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Island bioarchaeology and ritual knowledge transfer at Biniadrís cave (Menorca, Spain): a longue durée perspective

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The Biniadrís cave is located in the southern part of the island of Menorca (Spain). It is the fourth funerary cave with preserved materials discovered in Menorca up to now, along with Es Càrritx, Es Mussol, and Es Pas. However, the chronology of Biniadrís is more extensive, covering more than seven centuries, allowing for a study of human practices over the “longue durée”. What makes Biniadrís unique is its large number of bioarchaeological remains, mainly human remains and other organic and inorganic material, in an extraordinary state of preservation. The main goal of this paper is to reconstruct the burial ritual using comprehensive bioarchaeological methods, including ¹⁴C radiocarbon dating, to understand the modality and temporality of use of the Biniadrís cave during the pre- and protohistory of the Balearic Islands. The palaeodemographic data derived from our ongoing excavation are described here in detail and point to interesting patterns, such as the equal representation of female and male individuals across all ages, including very young and older individuals. The fact that all individuals are equally represented and integrated into the community in the funerary settings provides insights into the group ideology, which are discussed further. These burial practices are interpreted as a strong expression of community identity at Biniadrís linked to its island setting, as seen from the preservation of the funerary memory over such a long period, which is unique for this cave. The multi-proxy approach employed here to study the bioarchaeological and organic remains contributes to a better understanding of the “longue durée” of the funerary ritual and the reconstruction of human behavior during the Late Bronze and Iron Ages of an island community in the western Mediterranean.

KEYWORDS

late bronze age, social identity, bioarchaeology, palaeodemography, funerary record, chronology, Western Mediterranean

1 Introduction

The Balearic Islands represent an anomaly or paradox being the last archipelago to be permanently settled in the Mediterranean in prehistory, defying the general trend of island colonization in the Neolithic (Dawson, 2014; Cherry and Leppard, 2018). On current knowledge, the earliest direct evidence of human presence in the archipelago cannot be traced before the mid-3rd millennium cal BC (Calvo et al., 2002; Bergadá et al., 2005). However, indirect evidence from pollen analyses has revealed an increase of aridification from the 6th millennium cal BC to the end of the 3rd millennium cal BC (Servera-Vives et al., 2023). Human impact, including deforestation and farming practices, but also a climatic event might have been the potential driving factors for this environmental change. In its initial phase, starting in the mid-3rd millennium, human occupation is represented by open-air sites with diversified associated funerary practices, with single burials found in natural caves, collective burial sites, and dolmens (Gili et al., 2006; Guerrero Ayuso et al., 2007; Calvo et al., 2012; Calvo Trias et al., 2001; Ramis, 2010; De Cet, 2017). The 2nd millennium cal BC is characterized by a more connected Mediterranean and the arrival of new groups, which could have reached the Balearics (Coll et al., 1997). This period represents a period of flourishing (Lull et al., 1999), especially in Menorca and Mallorca (Cherry and Leppard, 2018; De Cet et al., 2017; Ramis, 2014). Several marked changes from the second half of the 2nd millennium BC (1600–1550 cal BC) can be observed in the monumentality based on cyclopean architecture of the subsequent phase known as “Navetiform”. This term refers to the boat-shaped building technique (*navetas*), a technique that reflects community engagement and group identity (Fornés et al., 2009), and is deeply embedded within the island landscape. Nevertheless, the process of monumentality shifted from the first millennium BC toward other spaces, which were organized and modified by the community (Lull et al., 1999; Portillo et al., 2014).

The cultural dynamics of each island are very distinctive. By the end of the 2nd millennium BC, new social interactions and cultural changes are associated with the Talaiotic culture particularly in Menorca and Mallorca (Galmés-Alba and Calvo-Trias, 2021; Pons, 2017). Therefore, communities on each island were shaping their own identity, as can be seen in the types of sites such as the monumental tower-like monuments (*talaiots*), sanctuaries, and in domestic spaces (Gornés, 2022). The funerary world remains quite complex and diverse in the Balearics in terms of burial practices. From the Middle Bronze and Early Iron Ages, these varied from individual burial in necropolises to collective burials in natural caves with cyclopean architecture, hypogea, and *navetas* (Gornés, 2016; Gili et al., 2006). During this time, the increased presence of exogenous material such as ivory and tin is attested and suggests the Balearics were already connected within a larger exchange network in the Mediterranean (Calvo et al., 2012). Regarding the study of funerary practices at natural caves, after the investigation of the three major funerary caves discovered in Menorca—Es Mussol (Lull et al., 1999), Es Càrritx (Lull and Micó Pérez, 1999; Rihuete Herrada, 2003), and Es Pas (Fullola et al., 2007; Armentano and Malgosa, 2003; Armentano et al., 2010)—the Biniadrís cave, in the Calescoves area, is now under investigation and presented in this paper. Concerning the funerary practices within the Calescoves

