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RESEARCH

Life during the Mesolithic in the Cantabrian region: new carbon, nitrogen and strontium isotopic data from dentine sequences and enamel from Los Canes Cave (Asturias, Northern Spain)

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Abstract

The Mesolithic period has a long history of study in the Cantabrian region (Northern Iberia) due to the relatively high concentration of human remains dating to this period. Previous analysis of stable carbon and nitrogen isotopes focussed on bone collagen, useful in broadly characterising Mesolithic diet, and particularly in identifying distinct inland and coastal diets. But this long-term average view does not permit the study of variation throughout the year that we might expect to see in hunter-gatherer diets. In this study, we present new radiocarbon dates and sequential dentine data from Los Canes Cave (Asturias), as well as some of the first enamel strontium isotope results for the area. All the new and old radiocarbon dates fell within the 6th millennium, indicating the long use of Los Canes for funerary activity. The sequential stable carbon and nitrogen isotope results show a C_3 terrestrial based diet for all the individuals. The mean $\delta^{13}C$ value is -19.6‰ ± 1.0 (σ), ranging from -21.5 to -15.2‰. The mean $\delta^{15}N$ value is 9.0‰ ± 1.47 (σ) ranging from 6.5‰ to 15.8‰. The methodology used for this work also allowed us to study diet through different stages of the life cycle of these individuals, including the impact of breastfeeding and weaning, as well as to identify possible stress-related moments reflected in the isotopic data. Our data suggest a prolonged and late weaning period that took up to four years to complete. Breastfeeding probably continued as a complementary food for children to fulfil their nutritional needs and to support the immune system. Isotopic changes around the age of eleven could be associated with physiological stress related to puberty. However, there were no drastic changes in the diets, as all the individuals rely on terrestrial C_3 resources with the exception of one individual, who may have consumed low trophic marine resources for several months. The human $^{87}Sr/^{86}Sr$ values presented a mean of 0.70955 ± 0.0003, ranging from 0.70893 to 0.70981, suggesting that all the individuals spent their childhood in the region around Los Canes cave. Combining both proxies allow us to discuss the territorialization of the space, reinforcing the theory that some communities were occupying the coast, while others were focused on the inland mountains, but were in contact with each other.

Keywords Mesolithic · Carbon and nitrogen · Strontium · Dentine sequence · Serial section

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Introduction

The Mesolithic is one of the best-known prehistoric periods in the Cantabrian region due to the large number of sites and the long tradition of Archaeological research. Many of the best-known Mesolithic sites are close to the current coastline, which, taking into account the complex orography of the territory and the paleo-economic information provided by these sites, suggest that the human groups that lived in the area consumed a broad-spectrum diet, including both marine and terrestrial resources (Arias 2007). This diverse exploitation may have provided enough resources to reach a relatively high population density, based on the high number of Mesolithic sites (Arias 1999; Fano 1998).

The information obtained from shell middens shows an intense exploitation of different species of marine and terrestrial molluscs (Álvarez-Fernández et al. 2011; Aparicio 2001; Bailey and Craighead 2003; García-Escárzaga 2014; Gutiérrez-Zugasti 2011), while fishing activity increased (Álvarez-Fernández 2015; Fano *el at* 2013) and hunting continued playing a key role in the subsistence of these prehistoric groups, especially deer (*Cervus elaphus)* (Altuna and Mariezkurrena 2012; Álvarez-Fernández and Altuna 2013; Marín and González-Morales 2009), as well as chamois (*Rupicapra pyrenaca)*, ibex (*Capra ibex)* and wild boar (*Sus scrofa)*. However, due to the good climatic conditions of the region, the vegetal resources, which tend to be underrepresented in the archaeological record, might also have been an important part of the diet for these groups (Fernández-Crespo et al. 2020; Zapata 2000).

The Cantabrian region is also one of the places of the Iberian Peninsula with a relatively high proportion of Mesolithic burials, providing key information about the funerary practices of the time. The majority are individuals who were intentionally buried in occupation levels from caves or rock shelters (Arias 2007, 2012; Arias and Álvarez-Fernández 2004; Armendáriz et al. 2010; Barandiarán and Cava 2001; Fernández-Tresguerres and Garralda 1986; Iriarte et al. 2010; Tapia et al. 2008; Vidal and Prada 2010). Furthermore, disarticulated human remains were also found in shell middens (Albisu and Etxeberria 2005; Arias 2007; et al. 2013; Castaños 1998/2000; Garralda 1981; Gutiérrez-Zugasti and González-Morales 2013).

The demographic profile of all the burials did not exhibit any sex/gender differences among the individuals who, in the majority of the cases, were deposited on their side (others were laid on their back) with the legs flexed. Sometimes, the grave goods are quite complex and might be influenced by the age of the individual, as seen in the juvenile from structure 6-II of Los Canes (Arias 2002, 2013; Arias and Garralda 1996).

However, despite the propitious environmental conditions and the funerary practices, the prehistoric groups of the region did not develop a complex social organization, as there is no evidence of permanent settlements or clear signs of food storage (Arias 1999). However, based on the lithic industry (Arias 1999) and previous isotopic work (Arias 2005/2006; Arias and Schulting 2010; Schulting et al. 2024), there is evidence of territorialization of the space, in which some human groups exploited marine and terrestrial resources of the coast while others remained in the inland mountains and exploited only terrestrial resources.

Isotopic dietary studies in the region

The measurement of $\delta^{13}C$ and $\delta^{15}N$ in the collagen of human tissues has proven to be a very useful technique of investigating aspects of the diets of individuals during the period of tissue formation. Bone, as a living and active tissue, is continuously remodelling, being reabsorbed and replaced through the life of the individual once skeletal growth and formation ceases. The rate of turnover varies from one bone to another, between 3% −4% per year, taking from 10 to 15 years to complete the process (Bell et al. 2001; Hedges et al. 2007; Fahy et al. 2017) depending on the proportion of trabecular bone (Valentin 2002).

In contrast, the measurement of these isotopes in tissues which grow incrementally such as hair and dentine can be used to provide specific temporal resolution for the changes in diet of an individual (e.g. Fuller et al. 2006; Mekota et al. 2006; de Luca et al. 2012). Measuring the isotope ratios in tissues developing at different life stages offers the potential to follow the diet of an individual through childhood and adolescence, and to then compare it to the last few years of life (Beaumont et al. 2013). The developmental age of each tooth is very well established (Ubelaker 1989; AlQahtani et al. 2010) and is only minimally affected by sex, geographical origin, or nutritional status (Reid and Dean 2000, 2006; Elamin and Liversidge 2013). Thus, it is possible to calculate the approximate age at which each section of dentine was formed (Czermak et al. 2020). The analysis of dentine has been used in previous studies to show short-term dietary changes during the childhood of individuals from different periods (Montgomery et al. 2013; Beaumont and Montgomery 2016; Fernández-Crespo et al. 2020; Higuero Pliego and Beaumont 2023).

The first isotope analysis from the prehistory of the Cantabrian region was performed on human remains from Los Canes, J3, Poza l'Egua and Colomba (Arias 2005/2006). Subsequently, more isotope data were obtained from two individuals from La Braña-Arintero cave (Arias and Schulting 2010), Chan do Lindeiro (Grandal-D'Anglade and Vidal-Gorosquieta 2017), Santimamiñe (Sarasketa-Gartzia et al. 2018), and Aizpea (Fernández-Crespo et al. 2020). For a recent review see Schulting et al. (2024).

Bulk collagen data suggest two dietary regimes (Table 1): a C_3 terrestrial one, represented by all the individuals except three, and a more marine one in the cases of J3, Poza l'Egua and Colomba. These sites are close to the coast, making it quite possible that the different groups that inhabited those caves exploited that environment as previous studies suggested (Álvarez-Fernández 2015; Álvarez-Fernández et al. 2011; Aparicio 2001; Bailey and Craighead 2003; Fano et al. 2013; García-Escárzaga 2014). This suggests a potential territorial division of the Cantabrian landscape, with groups living along the coast monopolising the consumption of marine resources, perhaps restricting access by other groups (Arias 2005; Arias and Schulting 2010; Schulting et al. 2024), a hypothesis supported by the regionalisation seen in raw materials, of local origins (Arias 1999). Whether such apparent territoriality (presumably working both ways, with limited use of the inland mountain resources by coastal communities) was actively maintained or the outcome of restricted mobility is unknown.

However, it must be taken into account that the Cantabrian region extends over 400 km parallel to the coast, with variable width (Fig. 1). While the sites of Los Canes, Poza l'Egua and Colomba are quite close to each other (Eastern Asturias), La Braña-Arintero is on the other side of the Cantabrian Mountain range (León). Santimamiñe and J3 have a more eastern location (however, with great separation in between), and Aizpea is close to the Pyrenees. In the opposite direction to the other sites, Chan do Lindeiro is located in Lugo (Galicia) and is the westernmost site with human isotopic data. Despite the geographical differences, the marine values from Poza l'Egua, Colomba and J3 still suggest territorialization along the Cantabria coast (Arias 2005/2006) (Table 1) (Fig. 1).

Table 1 Radiocarbon datation, $\delta^{13}C$ and $\delta^{15}N$ values on bone collagen, and location from mesolithic sites in Northern Iberia, adapted from Schulting et al. 2024. Data source: Arias 2005, 2012, 2013; Arias and Fano 2005; Arias and Schulting 2010; Arias et al. 2007, 2014; Barandiarán and Cava 2001; Drak 2015; Drak et al. 2008; Fernández-Crespo et al. 2020; García-Sagastibelza et al. 2020; Grandal-D'Anglade and Vidal-Gorosquieta 2017; Sarasketa-Gartzia et al. 2018; Iriarte et al. 2005; López Quintana et al. 2015; Noval 2014; Tapia et al. 2008; Vidal and Prada 2010. All the Radiocarbon dates and the isotopic values came from the same bone, except for Cotero de La Mina, indicated by an "*". In this case, the Radiocarbon date came from a piece of charcoal while the isotopic values were obtained from a human clavicle

Site	Sex	Age	^{14}C Date (BP)	Lab code	$\delta^{13}C$	$\delta^{15}N$	C: N
Inland							
Arangas	-	Adult	8240±40	OxA-24,799	-18.8	9.1	3.3
Cotero de la Mina	-	-	5133±55*	-	-20.2	9.5	n.d.
Paré de Nogales	-	Adult	7365±36	OxA-X-23999-26	-19.2	8.2	3.2
Braña-Arintero 1	M	Adult	6980±50	Beta-226,472	-18.8	10.4	3.2
Braña-Arintero 2	M	Adult	7030±50	Beta-226,473	-18.9	10.5	3.2
Chan do Lindeiro−01	F	Adult	7995±70	Ua-13,398	-20.5	8.4	3.1
Chan do Lindeiro−12	F	Adult	8235±51	Ua-38,115	-20.8	8.1	3.1
Chan do Lindeiro−07	F	Adult	-	-	-20.5	9.0	3.1
Aizpea	F	Adult	6600±50	GrA-779	-20.3	7.2	3.5
Los Canes 1 A (combined)	F	Adult	6197±45	-	-19.8	8.1	3.2
Los Canes 2 A (combined)	M	Juvenile	7171±36	-	-19.7	7.9	3.3
Los Canes 2B	M?	Adult	7118 24	OxA-23,184	-19.2	8.1	3.3
Los Canes 3 A	M	Adult	6930±95	AA-6071	-19.2	7.7	n.d.
Los Canes 3B	-	Infant	7210±40	OxA-19,918	-18.3	11.3	3.3
Los Canes 3 C	-	Adult	6243±35	OxA-23,181	-19.7	7.6	3.2
Los Canes 3D	-	Indet	7315±40	OxA-X-2395-20	-20.7	7.5	3.3
Los Canes (UE8)	-	Adult	5980±70		-21.9	7.7	n.d.
Coastal							
Poza l'Egua	M	Adult	8550±80	TO-10,222	-16.7	12.1	n.d.
J3	M	Adult	8300±50	GrA-23,733	-16.7	11.5	n.d.
Colomba	M	Adult	7090±60	TO-10,223	-15.8	12.6	n.d.
Santimamiñe	M	Adult	6130±40	Beta-307,665	-16.3	10.4	n.d.
Lumentxa (combined)	-	Adult	6116±26	-	-17.2	10.0	3.2
Linatzeta (combined)	-	Infant	7337±26	-	-15.7	12.9	3.2
Atxuri-I	-	Adult?	7290±30	Beta-442,236	n.d.	n.d.	3.3
Tito Bustillo	M	Adult	8470±50	Beta-197,042	n.d.	n.d.	n.d.
Cuartamentero	M	Adult	8395±40	OxA-18,230	-12.8	14.3	3.3
Mazaculos	M	Adult	7290±30	OxA-18,237	-14.8	11.6	3.2
El Toral III	-	Adult?	7080±30	UGAMS-5400	n.d.	n.d.	n.d.

