laffranchi, Z., Roca, M.G., Granados Torres, A., Delgado Huertas, A., 2020. Exploring diet in an isolated medieval rural community of Northern Iberia: The case study of San Baudelio de Berlanga (Soria, Spain). J.

Archaeol. Sci. Rep. 30(January), 102218. https://doi.org/10.1016/j.jasrep.2020.102218

Joly, F.D., 2003. Espaço, poder e escravidão no De Re Rustica de Columela. Revista Brasileira de História. 23(45), 281–299. https://doi.org/10.1590/s0102-01882003000100012

Katzenberg, M.A., 2008. Stable isotope analysis: A tool for studying past diet, demography, and life history, in: Katzenberg, M.A., Saunders, S.R. (Eds.), Biological Anthropology of the Human Skeleton, second ed. John Wiley & Sons, Hoboken, NJ, pp. 413–441. https://doi.org/10.1002/9780470245842.ch13

Katzenberg, M.A., 2012. The ecological approach: Understanding past diet and the relationship between diet and disease, in: Grauer, A.L. (Ed.), A Companion to Paleopathology. Wiley-Blackwell, Malden, MA, pp. 97–113.

Keenleyside, A., Schwarcz, H., Stirling, L., Lazreg, N.B., 2009. Stable isotopic evidence for diet in a Roman and Late Roman population from Leptiminus, Tunisia. J. Archaeol. Sci. 36, 51–63. https://doi.org/10.1016/j.jas.2008.07.008

Kendall, E., 2016. The "terrible tyranny of the majority": Recognising population variability and individual agency in past infant feeding practices, in: Powell, L., Southwell-Wright, W., Gowland, R. (Eds), Care in the Past: Archaeological and Interdisciplinary Perspectives. Oxford: Oxbow Books, pp. 39–51.

King, A., 1999. Diet in the Roman world: A regional inter-site comparison of the mammal bones. J. Rom. Archaeol. 12, 168–202. https://doi.org/10.1017/s1047759400017979

Knipper, C., Peters, D., Meyer, C., Maurer, A.F., Muhl, A., Schöne, B.R., Alt, K.W., 2013. Dietary reconstruction in Migration Period Central Germany: A carbon and nitrogen isotope study. Archaeol. Anthropol. Sci. 5, 17–35. https://doi.org/10.1007/s12520-012-0106-3

Laffranchi, Z., Cavalieri-Manasse, G., Salzani, L., Milella, M., 2019. Patterns of funerary variability, diet, and developmental stress in a Celtic population from NE Italy (3rd-1st c BC). PLoS ONE. 14(4), e0214372. https://doi.org/10.1371/journal.pone.0214372

Lieverse, A.R., 1999. Diet and the aetiology of dental calculus. Int. J. Osteoarchaeol. 9, 219–232. https://doi.org/10.1002/(SICI)1099-1212(199907/08)9:4<219::AID-OA475>3.0.CO;2-V

Long, C.L., Schaffel, N., Geiger, J.W., Schiller, W.R., Blakemore, W.S., 1979. Metabolic response to injury, illness: estimation of energy and protein needs from indirect calorimetry and nitrogen balance. J. Parenter. Enteral Nutr. 3, 452–456. https://doi.org/10.1177/014860717900300609

Longin, R., 1971. New method of collagen extraction for radiocarbon dating. Nature. 230, 241–242. http://dx.doi.org/10.1038/230241a0

Lopez, B., Pardiñas, A.F., Garcia-Vazquez, E., Dopico, E., 2012. Socio-cultural factors in dental diseases in the Medieval and early Modern Age of northern Spain. Homo. 63(1), 21–42. https://doi.org/10.1016/j.jchb.2011.12.001

López-Costas, O., 2012. Antropología de los restos óseos humanos de Galicia (thesis). University of Granada.

López-Costas, O., Müldner, G., Martínez Cortizas, A., 2015. Diet and lifestyle in Bronze Age northwest Spain: The collective burial of Cova do Santo. J. Archaeol. Sci. 55, 209–218. https://doi.org/10.1016/j.jas.2015.01.009

Ma, M., Dong, G., Jia, X., Wang, H., Cui, Y., Chen, F., 2016. Dietary shift after 3600 cal yr BP and its influencing factors in northwestern China: Evidence from stable isotopes. Quat. Sci. Rev. 145, 57–70. https://doi.org/10.1016/j.quascirev.2016.05.041

Mays, S.A., 1998. The Archaeology of Human Bones. Routledge, New York. https://doi.org/10.2307/2694542