area in later periods, there is a necropolis with more than a hundred caves dated from the 9th to the 2nd century BC (Veny Meliá, 1982; Gornés and Gual, 2000; Gornés, 1997, 2000). From the 4th century BC until the 7th century AD, this area was of great importance for anchorage (Fernández-Miranda, 1991; Belén Deamos and Fernández-Miranda, 1977; Belén Deamos et al., 1979). In the vicinity, there is also the Coberxo Blanc sanctuary linked to navigation (Orfila et al., 2010), a documented shaft with stairs (Veny Meliá, 1982; Plantalamor Massanet, 1991), and other coastal settlements such as Es Castellet (Anglada et al., 2010; Hernández Sanz, 1896–1897; Plantalamor Massanet, 1991; Sánchez López et al., 2013) with contemporary chronologies. These later sites suggest that the island communities were also oriented toward the sea. The extent of isolation and interaction during the period of Biniadrís is therefore another focal aspect of this paper. The Biniadrís cave is located about 2 km inland in the Middle and Upper Miocene platform of the Calescoves area in the southern part of the island of Menorca (Spain) (Figure 1). It is a natural cave located at the Biniadrís gorge, which is part of Menorca's Migjorn platform. It is an endokarst formation, open in the middle toward the upper part of the cliff without water circulation oriented toward the direction of the valley. The formation of the cave is thought to be associated with the evolution of the gorge or a period of sea-level stabilization (Trías, 2004).

Since its discovery (Moreno Onorato et al., 2019), the Biniadrís cave has provided insights into the island's prehistoric occupation due to its exceptional state of preservation of different materials. These findings are similar to those documented at the other funerary caves of the same chronology excavated on the island, such as Es Mussol and Es Càrritx (Lull et al., 1999; Lull and Micó Pérez, 1999; Lull et al., 2014; Rihuete Herrada, 2000), as well as Es Pas (Fullola et al., 2007, 2008). The particularity of Biniadrís resides in the small funerary space, extending around 18 m² (Figure 2), whose entire surface is full of commingled human bone remains, macro- and microfaunal remains, residues of organic material, and associated items. Due to the exceptional assemblage of human remains and the complexity of the mortuary treatment, the only way to overcome this analysis is throughout the multi-proxy bioarchaeological research designed in this study. The upper layer is made up of around 8 cm of microfaunal remains, which have effectively sealed the evidence for prehistoric activity at the cave since antiquity (Figure 3).

The position of the human remains does not follow any discernible anatomical order, owing to the multiple funerary practices that took place in the cave during its period of use. This is a recurrent funerary practice in Balearic prehistory, which has been observed in megalithic monuments (Aranda Jiménez et al., 2020), but also in ritual caves (Lull et al., 1999). Although the archaeological record has yielded one of the largest commingled bone assemblages for Menorca, the manipulation and subsequent removal of human remains was carefully done. This can be observed in the reduced fragmentation and overall completeness of the osteoarchaeological record. The timing of the use of the cave has been assessed through radiocarbon analysis and the scientific results showed that this cave was in use for at least seven centuries during the Late Bronze and Iron Ages, corresponding to the Naviform, Talaiotic, and post-Talaiotic periods. This phenomenon



could be explained as the result of the *longue durée* of the funerary memory on the island of Menorca, as seen from the transfer and preservation of knowledge through time of the groups who used the Biniadrís cave as a place to bury their ancestors. In this paper, we will also discuss how this exceptional longevity can be seen as an expression of place attachment and community identity related to the island environment (Dawson, 2020). The reconstruction of the paleodemographic profile in addition to the evaluation of health and the activity patterns in conjunction with the radiocarbon and isotope analyses aligns with the principles of Environmental Archaeology.