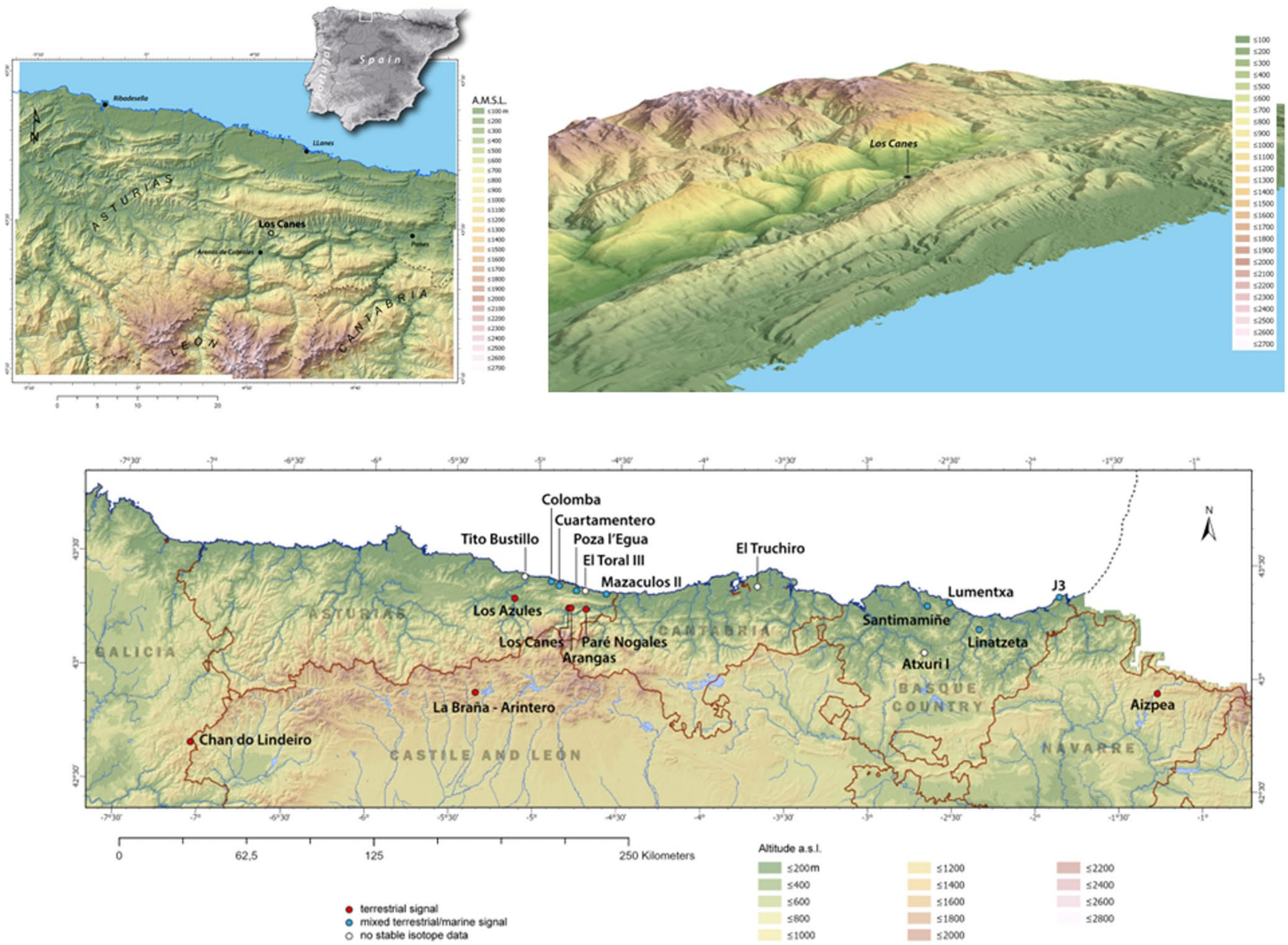

Fig. 1 location of Los Canes cave within the Iberian Peninsula and the Cantabrian region, and map with the mentioned sites with previously analysed isotopic data in this work (Table 1) (by Teira L using ArcGIS Pro)

Strontium isotope analysis in the region

Strontium isotope ($^{87}Sr/^{86}Sr$) analysis performed on dental enamel has proved to be useful for studying geographical mobility and potential migrations, both in animal and human remains (Price 2015; Alt et al. 2016; Díaz del Río et al. 2017; Sarasketa-Gartzia et al. 2018; Villalba-Mouco et al. 2020). $^{87}Sr/^{86}Sr$ values vary depending on the geological areas and the bedrock age of a location (Copeland et al. 2010). As the ^{87}Sr contained in rock derives from the radioactive decay of ^{87}Rb, older rocks display higher $^{87}Sr/^{86}Sr$ values (Bentley 2004). Strontium isotopes enter the soil primarily through the erosion and weathering of the bedrock and the soil and are incorporated into the food chain through plants. Plants are the main source of Sr, with minimal isotopic fractionation due to the very small relative differences in isotopic mass. However, it must be taken into account that the bioavailable $^{87}Sr/^{86}Sr$ values from a specific area might be altered through the depositions of non-local strontium, e.g., through the marine seaspray effect, atmospheric dust, or the impact of rivers and lakes (Frei et al. 2020).

Strontium is fixed in enamel during its mineralization, a non-remodelling tissue with high resistance to diagenetic changes (Bentley and Knipper 2005). It reflects the bioavailable strontium isotope ratio values from the region where an organism lived during enamel mineralization, thus allowing the tracking of individual mobility over time as well as geographical provenance (Ericson 1985; Price et al. 2002; Bentley and Knipper 2005; Bentley et al. 2004). Prior to this study, $^{87}Sr/^{86}Sr$ values were only available from two individuals, one from Santimamiñe (Sarasketa-Gartzia et al. 2018) and another from Aizpea (Fernández-Crespo et al. 2020). Santimamiñe is on the boundary between what was considered to be local and non-local values (0.71038). The values from Aizpea, however, support a restricted mobility of the individual during the years the tooth was forming, in accordance with a higher degree of territoriality than is usually attributed to Mesolithic communities.

Los Canes Cave

From the beginning of the Holocene, the geographical characteristics of the Cantabrian region (mainly the Cantabrian mountains) allowed the existence of a dense vegetation year-round, in contrast with the drier conditions on the southern side of the mountain range (Muñoz et al. 2004). It has been suggested that the Mesolithic environment in which the prehistoric human groups lived would have been very similar to that of the present (Fano 2004).

Los Canes cave is located in the eastern part of Asturias (northern Iberia), on the southern slope of the Cuera mountain chain. It is considered a mountainous location due to the abrupt topography in the surroundings, despite its relatively low altitude (325 m above sea level), which reaches 1315 m.a.s.l. only 4 km north-east from the cave, and only 150 m at the bottom of the Cares valley, 3 km to the south. Thus, there is a difference of 1165 m elevation within 7 km. Although it is defined as an inland site, the cave is located only 11 km from the current coastline with a 1000 m high pass that must be crossed. However, that only means a 4–5 h walk from the cave, and shells of edible marine molluscs such as limpets are present in the Palaeolithic and Mesolithic layers of the site (Arias 2002). The cave consists of a narrow passage in a SE-NW direction, 1–2 m wide and 50 m long, where archaeological evidence was found in two areas: at the entry of the cave, a 7 m length chamber with a long stratigraphic sequence, and at the end, where an assemblage of Palaeolithic engravings was found (Arias et al. 1981; Martínez Villa 2020).

The excavations, led by P. Arias and C. Pérez between 1985 and 1993, uncovered a complex archaeological sequence ranging from the late Solutrean (c. 18250 cal BC) to the late Bronze Age (c. 1100 cal BC). The stratigraphical sequence starts with a succession of undisturbed sub-horizontal layers only preserved in the back of the entrance of the cave. The earliest one being a late Solutrean layer dating to around 18,250 cal BC, covered by a lower Magdalenian layer (SU 2B), dated c. 17,000 cal BC, and followed by an Upper Magdalenian layer dated c. 13,500 cal BC (SU 2 C). Above these, a succession of four early Mesolithic layers (probably Azilian) were identified (SU 3 A, 3B, 3 C and 4; the two earliest dated around 11500 cal BC). Later during the Holocene, the sequence was severely affected by natural and anthropogenic processes such as karstic reactivation eroding the sediments close to the back wall of the cave entrance. Later, through the late seventh and the sixth millennia cal BC, the cave was used as a burial place by late Mesolithic groups. Several graves were dug in a very restricted area (7 × 2 m), disturbing most of the late Pleistocene deposits. Three graves were well-preserved, but there is evidence that some others were previously disturbed. Finally, the upper part of the Mesolithic phase, which represents 30–35% of the excavated volume of the cave entrance, was affected by early Neolithic activity during the first half of the fifth millennium cal BC, and by very shallow Bronze Age burials, from the second millennium cal BC. The consequence of these processes was, on one hand, that the preserved volume of the Palaeolithic layers was extremely small; and on the other, that the Mesolithic structures contained many displaced artefacts, bones, and shells from the Palaeolithic layers (Arias 2002).

Of special interest are the three funerary structures where several individuals were buried, and three almost complete individuals were found. In structure 6-I, individual 1 A was a mature female (around 60 years old) presenting signs of osteoarthritis through the body as well as poor dental hygiene (caries, marked wear and ante-mortem loss of teeth) (Drak 2015; Drak et al. 2020). A second individual (1B) in this structure was only represented by one tooth. In structure 6-II, the remains of a juvenile male aged between 15 and 20 years were found (individual 2 A), with signs of periostitis in different bones (femora, humeri, tibiae and fibulae, and ribs), enamel hypoplasia and cribra orbitalia, suggesting several episodes of physiological stress during life (Drak 2015; Drak et al. 2020). Individual 2B, who was buried before individual 2 A, was an adult of around 25 years old only represented by some teeth and bones from both hands and feet (Drak 2015; Drak et al. 2020). Finally, structure 6-III contained one complete individual (3 A) and remains from other three in the uppermost part of its filling (33B, 3 C and 3D) (Drak 2015; Drak et al. 2020). Individual 3 A was a male over 50 with generalized osteoarthritis throughout the skeleton (clavicles, scapulae, several vertebrae, both femoral heads, etc.), a fractured vertebra (12th thoracic) as well as multiple carious lesions on the teeth. Individual 3B was represented by several infantile bones with possible signs of rickets. Individual 3 C only presented a pair of adult cuboids and, finally, from the individual 3D only a deciduous molar was found (Drak 2015; Drak et al. 2020).

Also, in order to interpret the human isotope values, the previously baseline analysed from several faunal species from the same site and period was used (Schulting et al. 2024; Table 2) (Table 2).

Materials and methods

The teeth from Los Canes Cave

The best-preserved teeth from the three individuals (1 A, 2 A and 3 A) were selected for dentine sequence analysis. Previous $\delta^{13}C$ and $\delta^{15}N$ analysis of bone collagen from these individuals suggests a terrestrial C_3 diet (Arias

Table 2 δ^{15}N and δ^{13}C values from different mesolithic animal species from Los canes cave used to build the baseline for the site. Data from Schulting et al. 2024

Species	*n*	mean δ^{13}C	± 1σ	mean $\delta^{15}N$	± 1σ
Cervus elaphus	6	-21.5	0.4	4.0	0.6
Capreolous capreolus	3	-20.9	0.9	3.9	0.1
Capra pyrenaica	5	-20.2	0.6	3.9	0.9
Rupicapra pyrenaica	4	-20.1	1.0	4.6	0.6
Capra/Rupicapra	1	-20.0	–	2.8	–
Sus scrofa	2	-20.8	1.0	4.1	0.2
Ursus sp.	1	-20.4	–	2.5	–

2005/2006). Combining this previous work with new analyses provides new information on the diet during different stages of the life of these individuals. We analysed stable carbon and nitrogen isotope ratios, and enamel strontium values from a total of seven teeth: four from the three individuals mentioned above, and three isolated teeth from different stratigraphic units (Table 3). We took into account that the isolated ones could potentially be from the same individuals, as one another, or one of the burials analysed. However, when comparing the dentine sequences in pairs, there was no match among them.The isolated teeth and the one corresponding to individual 1 A were dated by ^{14}C, and strontium isotope analysis on enamel was carried out on all of them. so, every tooth was photographed and digitised via microCT-scan, which allows for recording the inner structure of the tooth (Fig. 2).

Plant and shell samples for strontium analysis

To interpret the data from the enamel samples, a baseline for the bioavailable strontium from different geological units was made. We analysed plants and snail shells from five different locations: the cave and its surroundings (Table 4).