Milella, M., Gerling, C., Doppler, T., Kuhn, T., Cooper, M., Mariotti, V., Belcastro, M.G., Ponce de León, M.S., Zollikofer, C.P.E., 2019. Different in death: Different in life? Diet and mobility correlates of irregular burials in a Roman necropolis from Bologna (Northern Italy, 1st–4th century CE). J. Archaeol. Sci. Rep. 27, 101926. https://doi.org/10.1016/j.jasrep.2019.101926

Moore, W.J., Corbett M.E., 1971. The Distribution of Dental Caries in Ancient British Populations 1. Anglo-saxon Period. Caries Res. 5, 151–168. https://doi.org/10.1159/000259743

Moreno-Larrazabal, A., Teira-Brión, A., Sopelana-Salcedo, I., Arranz-Otaegui, A., Zapata, L., 2015. Ethnobotany of millet cultivation in the north of the Iberian Peninsula. Veg. Hist. Archaeobot. 24, 541–554. https://doi.org/10.1007/s00334-015-0518-y

Müldner, G., Richards, M.P., 2007. Stable isotope evidence for 1500 years of human diet at the city of York, UK. Am. J. Phys. Anthropol. 133, 682–697. https://doi.org/10.1002/ajpa.20561

Nehlich, O., Boric, D., Stefanovic, S., Richards, M., 2010. Sulphur isotope evidence for freshwater fish consumption: A case study from the Danube Gorges, SE Europe. J. Archaeol. Sci. 37, 1131–1139. https://doi.org/10.1016/j.jas.2009.12.013

Ortega Pérez, J.R., De Miguel Ibáñez, M.P., 1997. Necrópolis de la Villa Romana “Casa Ferrer I” (Alicante): Avance de su estudio. XXIV Congreso Nacional de Arqueología, 4, 525–529.

Ortner, D.J., 2003. Identification of Pathological Conditions in Human Skeletal Remains, second ed. Academic Press, London.

Oxenham, M.F., Cavill, I., 2010. Porotic hyperostosis and cribra orbitalia: The erythropoietic response to iron-deficiency anaemia. Anthropol. Sci. 118(3), 119–200. https://doi.org/10.1537/ase.100302

Pate, F.D., 1994. Bone chemistry and paleodiet. J Archaeol Method Theory. 1(2), 161–209. https://doi.org/10.1007/BF02231415

Pate, J., 2001. Carbon isotope discrimination and plant water-use efficiency, in: Unkovich, M.J., Pate, J.S., McNeill, A., Gibbs, J. (Eds.), Stable Isotope Techniques in Study of Biological Processes and Functioning of Ecosystems. Kluwer Academic Publishers, Dordrecht, Netherlands, pp. 19–36.

Peña-Chocarro, L., 1999. Prehistoric Agriculture in Southern Spain During the Neolithic and the Bronze Age: The Application of Ethnographic Models. Archaeopress, Oxford, UK.

Polo Cerdá, M., Garcia-Prosper, E., 2005. Restos óseos hallados en el interior de la cloaca de la vía Romana del “solar de la morería” de Sagunto. ARSE. 39, 209–228.

Prowse, T., Schwarcz, H.P., Saunders, S., Macchiarelli, R., Bondioli, L., 2004. Isotopic paleodiet studies of skeletons from the Imperial Roman-age cemetery of Isola Sacra, Rome, Italy. J. Archaeol. Sci. 31(3), 259–272. https://doi.org/10.1016/j.jas.2003.08.008

Prowse, T.L., Saunders, S.R., Schwarcz, H.P., Garnsey, P., Macchiarelli, R., Bondioli, L., 2008. Isotopic and dental evidence for infant and young child feeding practices in an imperial Roman skeletal sample. Am. J. Phys. Anthropol. 137, 294–308. https://doi.org/10.1002/ajpa.20870.

Reitsema, L.J., 2013. Beyond diet reconstruction: Stable isotope applications to human physiology, health, and nutrition. Am. J. Hum. Biol. 25(4), 445–456. https://doi.org/10.1002/ajhb.22398

Reitsema, L.J., Crews, D.E., Polcyn, M., 2010. Preliminary evidence for medieval Polish diet from carbon and nitrogen stable isotopes. J. Archaeol. Sci. 37, 1413–1423. https://doi.org/10.1016/j.jas.2010.01.001.

Ren, L., Li, X., Kang, L., Brunson, K., Liu, H., Dong, W., … Dong, G., 2017. Human paleodiet and animal utilization strategies during the Bronze Age in northwest Yunnan province, southwest China. PLoS One. 12, e0177867. https://doi.org/10.1371/journal.pone.0177867.