2 Material and methods

2.1 The funerary space

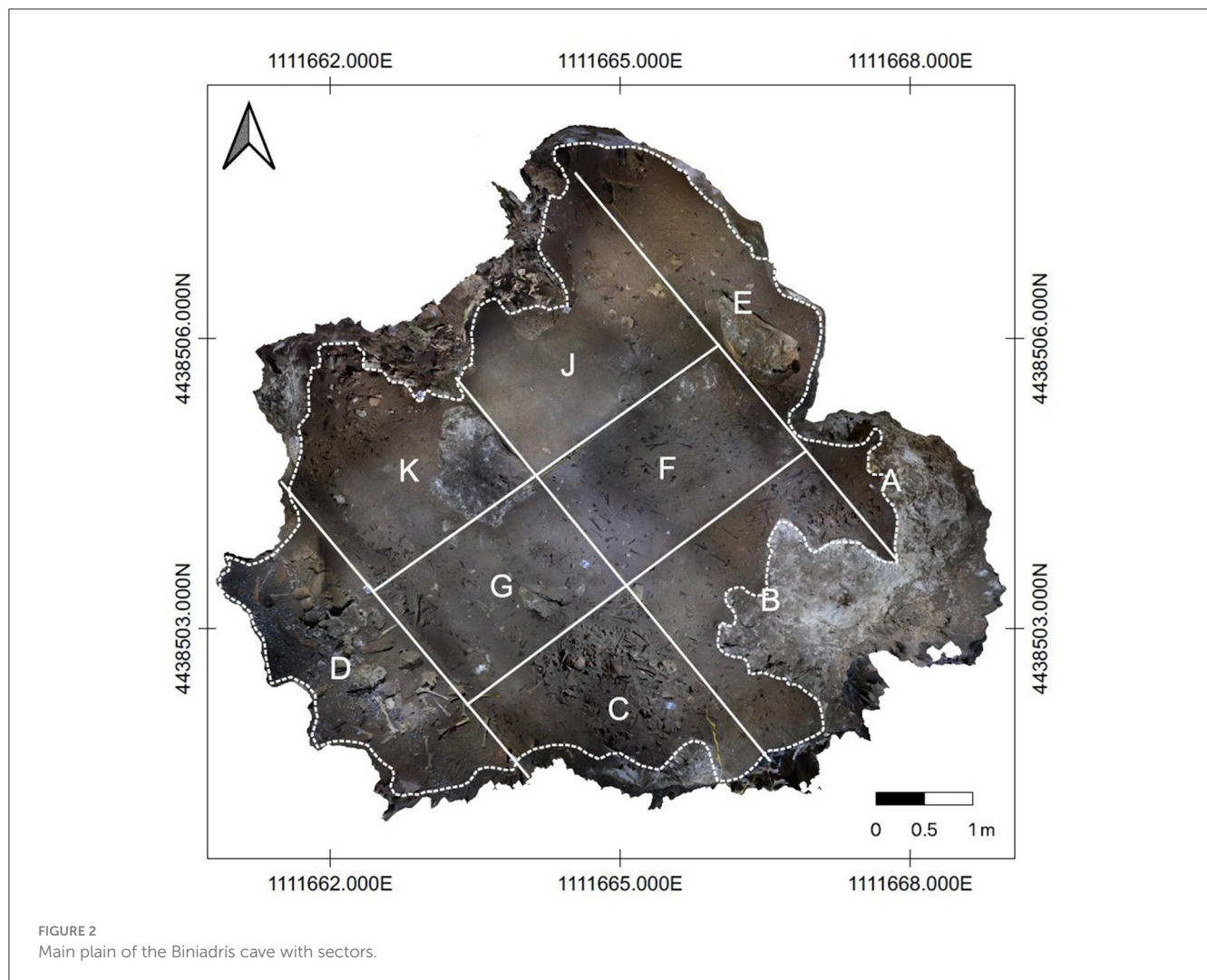
Biniadrís is a natural cave with minor anthropic modifications but with intentionally designed funerary spaces. Of special interest is the gate of cyclopean construction with a large stone lintel and stone slabs. The architecture is made of a mixed technique of dry stone but also with the use of clay at the bottom of the entrance wall to provide stability. A small corridor with paved stones was flanked by two lateral stones, which give access to an area where the different rituals took place.

The entire surface is covered with remains that are mainly human and associated funerary objects. Within the cave, several

spaces functioned differently. For instance, in sector A, many intentionally broken ceramic vessels were found as part of certain funerary rituals. However, at the opposite end, in sector (D), which is an area specifically hidden from the entrance and without direct sunlight, a wooden structure of log slices, planks, and other cut-wood features was surrounded by a selection of one dozen complete skulls (Figure 4). Without a doubt, this is the most spectacular area of the cave. Not only for the singularity of this funerary setting but also for the exceptional state of preservation and its striking ritual significance. There are no other parallels on the island apart from Es Càrritx (Lull et al., 1999; Lull and Micó Pérez, 1999; Lull et al., 2014; Rihuete Herrada, 2000). The combination of the different nature of the organic and inorganic materials plus the practices and symbolism embedded at the Biniadrís cave, has resulted in a space that stands out as sacred and special in Balearic archaeology.

2.2 Bioarchaeological analyses

Human remains are the most abundant material found at the Biniadrís cave. Since the remains are commingled, their analysis requires using established calculation methods, such as the minimum number of individuals (MNI), along with others, to investigate the palaeodemographic profile and, therefore, to estimate the population size. These methods are also required to study the health status, disease profiles, and mortuary practices



of the community (Osterholtz et al., 2014, p. 35; [Konigsberg and Adams, 2014](#)). The MNI-calculation is based on counting elements depending on their relative completeness considering that each fragment must share a unique landmark to avoid double-counting of fragments from the same individual. The analysis of the adult and non-adult individuals followed commonly established standard bioarchaeological methods ([Buikstra and Ubelaker, 1994](#); [Ferembach et al., 1979, 1980](#); [Steckel et al., 2005](#)).