Sequential dentine analysis and radiocarbon dating

Both the sequential dentine analysis and radiocarbon dating techniques use bone collagen, which was obtained from dentine in the Research Laboratory for Archaeology & the History of Art, University of Oxford (UK). Prior to any destructive analysis, all the teeth were microCT scanned in the Museo de Ciencias Naturales de Madrid, to record all morphological and structural data. First, the sequential dentine analysis was performed, and then the remaining collagen was used for radiocarbon dating.

Sequential dentine analysis

A modified version of the protocol developed by Czermark et al. (2020) was followed in this study. Every tooth was surface cleaned with aluminium oxide (Al_2O_3) pellets

Table 3 Teeth from Los canes used in this study. Four of the teeth came from three of the buried individuals while the other three were isolated

Code	Tooth	SU/structure
Can1.M_3	Upper right third molar	6-I
Can2.M_3	Lower right third molar	6-II
Can3.C	Upper right canine	6-III
Can3.M_3	Upper left third molar	6-III
Can8.P_2	Upper right second premolar	6-A
Can9.I_1	Upper right first incisor	Surface
Can13.M_2	Upper left second molar	5

to eliminate superficial debris. Then, teeth were partially embedded in plaster and cut through the axial plane in two halves. One of the resulting halves was used for this analysis, instead of a 2 mm central slice as originally proposed by the protocol, due to poor preservation, while the other was preserved. The selected half was placed in 0.5 molar hydrochloric acid (HCl) until fully demineralised.

Samples were taken along the axial axis of the tooth using a 1 mm diameter biopsy punch (Kai Medical), starting from the crown until reaching the tip of the root. During this process, the anatomical region of the tooth (crown, ½ root or ¾ root, following AlQahtani et al. 2010), from where the samples came was registered for later assigning an estimated age. This was done by dividing the median time of growth of each anatomical section by the number of obtained samples. Then, microsamples were placed in different Eppendorf tubes with MilliQ water. Microsamples were frozen for 24 h and then freeze-dried for another 24 h. Finally, microsamples weighing more than 0.35 mg were placed in tin capsules for isotope ratio mass spectrometry.

If this minimum weight was not reached, two or more consecutive microsamples were combined as long as they belonged to the same anatomical region. When several samples from the same tooth had to be combined, a "half + 1" criteria was applied. This means that even after combining, the total number of samples from the tooth should be above half + 1 the number of samples initially taken to consider the tooth as viable for this approach. In case this was not accomplished, the tooth was sampled again but with 1.5 mm biopsy punches. This was done with several teeth and all of them reached the minimum weight required for analysis.

Measurements were made on a Sercon 20/22 Isotope Ratio Mass Spectrometer (IRMS) in the School of Archaeology, University of Oxford. Drift correction was done with an alanine standard, with additional alanine (-27.11‰ and 1.56‰ for δ^{13}C and δ^{15}N, respectively), and internal cow (-24.28‰, 7.86‰) and seal (-12.54‰, 16.14‰) standards providing a three-point calibration relative to international standards VPDB and AIR for δ^{13}C and δ^{15}N, respectively (cf. Coplen et al. 2006). Based on repeated measurements of laboratory standards, instrument precision is ca. ±0.2‰ for both isotopes.

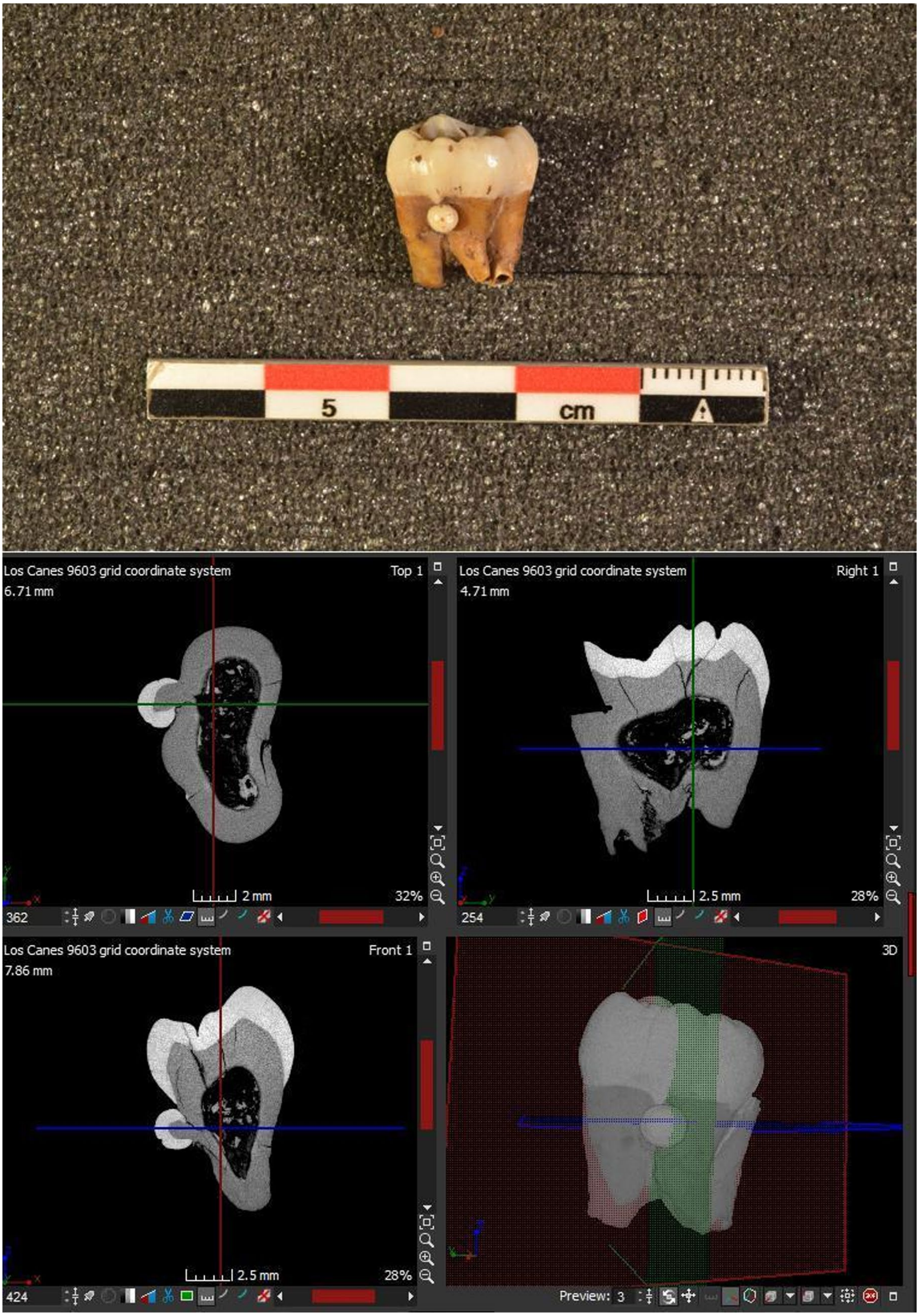

Fig. 2 Photography and microCT-scan from tooth Can2, where the inner structure as well the enamel pearl is observed

Table 4 New radiocarbon dates for the tooth from the individual 1 A (Can1.M_3) as well as the other three isolated Mesolithic teeth using the curve IntCal20 (Reimer et al. 2020) on OxCal v4.4.4 (Bronk Ramsey 2021)

Lab reference	Code	$\delta^{13}C$	Date BP	Date Cal BC (68.2%)	Date Cal BC (95.4%)
OxA-38,459	Can1.M_3	-20.6	6199 ± 29	5215–5076	5286–5050
OxA-38,463	Can8.P_2	-20.3	7044 ± 31	5983–5902	6001–5848
OxA-38,464	Can9.I_1	-18.5	7130 ± 31	6033–5986	6061–5926
OxA-38,632	Can13.M_2	-18.7	7112 ± 29	6021–5931	6052–5917

Radiocarbon dating

Remaining collagen from the demineralised tooth sections was used for radiocarbon dating. The samples were subjected to the laboratory's standard acid-base-acid pretreatment prior to gelatinisation and ultrafiltration (Brock et al. 2010). Graphite targets were then prepared for measurement by AMS.

Strontium analysis

The strontium isotope sample preparation and analysis took place at the MC-ICP-MS Facility of the Department of Geological Sciences, University of Cape Town (South Africa). The enamel sample was taken from along the longitudinal axis of the crown, thus representing a single average value for the years while the crown was developing. The surface was cleaned and cut using a Dremmel diamond saw. Then the sample went through ultrasound cleaning for 15 min, to ensure the elimination of any possible impurities. The solution preparation began with the addition of 3 ml of a 65% nitric acid (HNO_3) solution and kept at 140 °C for an hour, which dissolved the enamel. The Savillex PFA beaker was then opened, and the sample evaporated. The next step was to redissolve it in 1.5 ml of 2 M HNO_3 for 24 h. Finally, the sample was centrifuged at 2400 rpm for 20 min.

The plant samples were ashed at 650 °C for 24 h and the ashes were mechanically pulverised. Then, 4 ml of a solution based on 4 parts of hydrofluoric acid (HF) and 1 of nitric acid (HNO_3) were added to the Savillex PFA beakers containing ± 50 mg of each sample. The closed beakers were left for 48 h at 140 °C, until the sample was dissolved. The beakers were then opened, and the sample dried down. Later, 2 ml of a 65% HNO_3 were added to redissolve the sample, and again dried down; finally, 1.5 ml 2 M HNO_3 was added. The final content was centrifuged at 4000 rpm for 20 min.

The snail shells were broken and brushed cleaned to eliminate all sediment remains. Then the shell fragments were cleaned by ultrasonication in 15-minute cycles and left to dry at 60 °C for 24 h. Following this, 3 ml of 65% HNO_3 were added to Savillex PFA beakers with ± 50 mg of each shell and kept at 140 °C until total dissolution. Finally, another 1.5 ml of 2 M HNO_3 was added, and the content was centrifuged similar to the plant samples.

The strontium elemental separation of all the samples (enamel, plants, and snail shells) were done using a routine method with Sr.Spec resin after Pin et al. (1994). All $^{87}Sr/^{86}Sr$ ratios were measured using a Nu Instruments NuPlasma HR MC-ICP-MS, and referenced to bracketing analysis of NIST987, using a $^{87}Sr/^{86}Sr$ reference value of 0.710255. All the strontium isotope data were corrected for isobaric rubidium interference at mass 87 using the measured signal for ^{85}Rb and the natural $^{85}Rb/^{87}Rb$ ratio. Instrumental mass fractionation was corrected using the measured $^{86}Sr/^{88}Sr$ ratio and the exponential law, and a true $^{86}Sr/^{88}Sr$ value of 0.1194 (Salazar-García 2011; Copeland et al. 2016; Snoeck et al. 2016).

Results

Quality indicators

The C: N ratio is widely accepted as an effective quality indicator for collagen. Acceptable ratios are those falling in the range 2.9–3.6 (DeNiro 1985; Van Klinken 1999), or the more constrained range of 3.1–3.5 which applies more to radiocarbon dating, where small amounts of contamination by modern carbon have a far greater impact than on $\delta^{13}C$ measurements (the Oxford Radiocarbon Accelerator Unit currently uses the even more constrained range 3.1–3.4). All the samples, with one exception, fell within the DeNiro's range. Most of them also fell into the range of 3.1–3.5, indicating the good quality of the results obtained. The exception (Can2.M_3_12_13) is still reported but was eliminated from the sequential analysis.

Radiocarbon dates

Individuals 2 A and 3 A were previously radiocarbon dated by Arias (2005/2006), providing Mesolithic dates. New dates were obtained on a tooth from individual 1 A (Can1.M_3), together with teeth labelled Can8.P_2, Can9.I_1 and Can13.M_2. The new dates from these four teeth are presented in Table 4, while Fig. 3 shows all available dating from the Mesolithic individuals of the site. All the new dates fall within the 6th millennium, with three individuals expanding from the very beginning of that period until the first half. Can1.M3 was the only individual from the second half of the 6th millennium, indicating the long use of Los Canes for funerary activity.