Reynard, L.M., Tuross, N., 2015. The known, the unknown and the unknowable: Weaning times from archaeological bones using nitrogen isotope ratios. J. Archaeol. Sci. 53, 618–625. https://doi.org/10.1016/j.jas.2014.11.018

Rivera, F., Mirazón Lahr, M., 2017. New evidence suggesting a dissociated etiology for cribra orbitalia and porotic hyperostosis. Am. J. Phys. Anthropol. 164(1), 76–96. https://doi.org/10.1002/ajpa.23258

Roberts, C., Manchester, K., 2010. The Archaeology of Disease, third ed. History Press, Stroud, UK.

Rodríguez Aguilera, Á., García-Consuegra Flores, J.M., Rodríguez Aguilera, J., Pérez Tovar, M.J., Marín Díaz, P., 2014. La villa Bajoimperial y Tardo Antigua de Los

Mondragones (Granada). Cuadernos de Prehistoria y Arqueología de La Universidad de Granada. 24, 459–496.

Rovira Buendía, N., 2007. Agricultura y gestión de los recursos vegetales en el sureste de la península ibérica durante la prehistoria reciente (thesis). University Pompeu Fabra, Barcelona, Spain.

Rullkötter, J., 2006. Organic matter: The driving force for early diagenesis, in: Schlulz, H.D., Zabel, M. (Eds.), Marine Geochemistry. Springer, pp. 125–169.

Rutgers, L.V., van Strydonck, M., Boudin, M., van der Linde, C., 2009. Stable isotope data from the early Christian catacombs of ancient Rome: New insights into the dietary habits of Rome's early Christians. J. Archaeol. Sci. 36(5), 1127–1134. https://doi.org/10.1016/j.jas.2008.12.015

Salazar García, D.C., 2011. Patrón de dieta de la población púnica de Can Marines (Ibiza) a través del análisis de isótopos estables (C y N) en colágeno óseo. Sagvntvm. 43(0), 95–102. https://doi.org/10.7203/sagvntvm.43.1213

Salazar-García, D.C., Romero, A., García-Borja, P., Subirà, M.E., Richards, M.P., 2016. A combined dietary approach using isotope and dental buccal-microwear analysis of human remains from the Neolithic, Roman and Medieval periods from the archaeological site of Tossal de les Basses (Alicante, Spain). J. Archaeol. Sci. Rep. 6, 610–619. https://doi.org/10.1016/j.jasrep.2016.03.002

Salesse, K., Dufour, E., Lebon, M., Wurster, C., Castex, D., Bruzek, J., Zazzo, A., 2014. Variability of bone preservation in a confined environment: The case of the catacomb of Sts Peter and Marcellinus (Rome, Italy). Palaeogeogr. Palaeoclimatol. Palaeoecol. 416, 43–54. https://doi.org/10.1016/J.PALAEO.2014.07.021

Sánchez López, E., 2013. Las actividades productivas en Florentia iliberritana: ciudad y campo. Revista Del Centro de Estudios Históricos de Granada y Su Reino. 25, 49–57.

Saragoça, P., Maurer, A.F., Šoberl, L., Lopes, M. da C., Alfenim, R., Leandro, I., … Barrocas, C.D.., 2016. Stable isotope and multi-analytical investigation of Monte da Cegonha: A Late Antiquity population in southern Portugal. J. Archaeol. Sci. Rep. 9, 728–742. https://doi.org/10.1016/j.jasrep.2016.07.010

Scheuer, L., Black, S., 2000. Developmental Juvenile Osteology, first ed. Elsevier Academic Press, Cambridge, MA.

Schoeninger, M.J., 1995. Stable isotope studies in human evolution. Evolutionary Anthropology: Issues, News, and Reviews. 4(3), 83–98. https://doi.org/10.1002/evan.1360040305

Schoeninger, M.J., DeNiro, M.J., 1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. Geochim. Cosmochim. Acta. 48(4), 625–639. https://doi.org/10.1016/0016-7037(84)90091-7

Schwartz, J.H., 1995. Skeleton Keys: An Introduction to Human Skeletal Morphology, Development, and Analysis. Oxford University Press, Oxford, UK.