Sex and age were determined following established protocols by [Buikstra and Ubelaker \(1994\)](#) and [Ferembach et al. \(1979, 1980\)](#). The specific age estimation focused on the combination of different methods, which included the degenerated morphology of the pelvis, along with the degenerative changes of the acetabulum ([Calce, 2012](#)), as well as the morphology of the auricular surface ([Lovejoy et al., 1985](#)) and the pubic symphysis ([Brooks and Suchey, 1990](#); [Todd, 1920, 1921](#)). In addition, we analyzed the closure of the cranial suturae ([Meindl and Lovejoy, 1985](#); [Hermann et al., 1990](#); [Olivier, 1960](#); [Vallois, 1937](#), modified by [Rösing, 1977](#)), as well as the palatine suture closure ([Mann et al., 1991](#)) and the first rib morphology ([Kunos et al., 1999](#)) and the ossification process of the sternal costae end after [Işcan et al. \(1984a,b\)](#) to estimate age. To assess the mature age classes in this commingled context, the

degeneration of the sternal end of the clavicle was used for age analysis after the method of [Falys and Prangle \(2015\)](#) and as a method comparison [Szilvássy \(1980\)](#). Moreover, the age estimation through dental eruption and mineralisation as well as the dental abrasion was included in the study [[Lovejoy et al., 1985](#); [Brothwell, 1981](#); [Mays et al., 2022](#); [Murphy, 1959](#), modified by [Smith and Knight \(1984\)](#); [AlQahtani \(2008\)](#); [Ubelaker \(1978\)](#); [Schour and Massler \(1941, 1944\)](#)].

Sex estimation was done mainly on the two most sexually dimorphic bone elements, the skull and the pelvis ([Buikstra and Ubelaker, 1994](#); [Ferembach et al., 1979, 1980](#); [Bruzek, 2002](#)). A good example of the analysis of growth and aging processes is provided by the Spitalfields Project ([Molleson and Cox, 1993](#)). In some cases, when almost complete, the method after [Murail et al. \(1999, 2005\)](#) was used to evaluate the difference of the pelvic appearance through metric analysis. Despite its lower accuracy, metric sex assessment through long bone measurements ([Bass, 2005](#)) was also carried out. Most sexually dimorphic measurements have been established for the femur and humerus. Therefore, it was decided to compare the vertical diameter of the humeral head as well as the distal breadth (comparable to the bicondylar width) based on [Stewart \(1979\)](#), [Spradley \(2011\)](#), [Mall et al. \(2001\)](#)



FIGURE 3
The Biniadrís cave during excavation.

and Krogman (1962), the maximum diameter of the femoral head and the femur circumference following Pearson (1917/1919), Krogman (1962) and Black (1978) among other metrical methods which are summarized in Bass (2005) and Işcan and Steyn (2013), Cunningham et al. (2016) and Grupe et al. (2015). In addition, the sexual dimorphism of the scapula and clavicle, following the methods published by Bass (2005), was included.

For non-adult human bone remains, the following standard methods on age development were used (Fazekas and Kósa, 1978; Scheuer et al., 2008; Lewis, 2007; Cunningham et al., 2016; Cardoso et al., 2016). The fusing states of the proximal and distal epiphyses follow the methodology of Acsádi and Nemeskéri (1974) as well as Buikstra and Ubelaker (1994). The classification of individuals' sex under the age of 12 years is not recommended at all and is partly problematic, because of a high error rate related to the lack of fully developed sexual dimorphism (Chamberlain, 2016, p. 19). For these reasons, sex determination in non-adult individuals was not pursued in any further analyses. However, it was recorded to complete the data collection and refers to the analyses of Schutkowski (1990).

For a deeper insight into the life of the deceased, metrical data and further analysis (Buikstra and Ubelaker, 1994; Bräuer and Knussmann, 1988; Martin and Saller, 1957; Ruff et al., 2012), pathological changes (Jacobs, 1992; Roberts and Manchester, 2010; Ortner and Aufderheide, 1991; Ortner, 2003; Ortner and Putschar,

1981; Adler, 2006; Aufderheide and Rodríguez-Martin, 1998; Waldron, 2008; Mann and Hunt, 2005) and morphological features on the bones (Alt, 1997; Barnes, 2008; Berry and Berry, 1967; Finnegan and Faust, 1974; Hauser and DeStefano, 1989; Mann et al., 2016) were also recorded, following a practice that corresponds to the standardized analyses of skeletons. Furthermore, the morphological conspicuousness, which occurred particularly due to the robustness of the bone morphology, was investigated in detail (Vilotte, 2006; Henderson, 2009; Henderson et al., 2017; Vilotte et al., 2016; Mariotti et al., 2007; Ruff, 2018; Handling et al., 2010; Cardoso and Henderson, 2013; Bonnet and Ferrari, 2010).