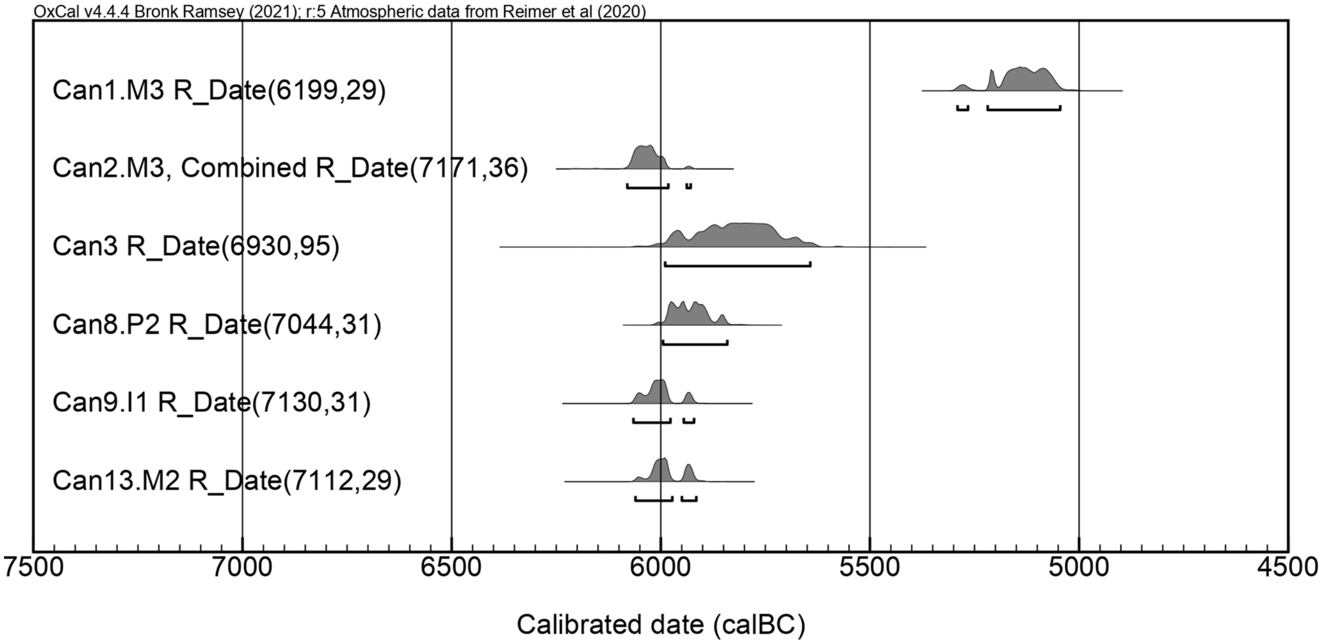

Fig. 3 Radiocarbon dates of all the individuals whose dentine was analysed in this work

Human δ^{13}C and δ^{15}N isotope values

Human dentine results are provided in Table S1. The mean δ^{13}C value is -19.6‰ ± 1.0 (σ), ranging between a minimum value of -21.5‰ and a maximum of -15.1‰ (Fig. 4). The mean δ^{15}N value is 9.0‰ ± 1.47 (σ) ranging from 6.5‰ to 15.8‰ (Fig. 4). However, there are several values that are more than two standard deviations above the mean, which is -17.6‰ for δ^{13}C and 12‰ for δ^{15}N. For the δ^{13}C there was only one sample higher, with a value of -15.1‰, belonging to individual Can9.I_1. For δ^{15}N, there were four values above that limit: one from individual Can8.P_2 (12.0‰), two from Can9.I_1 (15.8‰ and 13.3‰), and one from Can13.M_2 (12.6‰). Interestingly, none of the two higher δ^{15}N values from Can9.I_1 coincided with the higher δ^{13}C value from the same individual. Even more, the δ^{15}N outliers are always at the beginning of the dentine sequences and might be related to breastfeeding and the weaning process, as discussed below.

Strontium results (^{87}Sr/^{86}Sr) from Los Canes Cave

Strontium bioavailable baseline

In order to obtain a bioavailable Sr baseline for the immediate environs of the cave, modern plants and snail shells from five geological units (GU's) were sampled (Fig. 5). The mean value for modern plants ($n=10$) from Los Canes cave is 0.7082 ± 0.0002, and for snail shells ($n=3$) is 0.7087 ± 0.0011 (overall mean = 0.7083 ± 0.0006). For the GU "Barrios formation" (Ordovician), only plant samples ($n=10$) were collected, giving a ^{87}Sr/^{86}Sr mean value of 0.7121 ± 0.0058. The plant samples ($n=10$) from GU "Puentellés, Cavandi y Lebeña formations" (Carboniferous) gave a mean of 0.7134 ± 0.0027. For the GU "Picos de Europa formation" (Carboniferous), the plant mean value was 0.7089 ± 0.0004 ($n=8$) while for the snail shells ($n=2$) the mean was 0.7087 (overall mean = 0.7089 ± 0.0006). For the GU "Sotres formation" (Permian), the modern plant samples ($n=5$) gave a ^{87}Sr/^{86}Sr mean value of 0.7089 ± 0.0010, and the snail shells a mean value of 0.7093 ± 0.0016 (overall mean = 0.7091 ± 0.0013). Sample individual values are given in Table S2 and means per geological unit in Table 5.

Human ^{87}Sr/^{86}Sr enamel values

The human ^{87}Sr/^{86}Sr values are presented in Table 6, with a mean value of 0.7096 ± 0.0003 and ranging from 0.70893 to 0.70981. In Fig. 6 the bioavailable Sr values from the five geological units are compared with the values from the enamel. The human values are located within the different ranges from the geological units, which materially contributed to the formation of the enamel, thus consistent with a 'local' origin of the individuals.

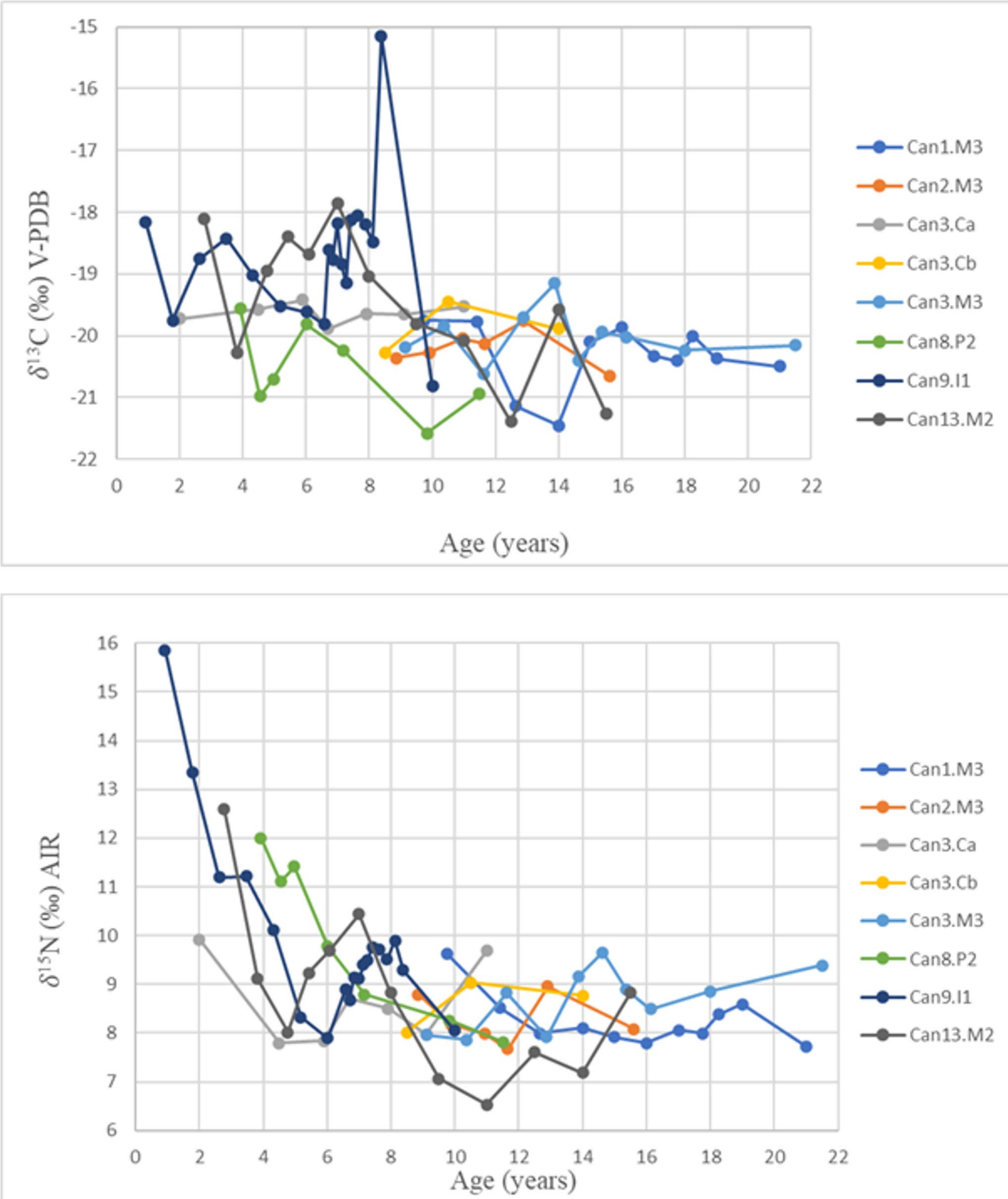

Fig. 4 δ^{13}C and δ^{15}N values from the dentine sequences through the years of dental development from Los Canes cave Mesolithic individual teeth

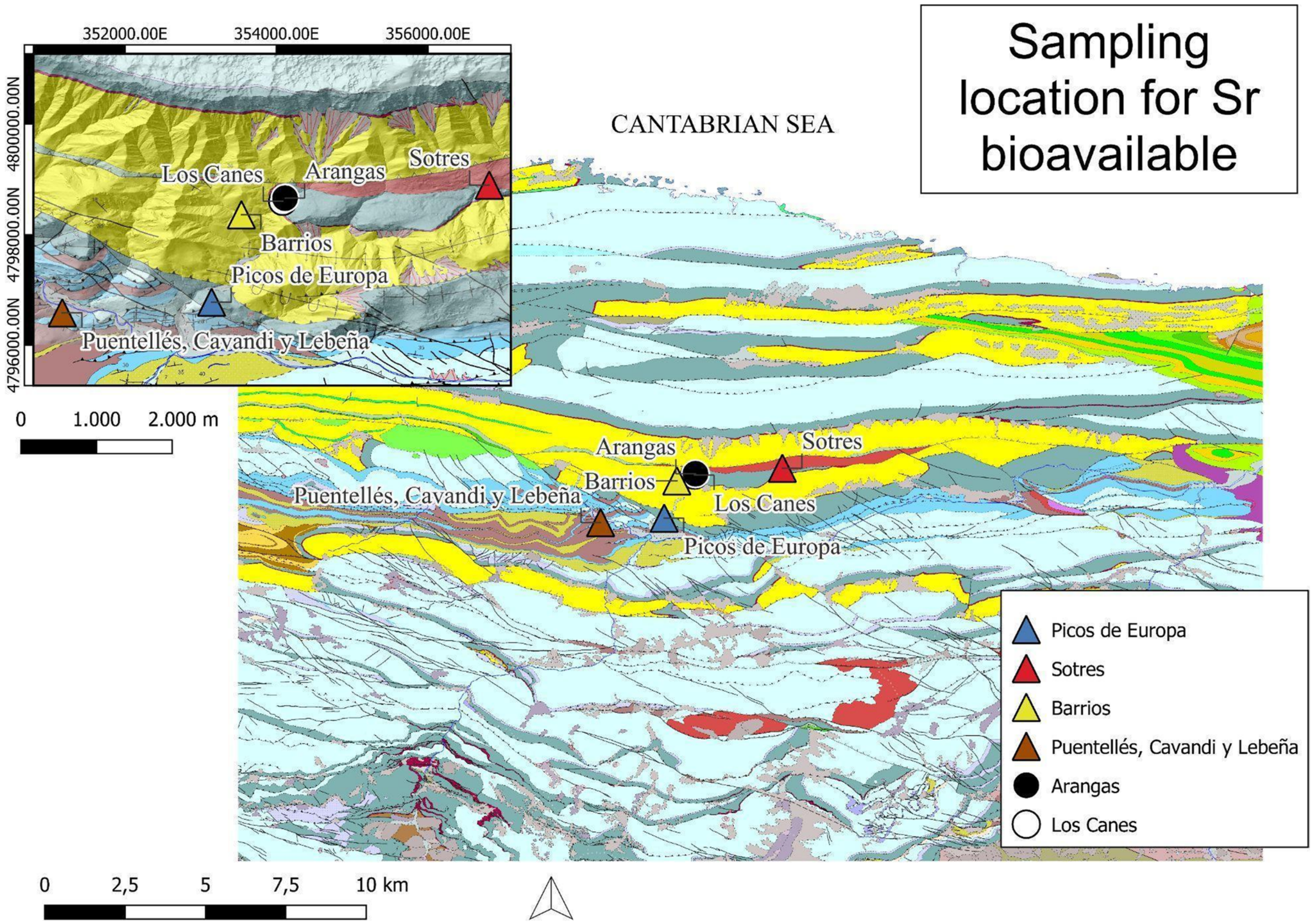

Fig. 5 Location of the sampling areas within each geological unit (García-Noriega C using QGIS and maps from the "Instituto Geográfico Nacional")