Scott, G.R., Poulson, S.R., 2012. Stable carbon and nitrogen isotopes of human dental calculus: A potentially new non-destructive proxy for paleodietary analysis. J. Archaeol. Sci. 39(5), 1388–1393. https://doi.org/10.1016/j.jas.2011.09.029

Siebke, I., Moghaddam, N., Cunningham, C.A., Witzel, C., Lösch, S., 2019. Those who died very young—Inferences from δ15N and δ13C in bone collagen and the absence of a neonatal line in enamel related to the possible onset of breastfeeding. Am. J. Phys. Anthropol. 169(4), 664–677. https://doi.org/10.1002/ajpa.23847

Suby, J.A., 2014. Porotic hyperostosis and cribra orbitalia in human remains from southern Patagonia. Anthropol. Sci. 122(2), 69–79. https://doi.org/10.1537/ase.140430

Svyatko, S.V., 2014. Dental palaeopathological analysis of the eneolithic-early Iron Age populations from the Minusinsk Basin, Southern Siberia: Palaeodietary implications. Archaeol. Ethnol. Anthropol. Eurasia. 42(2), 143–156. https://doi.org/10.1016/j.aeae.2015.01.014

Tafuri, M.A., Goude, G., Manzi, G., 2018. Isotopic evidence of diet variation at the transition between classical and post-classical times in Central Italy. J. Archaeol. Sci. Rep. 21(April), 496–503. https://doi.org/10.1016/j.jasrep.2018.08.034

Toso, A., Gaspar, S., Banha da Silva, R., Garcia, S.J., Alexander, M., 2019. High status diet and health in Medieval Lisbon: A combined isotopic and osteological analysis of the Islamic population from São Jorge Castle, Portugal. Archaeol Anthropol Sci. 11(8), 3699–3716. https://doi.org/10.1007/s12520-019-00822-7

Towle, I., Irish, J.D., 2020. Recording and interpreting enamel hypoplasia in samples from archaeological and palaeoanthropological contexts. J. Archaeol. Sci. 114, 105077. https://doi.org/10.1016/j.jas.2020.105077

Turner, B.L., Edwards, J.L., Quinn, E.A., Kingston, J.D., Van Gerven, D.P., 2007. Age-related variation in isotopic indicators of diet at medieval Kulubnarti, Sudanese Nubia. Int J Osteoarchaeol. 17(1), 1–25. https://doi.org/10.1002/oa.862

Valkiers, S., Varlam, M., Ruße, K., Berglund, M., Taylor, P., Wang, J., … De Bièvre, P., 2007. Preparation of synthetic isotope mixtures for the calibration of carbon and oxygen isotope ratio measurements (in carbon dioxide) to the SI. Int. J. Mass Spectrom. 264, 10–21. https://doi.org/10.1016/j.ijms.2007.03.012

Van der Merwe, N.J., Vogel, J.C., 1978. 13C content of human collagen as a measure of prehistoric diet in woodland North America. Nature. 276(5690), 815–816. https://doi.org/10.1038/276815a0

van Klinken, G.J., 1999. Bone collagen quality indicators for palaeodietary and radiocarbon measurements. J. Archaeol. Sci. 26, 687–695. https://doi.org/10.1006/jasc.1998.0385

van Klinken, G.J., Richards, M.P., Hedges, B.E.M., 2002. An overview of causes for stable isotopic variations in past European human populations: Environmental, ecophysiological, and cultural effects, in: Ambrose, S.H., Katzenberg, M.A. (Eds.), Biogeochemical Approaches to Paleodietary Analysis. Springer US, Boston, MA, pp. 39–63. https://doi.org/10.1007/0-306-47194-9_3

Villalba-Mouco, V., Sauqué, V., Sarasketa-Gartzia, I., Pastor, M.V., le Roux, P.J., Vicente, D., Utrilla, P., Salazar-García, D.C., 2018. Territorial mobility and subsistence strategies during the Ebro Basin Late Neolithic-Chalcolithic: A multi-isotope approach from San Juan cave (Loarre, Spain). Quat. Int. 481, 28–41. https://doi.org/10.1016/j.quaint.2017.05.051

Walker, P.L., Bathurst, R.R., Richman, R., Gjerdrum, T., Andrushko, V.A., 2009. The causes of porotic hyperostosis and cribra orbitalia: A reappraisal of the iron-deficiency-anemia hypothesis. Am. J. Phys. Anthropol. 139(2), 109–125. https://doi.org/10.1002/ajpa.21031

White, T.D., Black, M.T., Folkens, P.A., 2012. Human Osteology, third ed. Elsevier, Amsterdam, Netherlands.

Wood, J.W., Milner, G.R., Harpending, H.C., Weiss, K.M., Cohen, N., Eisenberg, L.E., Hutchinson, D.L., Jankauskas, R., Česnys, G., Katzenberg, A., Lukacs, J.R., Mcgrath, J.W., Roth, E.A., Ubelaker, D.H., Wilkinson, R.G., 1992. The osteological paradox. Curr. Anthropol. 33(4), 343–370. https://doi.org/papers2://publication/uuid/3AD1960D-AE51-4550-BE94-EBED5FB00559