Analysis of the musculo-skeletal stress markers was carried out using a precise and experimentally supported three-dimensional (3D) system of quantification and analysis, known as the Validated Entheses-based Reconstruction of Activity (V.E.R.A.) approach (Karakostis and Lorenzo, 2016; see reviews by Karakostis and Harvati, 2021; Karakostis, 2023). Following the V.E.R.A. 1.0 protocols (Karakostis, 2023), the enthesal 3D area measurements (square mm) were subjected to a principal component analysis (PCA) relying on the correlation matrix (due to varying ranges across variables). Subsequently, the strength of the correlation between the values of each PC axis and body size was evaluated using the vertical head diameter (as body size proxy) and three Pearson's correlation tests. All necessary assumptions for Pearson's test were met, including the normal distribution of the variables



FIGURE 4
Wooden structure and organization of human skulls (sector D).

(based on Shapiro Wilk's tests) and the absence of extreme outliers (based on boxplots and the interquartile range approach) (Tabachnick and Fidell, 2019). The goal of the V.E.R.A. 1.0 analysis was to identify enthesal variation that might reflect the observed substantial differences in robusticity across bones. In this study, we focused on the humerus, a widely studied bone element with fundamental importance for functional morphology and activity reconstruction.

Given the notable robustness observed in long bone, a total of 63 humeri (29 right, 34 left) were selected for a pilot study. These specimens were analyzed using the established scoring methods of Vilotte et al. (2016) and Mariotti et al., 2007 to establish a comparative framework for the V.E.R.A. 1.0 methodology. Given the limited scope of this pilot project, the decision was made to focus on the right humerus, as isotopic analyses were also conducted on this body side. The primary criterion for the application of the V.E.R.A. 1.0 methodology was age, with specimens restricted to the Middle Adult age category to minimize the potential effects of significant degenerative changes or ongoing ossification/bone growth. This selection process resulted in a sample of 20 isolated and well-preserved right humeri. On each bone, we selected three entheses corresponding to muscle groups that co-activate for various human movements involving the upper limbs (Table 1). Particularly, the entheses used involve the: (a) the lesser tubercle (muscles associated with arm adduction and medial

rotation); (b) medial epicondyle (elbow, wrist, and hand flexion); and (c) lateral epicondyle (wrist and hand extension) (Table 2). A total of seven bones bearing notable potentially pathological traits (i.e., enthesopathies) were excluded from the analysis, which finally focused on the remaining 14 bones.

The assessment of health and paleopathology requires an independent evaluation of each bone and tooth, following the protocols of Roberts and Connell (2004), Lovell (1997), and Steckel et al. (2006). Different categories of disease were considered. For infectious diseases, the methodology of Roberts and Manchester (2012) was employed. Traumatic injuries and the classification of fractures were analyzed according to Ortner and Putschar (1981), Waldron (2008, p. 139), Roberts and Connell (2004, p. 37) and Redfern and Roberts (2019). Joint disease, with a focus on the prevalent condition of osteoarthritis (OA) affecting synovial joints as described by Jurmain and Kilgore (1995) and was identified through characteristic skeletal alterations such as osteophytes, porosity & pittings, eburnation, new bone formation, and the fusion of joints (Waldron, 2008, p. 27; Rogers and Waldron, 1995; Roberts and Manchester, 2010; Aufderheide and Rodríguez-Martin, 1998; Cockburn et al., 1979; Rogers et al., 1985). The evaluation of each joint is additionally done after Schultz (1988), Steckel et al. (2006) and Sager (1969). Metabolic diseases, as the most complex conditions caused by hormonal or nutritional deficiencies, such as Vitamin D or C deficiency

including conditions like *cribra orbitalia*, porotic hyperostosis and osteoporosis (Brickley and Ives, 2008; Waldron, 2008; Roberts and Manchester, 2010; Brickley and Mays, 2019; Grupe et al., 2015). They were identified based on the criteria outlined by Roberts and Connell (2004) and Stuart-Macadam (1989). The conditions of the *cribra orbitalia* and porotic hyperostosis were evaluated through different criteria and approaches (Brickley, 2018; Cole and Waldron, 2019; O'Donnell et al., 2020; Rinaldo et al., 2019; Steckel et al., 2006). Finally, oral pathologies and cranial modifications were described for each tooth and cranium, respectively, following the descriptive standards of Buikstra and Ubelaker (1994), for enamel defects (Pinhasi and Mays, 2007; Reid and Dean, 2000, 2006) and general dental diseases (Brothwell, 1981; Roberts and Manchester, 2012; Hillson, 1996, 2001; Aufderheide and Rodríguez-Martin, 1998; Pinhasi and Mays, 2007; Dias and Tayles, 1997).