Table 5 Number of samples, overall mean and 2 Sd of the $^{87}Sr/^{86}Sr$ values obtained from the five different geological units sampled

Geological Unit	*N*	Nº plants	Nº snail shells	$^{87}Sr/^{86}Sr$ μ	2σ
Los Canes cave	13	10	3	0.70835	0.0006
Barrios	10	10	-	0.71212	0.0058
Puentellés, Cavandi y Lebeña	10	10	-	0.71354	0.0027
Picos de Europa	10	8	2	0.70918	0.0006
Stores	10	10	-	0.70918	0.0013

Table 6 List of analysed human enamel from Los canes cave

Area (GU)	Lab Code	Sample	$^{87}Sr/^{86}Sr$
Los Canes	S-DCSG-3428	Can1.M_3	0.70981
Los Canes	S-DCSG-3429	Can2.M_3	0.70941
Los Canes	S-DCSG-3430	Can3.C	0.70976
Los Canes	S-DCSG-3431	Can3.M_3	0.70972
Los Canes	S-DCSG-3436	Can8.P_2	0.70971
Los Canes	S-DCSG-3440	Can13.M_2	0.70893

Discussion

Mesolithic life histories at Los Canes Cave

The reconstruction of life histories through sequential isotope analysis on tooth dentine is a key means to understand the subsistence of an individual in different moments of their life cycle and the changes associated with them. Some of these moments, such as the breastfeeding and weaning periods, have a great impact on the individual's health in later years. Stable isotope analysis of sequential dentine samples has already been successfully used both in Iberian prehistory and history (Montgomery et al. 2013; Beaumont and Montgomery 2016; Fernández-Crespo et al. 2020; Higuero Pliego and Beaumont 2023). However, it is in the study of prehistory when it is more useful due, in part, to the lack of written sources.

Despite the importance of studies about the Mesolithic period in the Cantabrian region, and the potential information this methodology might provide (short consumption of

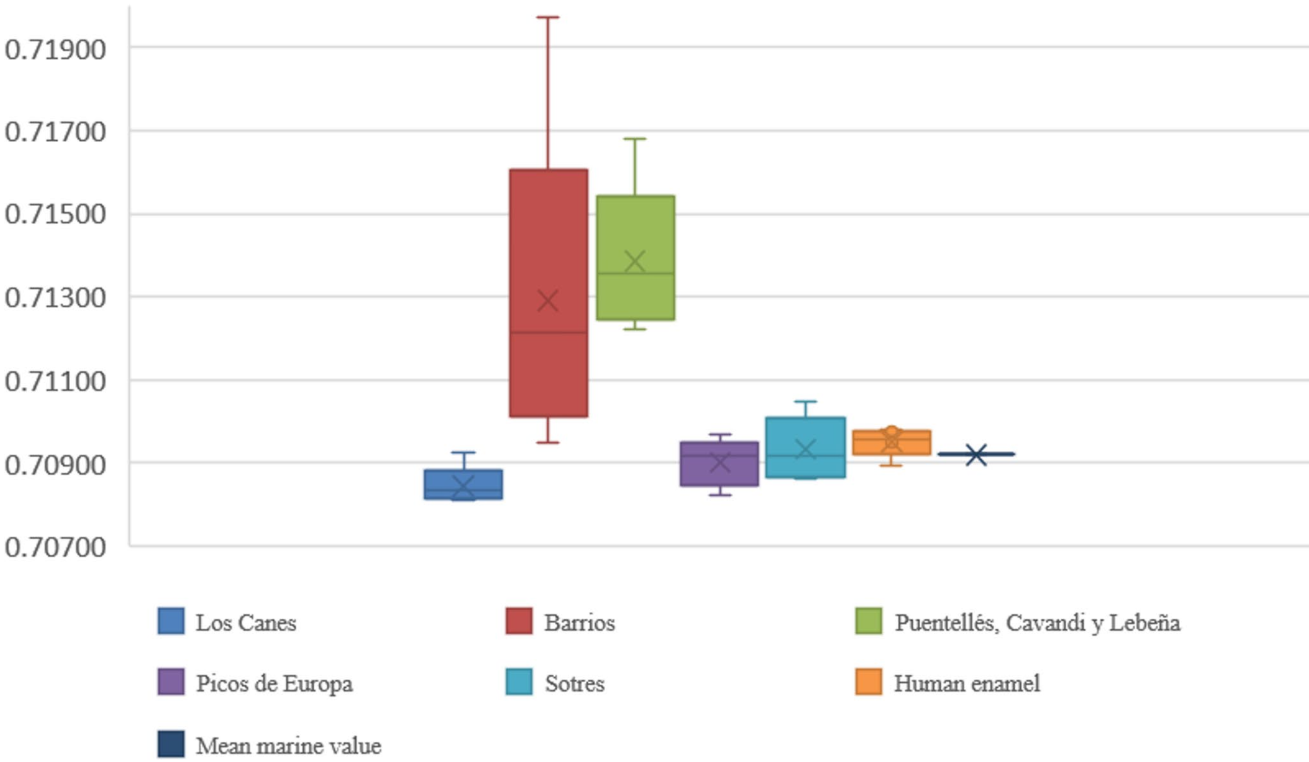

Fig. 6 Box plots of the $^{87}Sr/^{86}Sr$ means from the geological units and the comparison with the human enamel values from the Mesolithic individuals from Los Canes cave

different resources, seasonal variation, information masked by the bone collagen, etc.), it has not previously been applied. Thus, here we present the first dentine sequences for this context (Cantabrian Mesolithic), coming from Los Canes cave. Plots for each of the individuals show the dentine collagen profiles (and bulk collagen when available) for $\delta^{13}C$ and $\delta^{15}N$ against approximate age at formation (Fig. 7A and F).

Tooth Can13.M_2 is one of the chronologically oldest teeth from the sample and shows large differences in both the carbon and nitrogen values through the sequence (Fig. 7A). At the beginning of the sequence profile (before 3 years old), the $\delta^{15}N$ value show a decrease until 5 years of age (-4.6‰), when they increase for two years (age 7, +2.4‰) and then drop again for a period of four years (age 11, -3.9‰). From this point onwards, there is a tendency to higher values (+2.3‰ at the end of the sequence) that, however, did not reach previous peaks. The difference between the highest and lowest $\delta^{15}N$ values is 6‰, which indicates changes in the trophic level of the individual. The $\delta^{13}C$ values followed a similar profile: At the beginning (-2.2‰) of the isotope sequence, they decrease, then they increase until the individual reaches 7 years of age (+2.5‰), and decrease again until age 11. After that, there were some up and down variations. Considering both isotopes together, the weaning period might have lasted until the age of 4–5 years, promoting survival thanks to the nutritional and antimicrobial support of breastmilk while younger children's immune systems were still immature, and dietary needs and exposure to pathogens were increasing (Fernández-Crespo et al. 2022). This is suggested by a drop in both isotopes at the beginning of the sequence, the high $\delta^{15}N$ values and the variation between the highest and the lowest values. Both isotopes co-varied after that period, with increasing values until 7 years of age. This might be related to some introduction of marine resources in the diet during those two years, as the $\delta^{13}C$ values went from a typical C_3 terrestrial value of -20.2‰ to a more positive one of -17.8‰. Considering that C_4 plants did not arrive in the Iberian Peninsula until the Bronze Age, the intake of marine foods during those years is a more plausible explanation (Higuero Pliego 2020). It cannot be dismissed that they also played a role during the weaning period (e.g., Cheung et al. 2022).

Furthermore, the difference between the $\delta^{15}N$ value at the second peak (10.4‰) with the lowest of the series was 3.9‰, which is indicative of a dietary change in the trophic level of the individual. Finally, at the end of the sequence, both isotopes show a pattern of opposite covariance (Beaumont and Montgomery 2016), which might be indicative of two periods of physiological stress: the first one taking place between 11 and 12.5 (a duration of 1.5 years) and a recovery of the same length of time, and a second one immediately

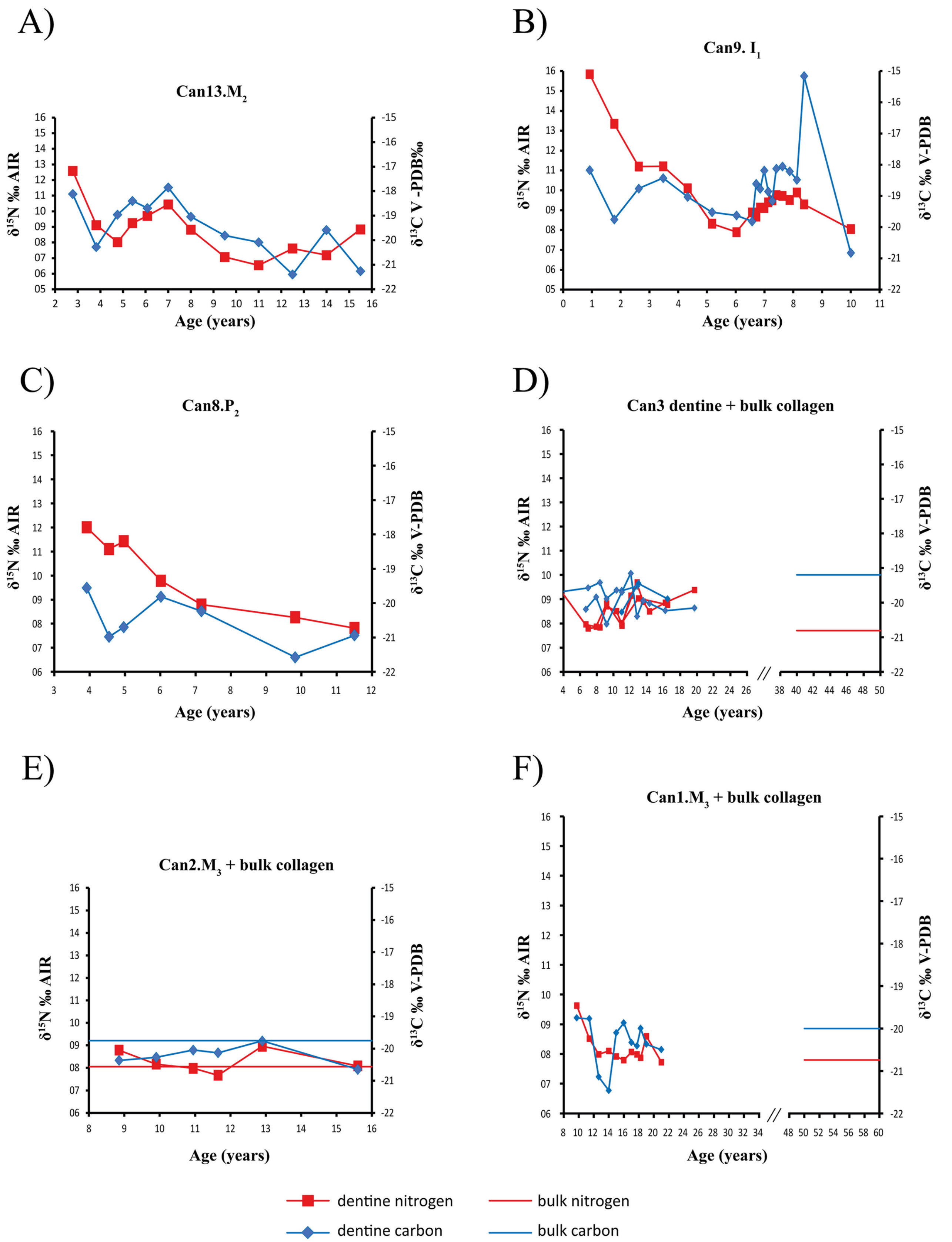

Fig. 7 $\delta^{13}C$ and $\delta^{15}N$ values from the isotopic sequences on tooth dentine from Los Canes Cave

afterwards (at 14-15.5 years). These periods might also be related to pubertal changes in the individual (Cocozza et al. 2021; Feuillâtre et al. 2022; Sánchez-Cañadillas et al. 2023) or supplementation by children of the parentally provisioned diet such as independent foraging (Fernández-Crespo et al. 2020). Unfortunately, that was the end of the sequence and there is no data available about the possible recovery of the individual from this last episode.