2.3 Biochemical analysis

2.3.1 $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$

A total of 22 samples were analyzed for diet composition (Table 3) through carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) stable isotopes. Since the burial deposit is commingled, to avoid double sampling of individuals, we based this strategy on the Minimum

TABLE 1 List of musculo-skeletal stress markers recorded at Biniadrís cave.

Bone	Entheses	Entheses type	Muscles (I = insertion, O = origin)
Humerus	Tuberositas deltoidea	F	M. deltoideus (I)
	Facies anterior medialis	F	Musculus coracobrachialis (I)
	Crista tuberculi minoris Crista tuberculi majoris	F	M. teres major (I) M. pectoralis major (I), M. latissimus dorsi (I)
	Tuberculum minus humeri Tuberculum majus humeri	FC	M. subscapularis (I) M. supraspinatus (I), M. teres minor (I), M. Infraspinatus (I)
	Crista supracondylaris lateralis humeri	FC	M. brachioradialis (O)

F, Fibrous entheses; FC, Fibrocartilaginous entheses.

Number of Individuals (MNI) determined by the right humerus. Fifteen zooarchaeological samples from different trophic-level species from the cave were also analyzed as a protein food intake reference of the local population. Collagen was extracted from all human remains for dietary purposes, as well as to estimate any reservoir effect and for radiocarbon dating.

The analysis of stable isotopes of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ proved to be a powerful technique to investigate the amount of protein in the diet. The sampling strategy followed in this paper entailed the selection of the long bones to provide information to reconstruct on average the last 10 years of the life of the individual (Richards and Hedges, 1999; Bocherens and Drucker, 2003).

The collagen extraction was performed at the Biogeology Laboratory of the University of Tübingen following the standard procedures (Deniro and Epstein, 1981; Bocherens et al., 1997). Thus, a total of 500 mg of bone was extracted for each sample, followed by a process of cleaning, drying, and crushing.

Afterwards, the samples were put through an elemental analysis in a CHN, Carlo Erba NA 1500, to check the potential bone collagen preservation as inferred from the content of nitrogen (Iacumin et al., 1996). Finally, the bone collagen was extracted using the standard laboratory procedure (Bocherens et al., 1997). The human and animal collagen samples were measured in duplicate in the Institute of Environmental Science and Technology (ICTA) at the Laboratory of the Autonomous University of Barcelona using a Thermo Flash 1112 (Thermo Scientific) elemental analyzer coupled to a Thermo Delta V Advantage MS with a ConFlo III interface. The ratios $^{13}\text{C}/^{12}\text{C}$ and $^{15}\text{N}/^{14}\text{N}$ were measured relative to the V-PDB for carbon and AIR for nitrogen using an international laboratory standard, IAEA 600 (caffeine), which showed an analytical error below 0.2‰ (1σ).

2.3.2 ^{14}C dating

A total of 30 radiocarbon dates (Table 3) were obtained from two human bone elements, the humerus and petrous bone, representing samples from different individuals (approximately 25% of the minimum number of individuals). The sampling strategy prioritized long bones with minimal spongy structure to maximize the likelihood of collagen preservation, as well as petrous bones due to their exceptional preservation quality.

Elemental yields for carbon and nitrogen in the extracted collagen ranged from 23.57% to 43.07% and 8.20 to 15.29%, respectively. All samples presented an acceptable C/N ratio ranging from 3.2 to 3.5 with a mean of 3.3. A possible reservoir effect was tested by $\delta^{13}\text{C}$ & $\delta^{15}\text{N}$ isotope analyses (Table 3). The dietary

TABLE 2 Eigenvalues and factor loadings of the principal component analysis (PCA).

Principal component	Eigenvalue	% of variance	Factor loadings		
			Lesser tubercle	Medial epicondyle	Lateral epicondyle
PC 1	1.43	47.6	0.64	0.53	0.56
PC 2	0.87	28.9	− 0.04	0.75	− 0.67
PC 3	0.70	23.5	− 0.77	0.40	0.50
Total		100			

TABLE 3 Radiocarbon dates (2σ) of the Biniadrís cave, as well as the δ¹³C and δ¹⁵N isotopic values and the estimated percentage of marine consumption.

ID	Lab.Code	SEX*	AGE	¹⁴ C Date	±	δ ¹³ C AMS [‰]	δ ¹³ C	δ ¹⁵ N	Cal. BC
1	ETH-96776	F?	25.0–40.0	2980	23	−20.0	−19.87	9.99	1280–1120 cal BC
2	ETH-96783	F?	25.0–40.0	2962	23	−20.7	−19.50	8.9	1265–1060 cal BC
3	ETH-77081	U	1.5–6.0	2953	21	−18.2	NA	NA	1260–1055 cal BC
4	ETH-96785	U	> 18.0	2950	23	−22.6	−19.30	8.7	1255–1055 cal BC
5	ETH-96775	F?	25.0–40.0	2945	23	−18.3	−19.89	8.53	1255–1050 cal BC
6	ETH-96781	M?	> 60.0	2940	23	−23.0	−19.27	9.24	1225–1050 cal BC
7	ETH-96782	F?	25.0–40.0	2938	23	−20.5	−19.42	8.76	1220–1050 cal BC
8	ETH-96788	U	25.0–40.0	2938	23	−20.3	−19.50	8.7	1220–1050 cal BC
9	ETH-93266	F?	40.0–60.0	2937	24	−19.6	−19.50	8.8	1225–1050 cal BC
10	ETH-96789	F?	40.0–60.0	2932	23	−20.8	−19.10	8.4	1220–1050 cal BC
11	ETH-96792	U	25.0–40.0	2931	23	−20.4	−19.70	8.4	1220–1050 cal BC
12	CEZA-52233	U	<18	2926	21	−20.8	NA	NA	1215–1025 cal BC
13	CEZA-52231	U	> 18	2925	23	−19.2	NA	NA	1215–1020 cal BC
14	ETH-96791	M?	25.0–40.0	2925	23	−20.7	−19.30	8.2	1215–1020 cal BC
15	CEZA-52229	F?	25.0–40.0	2917	23	−18.8	NA	NA	1210–1020 cal BC
16	CEZA-52228	U	> 18	2915	24	−18.2	NA	NA	1210–1015 cal BC
17	ETH-96774	F?	40.0–60.0	2903	23	−16.7	−19.61	8.79	1200–1010 cal BC
18	ETH-93269	M?	18.0–25.0	2887	25	−19.2	−19.63	8.66	1195–985 cal BC
19	ETH-93268	M?	40.0–60.0	2850	29	−19.2	−19.40	9.1	1110–925 cal BC
20	ETH-77080	U	25.0–40.0	2840	21	−29.7	−19.10	8.9	1105–920 cal BC
21	CEZA-52232	U	> 18	2766	28	−19.7	NA	NA	990–830 cal BC
22	ETH-77078	M?	25.0–40.0	2620	21	−20.8	NA	NA	810–780 cal BC
23	ETH-96787	M?	> 60.0	2565	23	−20.5	−19.70	9.7	805–590 cal BC
24	ETH-96784	U	25.0–40.0	2536	23	−20.0	−19.50	9.5	790–550 cal BC
25	ETH-96773	U	25.0–40.0	2526	23	−17.5	−19.63	9.25	785–550 cal BC
26	ETH-96790	U	40.0–60.0	2514	23	−20.6	−19.60	9.4	780–545 cal BC
27	ETH-93265	M?	25.0–40.0	2505	25	−16.6	−19.20	10.7	775–540 cal BC
28	ETH-77079	M?	40.0–60.0	2504	21	−20.8	NA	NA	775–545 cal BC
29	ETH-96772	U	25.0–40.0	2489	23	−18.8	−19.45	10.19	770–540 cal BC
30	ETH-96786	M?	> 18.0	2478	23	−21.9	−19.70	9.6	770–485 cal BC

F?, probably female; U, undetermined; M?, probably male.

values ranged from −19.1% to −19.89% (mean of −19.78%) for δ¹³C and between 8.2 and 10.19 (mean of 9.79) for δ¹⁵N. The same samples that were analyzed for δ¹³C and δ¹⁵N were also sent for radiocarbon analyses (¹⁴C AMS). They were measured at two different laboratories: the ETH Laboratory in Zurich (Switzerland) and the CEZA Laboratory in Mannheim (Germany). The ¹⁴C dates were calibrated using the terrestrial IntCal20 curve and the OxCal v.4.4. software, as the isotopic values ruled out a potential reservoir effect from consuming marine dietary protein (Reimer et al., 2013; Bronk Ramsey, 2001, 2009, 2013, 2017; Reimer et al., 2020).

The χ² Test (OxCal's R_Combine function following Ward and Wilson, 1978) and Bayesian Chronological Modeling (Bronk Ramsey, 2009) were used to determine the temporal distribution

of the cave's inhumations and their degree of contemporaneity through OxCal v.4.4 software.

3 Results

3.1 Paleodemographic analyses and palaeopathological conditions

The latest excavations yielded 13,182 bone elements. According to the MNI, this corresponded to at least 150 individuals based on the right humerus. From this MNI-calculation, a total of 37 non-adult individuals and 113 adults were identified. The estimation of sex analyses showed a balanced distribution of sex with the

different categories of age represented including a high number of non-adult bone elements. Because of the nature of the deposit and the commingled remains, a large amount of bone elements was classified as that of adults without specific age determination. Within the skeletal elements from Biniadrís, numerous anatomical variants showed up, potentially displaying trained muscles.