Tooth, Can9.I_1 (Fig. 7B) provides the longest sequence of all individuals, with 19 samples, representing a period of nine years. The δ^{13}C values along the whole sequence range between -19.7‰ and -18.0‰, except during the eighth year of life. That was when there was a considerable rapid increase to -15.1‰, dropping sharply immediately afterwards to -20.8‰. Regarding the δ^{15}N values, the sequence has a highest value of 15.8‰ and a lowest of 7.9‰. This is a continuous drop of 7.9‰ over the course of five years. After age 6 and until 8 years of age, the δ^{15}N values increased but were stable, ranging between 8.8‰ and 9.9‰, after which they finally dropped at the end of the sequence (-1.3‰). Taking into account the ages at which this tooth develops, it is quite possible that the first years were registering a very prolonged weaning process that took place during several years, providing the individual with some extra breastmilk with a high immunological value. Also of interest is the high δ^{13}C value of -15.1‰ associated with a moderate δ^{15}N value of 9.3‰; the C: N value of 3.2 suggests that there is no issue with the quality of collagen preservation for this sub-sample. As mentioned above, C_4 plants had not arrived in the area yet, suggesting a contribution from low trophic level marine resources such as shellfish, as the most plausible explanation.

Tooth Can8.P_2 (Fig. 7C) provided a simpler sequence mainly due to the combining of samples in order to reach the minimum weight for reliable IRMS analysis. There was a drop in the values of both isotopes but of very different intensity. While the δ^{13}C varied from −21.7‰ to -19.6‰ (a variation of 2.1‰), which indicated a diet based on terrestrial C_3 plants throughout the sequence, the δ^{15}N values showed greater variation. These values ranged from 12.0‰ at the beginning of the sequence, to 7.8‰ at the end, with a variation of 4.2‰, enough to indicate a change in the trophic level of the individual. Due to the age of the individual, the drop in both isotopes at the beginning of the sequences might be related to prolonged breastfeeding. However, the continuous decrease in the δ^{15}N values after 7 years of age, may be due to limited animal protein in the diet, and a decreasing intake over the time the tooth was developing. The carbon isotopes also suggest a mostly terrestrial diet based on C_3 resources.

The next sequence is from individual 3 A (Fig. 7D), who was found in structure 6-III and was an elderly man. The sequence is constructed from two different teeth: a third molar and a canine. For the δ^{15}N values, the maximum was 9.9‰ while the minimum was 7.8‰. The 2.1‰ range is lower than a full shift in trophic level, so different quantities and sources of protein intake during those years seem a possible explanation. For the δ^{13}C values, the maximum was -19.1‰ and the minimum-20.6‰ (range of 1.5‰). What is interesting when considering the sequences from both isotopes together, is that two opposite covariances appeared. This potentially indicates two periods of physiological stress. The first one lasted for a year, between the age of eight and nine, with a potential recovery of up to two years (9–11). The second one was immediately afterwards, starting at the age of eleven and lasting almost two years (age 13). As with Can13.M_2, these episodes might be related to the individual going through puberty. After that age, the values did not indicate any other episode of stress. As the individual from whom these two teeth came from was a mature adult, we know he survived until an older age.

The bulk bone collagen values are available for this individual from previous analysis (Arias 2005/2006; Arias and Schulting 2010; Schulting et al. 2024), reflecting mean diet for the last ca. 10 years or more of life (40–50). The δ^{15}N bulk value is the same as the lowest dentine value (7.7‰). However, within the dentine sequence there were much higher values suggesting a higher animal protein intake in the diet over several years. Even more, it must be taken into account that the bulk collagen is reflecting the mean protein intake during a period of time so that a mean value of 7.7‰ might suggest the existence of lower (and also higher) values during that time. These data could be pointing to the possibility of a lower meat intake during later life. In the case of δ^{13}C, the mean bulk value (-19.2‰) was again similar to the highest dentine value (-19.1‰). What is interesting in the adult diet of this individual is that the diet is not the same as it was when he was younger, nor was it within the same range, and it could possibly be related to the ageing processes, for example, consuming softer resources.

The sequence Can2.M_3 (Fig. 7E), comes from individual 2 A, a young male (ca. age 16) buried in structure 6-II. Due to the tooth being still in development and the combining of samples to reach the minimum weight, this tooth provided more limited information compared with the others. There is a decrease in the δ^{15}N values from the period between 9 and 12 years, from 8.8‰ to 7.7‰ (-1.1‰), then it increased up to 9.0‰ by the age of ca. 13 (+1.3‰, which may indicate going through puberty), and then decreased again by the end of the sequence and death of the individual (-0.9‰). The difference between the minimum and maximum value (1.3‰) does not support a change in the trophic level of the individual, but possibly only small changes in protein sources during those years. There was also little variation in the $\delta^{13}C$ values, always ranging between - 19.7‰ and - 20.6‰.

When comparing the $\delta^{15}N$ and $\delta^{13}C$ values from the dentine sequence and the bulk collagen, there is an overlap between both tissues due to his early death, around 16 years, before the tooth fully developed. The $\delta^{15}N$ mean bulk collagen value (7.9‰) and the mean dentine value are quite similar (8.2‰), while there are differences in the $\delta^{13}C$ values. The bulk collagen value was - 19.6‰ but the mean dentine value was - 20.2‰, which minimum was - 19.7‰.

Finally, we present the dentine sequence from individual Can1.M_3, an elderly female (1 A) buried in structure 6-I (Fig. 7E). The sequence begins with the $\delta^{15}N$ values showing a continuous drop from ca. 10 years of age (9.6‰) until almost age 13 (8.0‰). a difference of -1.6‰. Then, the values stabilise for five years (18) before a slight brief increase (+0.7‰) and then back again to previous values (-0.9‰). The difference between the highest value (9.6‰) and the lowest (7.7‰) is only 1.9‰, suggesting variation linked to protein sources. In the case of $\delta^{13}C$, the values are quite stable throughout the sequence, ranging from - 20.5‰ to -19.7‰, except for two samples that show more negative values (-21.1‰ and - 21.5‰). This might indicate a change in the diet during that time (2.5 years). Then, the individual came back to the previous diet. This individual also shows a couple of periods with opposite covariance towards the end of the sequence. However, compared with the other individuals who exhibit higher isotopic values changes, Can13.M_2 and Can3 (both the canine and the third molar), the difference in values in Can1.M_3 never surpassed a 1‰ threshold, so that might not be interpreted as episodes of stress nor related to puberty, as the episodes occurred later.

Regarding the diet during the last years of life, the $\delta^{15}N$ bone value was slightly lower (7.8‰) than mean dentine (8.2‰), which may point to little differences in the sources of protein intake during the years, as it was quite stable through the dentine sequence. In the case of the $\delta^{13}C$ values, both are quite similar (bone = -20.2‰, mean dentine = -20.3‰). In this case, and in contrast to individual 3 A (Can3.C and Can3.M_3), this mature woman had a more similar diet to that of her younger years, with little variation during the years for which both methodologies provide information.

Territorial mobility at Los Canes

Finally, based on their $^{87}Sr/^{86}Sr$ values all the Mesolithic individuals from Los Canes cave are consistent with living in the broad surroundings of the site during the time each tooth was growing, as the values fell within the bioavailable strontium range for all the nearby geological units. Due to the lack of available strontium isotope data for other archaeological remains from the same period and region, this study presents the first published strontium data from the Cantabrian region, there is little more that can be discussed, indicating a major direction for future research. However, the strontium data supports the hypothesis of the territorialisation of the region, in line with the $\delta^{13}C$ and $\delta^{15}N$ data (see below) and other archaeological materials (Arias 1999).

Los Canes Cave within the Cantabria mesolithic context

Taking all the published isotopic results and comparing it with the new data, interesting information about the Mesolithic diet of the region emerges. Figure 8 summarises these data (terrestrial mammals, fish, bone collagen, and mean dentine sequences values). Looking at the graph, almost all the human $\delta^{13}C$ and $\delta^{15}N$ values cluster together just above the mammals' values, supporting a terrestrial C_3 diet, independently of whether values are from 'bulk' bone collagen or dentine sequences. Three human $\delta^{13}C$ and $\delta^{15}N$ bone collagen values fell outside that range, clearly signalling a marine diet (Poza l'Egua, J3 and Colomba) (Arias 2005; Arias and Schulting 2010; Schulting et al. 2024). Also, some slight differences within the terrestrial diet are observed. All these values range from 7.7‰ to 10.6‰ in the case of $\delta^{15}N$ values, and from - 21.9‰ to -18.7‰ for $\delta^{13}C$. In the first case, the difference between the maximum and the minimum is 2.9‰. This difference suggests diverse animal protein intake during the time both tissues formed. Regarding the terrestrial human $\delta^{13}C$ values, there is a difference of 3.2‰. The C_4 crop millet does not appear in the Iberian Peninsula until the Bronze Age (Higuero Pliego 2020; González-Rabanal et al. 2022), and there are no significant native C4 plant resources likely to feature in diets before then. Another option could be the sporadic consumption of salmonids in the diet (spending most of their lives in the sea, salmon have marine isotopic values), remains of which have been found in Los Canes cave, indicating river fishing activity during the Mesolithic period of the cave. In fact, the most positive value from the terrestrial individuals came from Can9.I_1, who appears to have consumed some low-tropic-level marine resources for a short period. Our study also highlights the benefits of applying sequential dentine analysis in prehistory, as it has the capacity to provide information that is masked in bone due to remodelling processes and a lower temporal resolution. Combining both tissues (bone and dentine sequence) allows for the study of the diet of an individual during a period of years (and decades), showing changes related to the age (weaning period) as well as specific moments when the individual consumed different resources.

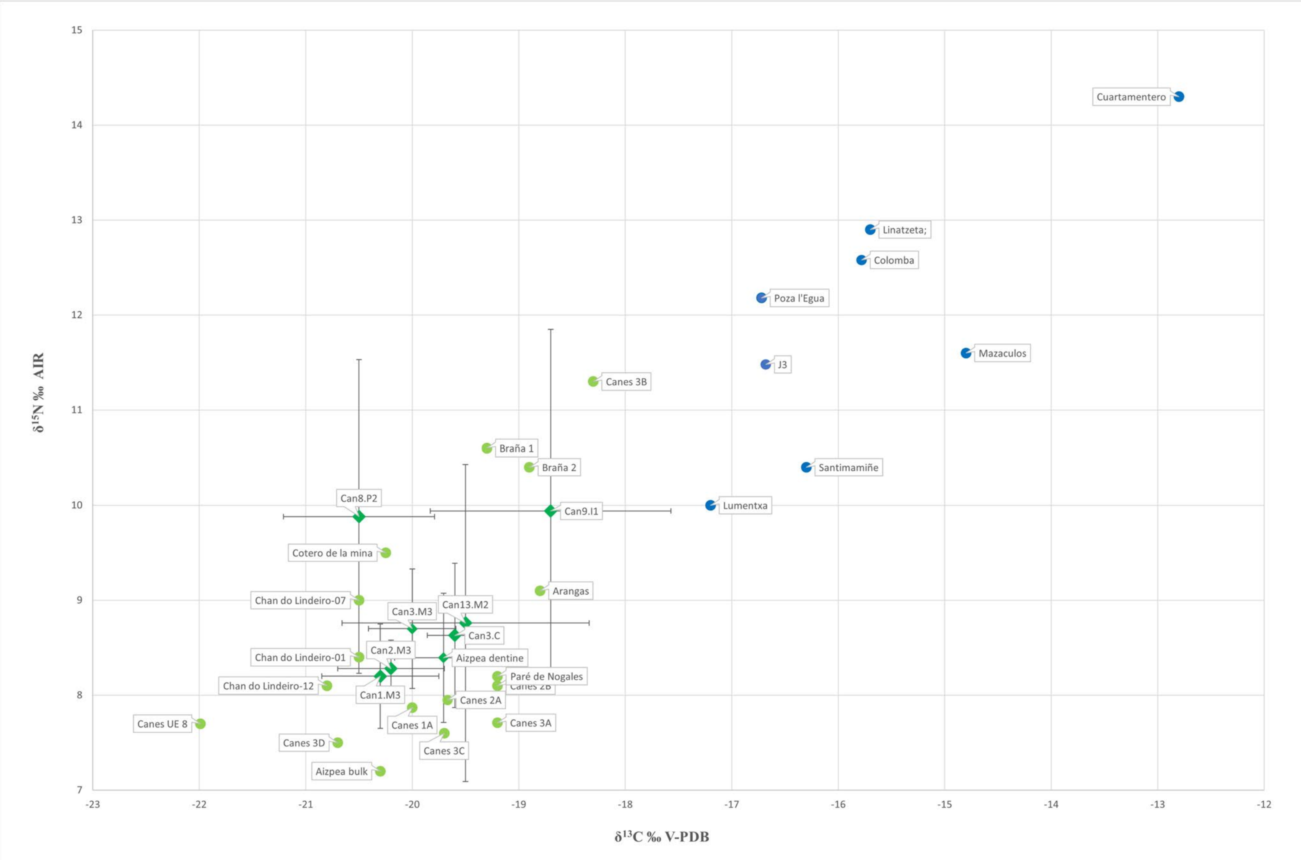

Fig. 8 Mesolithic human $\delta^{13}C$ and $\delta^{15}N$ values from marine (blue) and terrestrial (green) bulk collagen (circles), and dentine sequences (diamonds) from northern Spain

Conclusions

Years after the first isotopic analysis of human remains from the Cantabrian Mesolithic, the sequential dentine analysis of Mesolithic individuals from Los Canes cave have provided valuable new information. New data relate to different processes during the life cycle and years during which the analysed teeth were developing. Three isotopic sequences provided information on prolonged weaning periods, where breastfeeding was complemented with different foods, probably to improve chances of survival (Can8. P_2, Can9.I_1 and Can13.M_2). Another two isotopic sequences also showed isotope values compatible with consecutive periods of physiological stress (Can3.C and Can3.M_3, and Can13.M_2), possibly related to pubertal changes, and which both individuals survived. A third individual (Can2.M_3), may also signal isotopic changes be related to puberty as, similarly to the other ones, it happened at a similar age, around eleven years old. The dentine sequences also allowed the identification of abrupt changes in the diet, such as consumption of low trophic marine resources (Can9.I_1).

This information shows how the diet of the last hunter-gatherers in the Cantabria region (sixth millennium cal BC) was quite dynamic, though within limits, as these new data continue to support a degree of territoriality between interior and coast (Arias 1999), confirming previous analysis performed on bone collagen on different individuals from the Cantabria region. At inland sites, mainly within a mountain range, the diet was terrestrial and based on C_3 resources, in contrast with coastal sites distributed along the Cantabria coast, where a mixed diet based with a significant contribution of marine resources prevailed. However, at least one individual may have consumed marine resources for a short period of time. Additionally, the late weaning and the two individuals surviving through several periods of physiological stress indicates how these groups developed strategies and to assure the survival of the group.

The Sr data also supports the idea of a degree of territoriality for the last hunter-gatherers of the Cantabrian region, as the enamel samples from the same teeth that provided dietary information, suggest that the individuals grew up and lived in the surroundings area. The only possible evidence of a geographical movement is a short change in one $\delta^{13}C$ value of Can9.I_1, which quickly returned to a terrestrial diet after that moment. We consider that these data have provided new valuable information about the Mesolithic period in the region, so we aim to further analyse new dentine sequences from other archaeological sites, as well as to expand the strontium baseline and human data.

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Data availability All the data is provided within the manuscript.

Declarations

Competing interests The authors declare no competing interests.

References

Albisu C, Etxeberria F (2005) Estudio de Un diente humano mesolítico procedente de La Cueva de Kobeaga II. Illunzar 5:45–47

AlQahtani S, Hector M, Liversidge H (2010) Brief communication: the London atlas of HumanTooth development and eruption. Am J Phys Anthropol 142:481–490

Alt KW, Zesch S, Garrido-Pena R, Knipper C, Szecsenyi-Nagy A, Roth C, Tejedor-Rodríguez C, Held P, García-Martínez-de-Lagrán Í, Navitainuck D, Magallón HA, Rojo-Guerra MA (2016) A Community in Life and Death: The Late Neolithic Megalithic Tomb at Alto de Reinoso (Burgos, Spain). PLoS ONE 11(1): e0146176

Altuna J, Mariezkurrena K (2012) Macromammalian remains from the Holocene levels of El Mirón cave. En Straus LG y González-Morales MR (Eds.), El Mirón cave, Cantabrian Spain: The site and its Holocene archaeological record: 288–318. Albuquerque: University of New Mexico Press

Álvarez-Fernández E (2015) Continuity of human–marine fauna interaction during the holocene in Cantabrian Spain. Quatern Int 364:188–195

Álvarez-Fernández E, Altuna J (2013) La Cueva de Marizulo (Urnieta, Gipuzkoa), 50 años después: Revisión de Los Restos arqueozoológicos de Los niveles mesolíticos. Kobie 32:131–152

Álvarez-Fernández E, Chauvin A, Cubas M, Arias P, Ontañón-Peredo R (2011) Mollusc shell sizes in archaeological contexts in Northern Spain (13200 to 2600 cal BC): new data from La Garma A and Los Gitanos (Cantabria). Archaeometry 53:963–985

Aparicio MT (2001) Malacofauna Terrestre Del Yacimiento de Cubío Redondo (Matienzo, Cantabria). Munibe (Antropologia–Arkeologia) 53:61–66

Arias P (1999) The origins of the neolithic along the Atlantic Coast of continental europe: a survey. J World Prehistory 13:403–464

Arias P (2002) La Cueva de Los canes (Asturias). Los últimos Cazadores de La Península Ibérica ante La muerte. Universidad de Cantabria

Arias P (2007) Neighbours but diverse: social change in north-west Iberia during the transition from the Mesolithic to the Neolithic (5500–4000 cal BC). Proceedings of the British Academy 144: 53–71. Oxford: Oxford University Press

Arias P (2012) Funerary practices in cantabrian Spain (9000–3000 cal BC). In Gibaja JF, Carvalho AF, Chambon P (eds) Funerary practices in the Iberian Peninsula from the Mesolithic to the Calcolithic, BAR International Series 2417, 7–20

Arias P (2013) Los últimos cazadores. El mesolítico Asturiano Visto desde La Cueva de Los canes. In: Arias P, de Blas Cortina M, de la Rasilla M, Valdés AV (eds) De neandertales a albiones: cuatro Lugares esenciales En La prehistoria de Asturias. Santander, Real Instituto de Estudios Asturianos, pp 37–67

Arias P (2005/2006) Determinaciones de isótopos estables En Restos Humanos de La región Cantábrica. Aportación al estudio de La Dieta de Las poblaciones Del Mesolítico y El Neolítico. Munibe (Antropologia – Arkeologia). Homenaje Jesús Altuna 57:359–374

Arias P, Álvarez-Fernández E (2004) Iberian hunter-gatherers and death. A review of upper paleolithic and mesolithic funerary evidence in the Peninsula. En González-Morales MR y Clark GA. (Eds) The mesolithic of Atlantic Façade. Arizona State University, pp 225–248. Tempe anthropological research

Arias P, Fano MÁ (2005) Le role des ressources marines dans le Mésolithique de la région Cantabrique (Espagne): l'apport des isotopes stables. In Marchand, G, Tresset A (eds), Unité et diversité des processus de néolithisation sur la façade atlantique de l'Europe (7–4ème millénaires avantJ.-C.). Paris, Bulletin de la Société Préhistorique Française 36, 173–188

Arias P, Garralda MD (1996) Mesolithic burials in Los canes cave (Asturias, Spain. Hum Evol 11(2):129–138

Arias P, Schulting RJ (2010) Análisis de isótopos estables sobre los restos humanos de la Braña-Arintero. Aproximación a la dieta de los grupos mesolíticos de la Cordillera Cantábrica. In Vidal JM y Prada ME (Eds):Los hombres mesolíticos de la cueva de la Braña-Arintero (Valdelugueros, León): 130–137. Junta de Castilla y León (Estudios y Catálogos), León

Arias P, Gil G, Martínez Villa A, Pérez C (1981) Nota sobre Los Grabados digitales de La Cueva de Los canes (Arangas, cabrales. Boletín Del Instituto De Estudios Asturianos 104:937–956

Arias P, Fernández-Tresguerres JA, Álvarez Fernández E, Armendariz A, Cueto M, Fano MÁ, Fernández García R, Garralda M, Mensua C, Teira LC (2007) Excavación arqueológica de Urgencia En La Cueva de La Poza l'egua (Lledías, Llanes), excavaciones arqueológicas En Asturias 1999–2002. Oviedo, pp 227–239

Arias P, Álvarez-Fernández E, Cubas M, Teira LC, Tapia J, Cueto M (2014) Intervención arqueológica en el sistema kárstico de Arangas (Cabrales): Campaña de 2007. Excavaciones arqueológicas en Asturias 2007–2012. Oviedo: Principado de Asturias, Consejería de Cultura, pp 121–133

Armendáriz A, Arias P, Ontañón-Peredo R (2010) A grave in the lab: The late Mesolithic burial at El Truchiro cave (Cantabria, northern Spain). In Arias P, Cueto N (Eds) Meso 2010: Proceedings of the eighth international conference on the Mesolithic in Europe (Santander 13th – 17th September, 2010). Oxford: Oxbow

Bailey GN, Craighead AS (2003) Late pleistocene and holocene coastal paleoeconomies: A reconsideration of the molluscan evidence from Northern Spain. Geoarchaeology 18:175–204

Barandiarán I, Cava A (2001) Cazadores–recolectores en el Pirineo Navarro: El sitio de Aizpea entre 8000 y 6000 antes de ahora. Anejos de Veleia. Series Maior 10. Vitoria: Universidad del País Vasco

Beaumont J, Montgomery J (2016) The great Irish famine: identifying starvation in the tissues of victims using stable isotope analysis of bone and incremental dentine collagen. PLoS ONE 11(8), e0160065

Beaumont J, Gledhill A, Lee-Thorp J, Montgomery J (2013) Childhood diet: A closer examination of the evidence from dental tissues using stable isotope analysis of incremental human dentine. Archaeometry 55:277–295

Bell L, Cox G, Sealy A (2001) Determining isotopic life history trajectories using bone density fractionation and stable isotope measurements: A new approach. Am J Phys Anthropol 116:66–79

Bentley RA (2004) Characterising human mobility by strontium isotope analysis of the skeletons. In: Higham CFW, Thosarat R (eds) Khok phanom di: summary and conclusions. Oxbow Books, Oxford, pp 159–166

Bentley RA, Knipper C (2005) Geographic patterns in biologically-available strontium, carbon and oxygen isotopes signatures in prehistoric SW. Germany Archaeometry 47:629–644

Bentley RA, Price TD, Stephan E (2004) Determining the 'local' 87Sr/86Sr range forarchaeological skeletons: A case study from neolithic Europe. J Archaeol Sci 31:365–375

Brock F, Higham T, Ditchfield P, Ramsey CB (2010) Current pretreatment methods for AMS radiocarbon dating at the oxford radiocarbon accelerator unit (Orau). Radiocarbon 52:103–112. https://doi.org/10.1017/S0033822200045069

Bronk Ramsey C (2021) OxCal v.4.4.4. [software]

Castaños P (1998/2000) Estudio de Los Restos faunísticos Del Yacimiento de Kobeaga II. Illunzar 4:173–175

Cheung C, Herrscher E, Thomas A (2022) Compound specific isotope evidence points to use of freshwater resources as weaning food in middle neolithic Paris basin. Am J Biol Anthropol 179(1):118–133

Cocozza C, Fernandes R, Ughi A, Grob M, Alexander M (2021) Investigating infant feeding strategies at Roman Bainesse through bayesian modelling of incremental dentine isotopic data. Int J Osteoarchaeology 31:429–439

Copeland SR, Sponheimer M, Lee-Thorp JA, de Ruiter DJ, Le Roux P, Grimes V, Codron D, Berger L R, Richards MP (2010) Using strontium isotopes to study site accumulation processes. J Taphon 8:115–127. https://doi.org/10.5167/uzh-38862

Copeland SR, Cawthra HC, Fisher EC, Lee-Thorp JA, Cowling RM, le Roux PJ, Hodgkins J, Marean CW (2016) Strontium isotope investigation of ungulate movement patterns on the pleistocene Paleo-Agulhas plain of the greater cape floristic Region, South Africa. Q Sci Rev 141:65–84

Coplen TB, Brand WA, Gehre M, Gröning M, Meijer HAJ, Toman B, Verkouteren M (2006) New guidelines for δ13C measurements. Anal Chem 78:2439–2441

Czermak A, Fernáández-Crespo T, Ditchfield PW, Lee-Thorp J (2020) A guide for an anatomically sensitive dentine micro sampling and age-alignment approach for human teeth isotopic sequences. Am J Biol Anthropol 173:776–783. https://doi.org/10.1002/ajpa.24126

de Luca A, Boisseau N, Tea I, Louvet I, Robins RJ, Forhan A, Charles M, Hankard R (2012) δ^{15}N and δ^{13}C in hair from newborn infants and their mothers: A cohort study. Pediatr Res 71:598–604

DeNiro MJ (1985) Postmorten preservation and alteration in vivo collagen isotope ratiosin relation to palaeodietary reconstruction. Nature 317:806–809

Díaz del Río P, Waterman A, Waterman A, Thomas J, Thomas J, Peate D, Tykot R, García JMV (2017) Diet and mobility patterns in the late prehistory of central Iberia (4000–1400 cal BC): the evidence of radiogenic (87Sr/86Sr) and stable (δ18O, δ13C) isotope ratios. Archaeol Anthropol Sci 9:1439–1452

Drak L (2015) Las poblaciones del Holoceno inicial en la región cantábrica: cambios ambientales y microevolución humana. PhD thesis, Universidad Complutense de Madrid

Drak L, Garralda MD, Balbín R, Alcolea-González JJ (2008) Restos humanos mesolíticos de la Cueva de Tito Bustillo (Ribadesella, Asturias, España). In Nieto JL, Obón JA, Baena S (eds) Genes, Ambiente y Enfermedades en Poblaciones Humanas. Zaragoza, Sociedad Española de Antropología Física. Congreso Internacional, 113–125

Drak L, Garralda MD, Arias P (2020) Los canes mesolithic burials: archaeotanathology. J Archaeol Sci Rep 32:102381

Elamin F, Liversidge HM (2013) Malnutrition has no effect on the timing of human tooth formation. PLoS ONE 8:e72274

Ericson JE (1985) Strontium isotope characterization in the study of prehistoric human ecology. J Hum Evol 14:503–514

Fahy GE, Deter C, Pitfield R, Miszkiewicz JJ, 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

Fano MA (1998) El hábitat mesolítico En El Cantábrico occidental. Transformaciones ambientales y medio físico Durante El holoceno Antiguo. British Archaeological Reports, Oxford

Fano MA (2004) Un nuevo tiempo: el Mesolítico en la región cantábrica. En Kobie (Anejo 8): Las sociedades del Paleolítico en la región cantábrica, Diputación Foral de Bizkaia, pp. 337–402

Fano MA, Gutiérrez-Zugasti I, Álvarez-Fernández E, Fernández R (2013) Late glacial and postglacial use of marine resources in the Bay of Biskay, North Spain. In: Bailey GN, Hardy K, Camara A (eds) Shell energy: mollusc shells as coastal resources. Oxbow Books, Oxford, pp 155–166

Fernández-Crespo T, le Roux PJ, Ordoño J, Ditchfield PW, Schulting RJ (2020) The life-history of a late mesolithic woman in iberia: A sequential multi-isotope approach. Quaternaty Int 566:233–244

Fernández-Crespo T, Schulting RJ, Czermak A, Ordoño J, Lorenzo JI, Rodanés JM (2022) The post-weanling's conundrum: exploring the impact of infant and child feeding practices on early mortality in the bronze age burial cave of Moro de Alins, north-eastern Iberia, through stable isotope analysis. Archaeol Anthropol Sci 14:196

Fernández-Tresguerres JA, Garralda MD (1986) El hombre aziliense de Los Azules I (Cangas de Onís, Oviedo). Arqueología 14:37–43

Feuillâtre C, Beaumont J, Elamin F (2022) Reproductive life histories: can incremental dentine isotopes analysis identify pubertal growth, pregnancy and lactation? Ann Hum Biol 49:171–191

Frei R, Frei KM, Kristiansen SM, Jessen S, Schullehner J, Hansen B (2020) The link between surface water and groundwater-based drinking water – strontium isotope Spatial distribution patterns and their relationships to Danish sediments. Appl Geochem 121:104698

Fuller BT, Fuller JL, Harris DA, Hedges REM (2006) Detection of breastfeeding and weaning in modern human infants with carbon and nitrogen stable isotope ratios. Am J Phys Anthropol 129:279–293

García-Escárzaga A (2014) El Mesolítico Asturiense En El occidente de cantabria: Revisión de La información disponible a través de Una reflexión crítica. Kobie 32:113–130

García-Sagastibelza A, Arribas JL, López-Onaindia D, Pomeroy E, Rodríguez-Hidalgo A, Castex D, Couture-Veschambre C, Gómez-Olivencia A (2020) The human remains from the Lumentxa cave (Lekeitio, Biscay, Northern Iberian Peninsula): Paleobiology, taphonomy and chronology. Quatern Int 566:191–210

Garralda MD (1981) Las mandíbulas de Balmori y mazaculos II (Asturias): estudio antropológico. Boletín Del Instituto De Estudios Asturianos 103:595–603

González-Rabanal B, Marín-Arroyo AB, Cristiani E, Zupancich A, González-Morales MR (2022) The arrival of millets to the Atlantic Coast of Northern Iberia. Sci Rep 12(1):18589

Grandal-D'Anglade A, Vidal-Gorosquieta A (2017) Caracterización Isotópica de Elba, La Mujer Mesolítica de Chan do Lindeiro (Pedrafita, Luo, Península Ibérica). Cuad Laboratoiro Xeologico De Laxe 39:89–110

Gutiérrez-Zugasti FI (2011) Coastal resource intensification across the Pleistocene–Holocene transition in Northern spain: evidence from shell size and age distribution of marine gastropods. Quatern Int 244:54–66

Gutiérrez-Zugasti FI, González-Morales MR (2013) Excavaciones arqueológicas en Asturias 7 2007–2012. Intervención arqueológica en la cueva de El Mazo (Andrín, Llanes) campañas de 2009, 2010 y 2012. Principado de Asturias: Oviedo, pp 159–167

Hedges REM, Clement JG, Thomas DL, O'Connell TC (2007) Collagen turnover in the adult femoral mid-shaft: modeled from anthropogenic radiocarbon tracer measurements. Am J Phys Anthropol 133:808–816

Higuero Pliego A (2020) Análisis isotópico de carbono y nitrógeno en secuencias de dentina y de estroncio en esmalte procedente de restos humanos prehistóricos de la cueva de Los Canes (Asturias). PhD thesis, Universidad de Cantabria

Higuero Pliego A, Beaumont J (2023) The monks of San Millán: investigating the transition between pre-monastic to monastic diet using carbon and nitrogen isotope ratios in incremental dentine. J Archaeol Sci Rep 49:103981. https://doi.org/10.1016/j.jasrep.2023.103981

Iriarte MJ, Arrizabalaga A, Etxeberria F, Herrasti L (2005) La inhumación humana en conchero de J3 (Hondarribia, Guipúzcoa). In Arias P, Ontañón R, García-Moncó C(eds) Actas del III Congreso del Neolítico en la Peninsula Ibérica. Santander, Servicio de Publicaciones de la Universidad de Cantabria (Monografías del Instituto Internacional de Investigaciones Prehistóricas de Cantabria 1), 607–613

Iriarte MJ, Arrizabalaga A, Etxeberria F, Herrasti L, Álvarez-Fernández E (2010) Shell midden people in Northern iberia: new data from the mesolithic rock shelter of J3 (Basque Country, Spain). Zephyrus 65:117–127

López Quintana JC, Guenaga A, Etxeberria F, Herrasti L, Martínez de Pancorbo MA, Palencia L, Valverde L, Cardoso S (2015) Nuevos Datos sobre Le secuencia de Uso sepulcral de La Cueva de Santimamiñe (Kortezubi, Bizkaia). Arqueología Y Prehistoria Del Interior Peninsular 3:180–196

Marín AB, González-Morales MR (2009) Comportamiento económico de Los últimos cazadores-recolectores y primeras evidencias de domesticación En El occidente de asturias: La Cueva de mazaculos II. Trabajos De Prehistoria 66:47–74

Martinez Villa A (2020) Arte paleolítico cantábrico: Signos y símbolos. Los signos como indicadores de territorio y territorialidad. El caso del valle del Sella en la comarca oriental asturiana. Unpublished PhD thesis. Madrid, Universidad Nacional de Educación a Distancia

Mekota A, Grupe G, Ufer S, Cuntz U (2006) Serial analysis of stable nitrogen and carbon isotopes in hair: monitoring starvation and recovery phases of patients suffering from anorexia nervosa. Rapid Commun Mass Spectrom 20:1604–1610

Montgomery J, Beaumont J, Jay M, Keefe K, Gledhill AR, Cook GT, Dockrill SJ, Melton ND (2013) Strategic and sporadic marine consumption at the onset of the neolithic: increasing Temporal resolution in the isotopic evidence. Antiquity 87:10601072

Muñoz C, Ramil P, Gómez Orellana L (2004) Vegetation of the Lago de Sanabria (NW Iberia) since the end of the pleistocene: a palaeoecological reconstruction on the basis of two new pollen sequences. Veg History Archaeobotany 13:1–22

Noval MA (2014) Excavación arqueológica En La Cueva de El Toral III (Andrín, Llanes). Excavaciones Arqueológicas En Asturias 2007–2012. Oviedo, pp 381–384

Pin C, Briot D, Bassin C, Poitrasson F (1994) Concomitant separation of strontium and samarium-neodymium for isotopic analysis in silicate samples, based on specific extraction chromatography. Anal Chim Acta 298:209–217

Price TD (2015) Tracing past human movement: an example from the Muge middens. In: Bicho N, Detry C, Price TD, Cunha E (eds) Muge 150th: the 150th anniversary of the discovery of mesolithic Shellmiddens –, vol 1. Cambridge Scholars, Newcastle upon Tyne, pp 225–237

Price TD, Burton JH, Bentley RA (2002) The characterisation of biologically-available strontium isotope ratios for investigation of prehistoric migration. Archaeometry 44:117–135

Reid D, Dean M (2000) Brief communication: the timing of linear hypoplasias on human anterior teeth. Am J Phys Anthropol 113:135–139

Reid D, Dean M (2006) Variation in modern human enamel formation times. J Hum Evol 50:329–346

Reimer PJ, Austin WE, Bard E, Bayliss A, Blackwell PG, Ramsey CB, Butzin M, Cheng H, Edwards RL, Friedrich M, Grootes PM (2020) The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55cal kBP). Radiocarbon 62:725–757. https://doi.org/10.1017/RDC.2020.41

Salazar-García DC (2011) Aproximacion a la dieta de la poblacion calcolítica de La Vital a traves del analisis de isotopos estables del carbono y del nitrogeno sobre restos oseos. En Perez Jordá G, Bernabeu Auban J, Carrión Marco Y, García-Puchol O, Molina Balaguer LL y Gómez Puche, M (Eds) La Vital (Gandia, Valencia). Vida y muerte en la desembocadura del Serpis durante el III y el I milenio a.C. T.V. 113: 139–143. Valencia, Museu de Prehistoria de Valencia-Diputación de Valencia

Sánchez-Cañadillas E, Beaumont J, Santana-Cabrera J, Gorton M, Arnay-de-la-Rosa (2023) The early lives of the islanders: stable isotope analysis of incremental dentine collagen from the prehispanic period of the Canary Islands. Am J Biol Anthropol 182:300–317

Sarasketa-Gartzia I, Villalba-Mouco V, le Roux P, Arrizabalaga A, Salazar-García DC (2018) Late Neolithic-Calcolithic socio-economic dynamics in Norther Iberia. A milyi-isotope study on diet and provenance from Santimamiñe and Picos Ramos archaeological sites (Basque country, Spain). Quatern Int 481:14–27

Schulting RJ, Arias P, Meier-Augenstein W, Richards MP (2024) From the mountains to the sea: stable isotope data on humans and animals in mesolithic Northern Spain. Mesolithic Miscellany 30(2)

Snoeck C, Pouncett J, Ramsey G, Meighan IG, Mattielli N, Lee-Thorp JA, Schulting RJ (2016) Mobility during the neolithic and bronze age in Northern Irelandexplored usingstrontium isotope analysis of cremated human bone. Am J Phys Anthropol 160:397–413

Tapia J, Álvarez-Fernández E, Cubas M, Cueto M, Etxeberria F, Gutiérrez-Zugasti I (2008) La Cueva de Linatzeta (Lastur, Deba, Gipuzkoa): Un Nuevo contexto Para El estudio Del Mesolítico En Gipuzkoa. Munibe (Antropologia–Arkeologia) 59:119–131

Ubelaker D (1989) Human skeletal Remains. Excavation, analysis, interpretation. Taraxacum, Washington

Valentin J (2002) Basic anatomical and physiological data for use in radiological protection: reference values. ICRP publication 89. International Commission on Radiological Protection

Van Klinken GJ (1999) Bone collagen quality indicators for palaeodietary and radiocarbon measurements. J Archaeol Sci 26:687–695

Vidal J, Prada ME (2010) Los hombres mesolíticos de La Cueva de La Braña-Arintero (Valdelugueros, León), estudios y Catálogos 18. Junta de Castilla y León, León

Villalba-Mouco V, Bea M, Montes L, Salzar-García DC (2020) Mobility across the pre-Pyrenean mountain ranges during the chalcolithic through strontium isotopes in human enamel: La Cueva de Los cristales (Sarsa de Surta, Huesca, Spain). J Archaeol Sci Rep 31:102343

Zapata L (2000) La recolección de Plantas silvestres En La subsistencia Mesolítica y Neolítica. Complutum 11:157–116