Based on the highly robust appearance and the long period of use of the cave, the question arose as to whether this represents an enthesal change in the population caused by certain activity/occupation or whether at least two different population groups were present here. As this is a commingled remains context, it is difficult to include several entheses/muscle parts that are connected via several bones. In a preliminary study, the V.E.R.A. 1.0 method was used to investigate the enthesal variation between the (very) robust and gracile individuals regarding the use of the upper arm muscles. Activity reconstruction is important here to provide insight into the reasons for the occurrence of these two robustness groups. The selection of the upper arm was based on its frequent occurrence in the assemblage and its good state of preservation as well as the assumption that this was changed by more obvious factors. Furthermore, it was important to use fully grown individuals that showed no serious pathological changes of the enthesis and in general pathological lesions that could influence the method's results. Individuals were examined that showed a distinctive overall impression (gracile/robust) as well as the aspect of the respective entheses and their expression on the bone. The metric analyses allowed the humeri to be assigned to both male and female individuals.

An additional exception is the relatively high stature, where the individuals showed a body height within a range from 145 cm to 176 cm after the method of Ruff et al. (2012) mentioned in Grupe et al. (2015). The method does not consider sex as a determinant. In addition, there is an overrepresentation of the platymeric appearance in the femur. There are more recognized traits in the post-cranium than in the cranium. Interestingly, accessory facets, such as squatting facets on the tibia occur frequently. Approximately 147 tibiae of all ages are preserved at the distal end, 75 of which (left [$n = 42$]; right [$n = 47$]) exhibit a variation of the squatting facet (i.e., single or double-curved). The femur and the humerus display the most interesting morphological variations. Next to the prominent flat proximal shape of the femur, most of the individuals also created a prominent third trochanter as well as several cortical defects at the area of the *Tuberositas glutealis*. Another morphological change was detected in the distal femoral area with a cortical defect on the popliteal fossa, also known as Charles' facet. The identification is generally made by the observation of an irregular porous appearance and, in some cases, upraising and ingoing spots in the restricted area. In the Biniadrís collection, Charles' facet in adults appears infrequently but relatively often enough to warrant further analysis. In some cases, the femur has altered its appearance through the so-called hypotrochanteric fossa. The frequency of this fossa has a relation to age and might be a population-specific variation (Mann et al., 2016, p. 617). Also, the hypotrochanteric fossa might be related to the present "platymeric" appearance, which often appears as a 'flattening' on the tibiae and femora in this collection. The morphology of the humerus is characterized by the occurrence of

bone torsions, cortical defects at the deltoid muscle, and the *Crista tuberculi majoris/minoris*. This research is still in its beginning phase and further investigation with a larger sample size is needed. However, this preliminary study of the human remains showed that the enthesal differences suggest that the more robust specimens belong to generally large individuals who presented proportionally greater hand and elbow use (flexors and extensors).

Regarding the health condition of the individuals, this is remarkably well identified mainly through the presence of degenerative alterations on the bones, especially for the vertebral column. The pathological findings from Biniadrís show around 1,205 bone elements with pathological changes. Most of these are related to bone changes observed at joints, which is highly correlated to age as well as an overuse of the skeletal elements, mostly located at the articular surfaces and epiphysial ends. This joint change can cause pain and disability for the affected individual, especially in long-living populations. In the Biniadrís collection, a frequent occurrence of degenerative changes is related to long bones but also in a high amount present in the vertebral column. Additionally, frequent in this collection is the occurrence of ossified laminal spurs (*ligamenta flava*), represented by spurs along the arcus of the thoracic vertebrae. Ossification of this ligament seems to be related to increasing age as well as strenuous activity (Mann and Hunt, 2005, p. 78). Another indication of a high correlation between activity and bone formation in the sample is related to the appearance of these spurs, which is not often combined with other structures, such as osteophytes and inflammations. Next to it, in nearly all vertebrae, Schmorl's depressions occurred. The morphology of this depression resembles circles, letters, or small circular depressions as well as shallow pits mostly centered in the corpus of the vertebra. It occurs primarily in the lower vertebrae, including both thoracic and lumbar vertebrae. Additionally, their occurrence might be related to younger and older individuals as the morphology of the billowing curves on the vertebral corpus indicates. To Roberts and Manchester (2010, p. 140) the etiology of this disease is unknown and traumatic events with the previous influence of underlying infection, osteoporosis and neoplastic diseases can be taken into consideration in this disease development. Concerning oral pathologies, the most frequently occurring diseases were periodontal and alveolar changes. However, a periodontal disease related to antemortem tooth loss is lacking in this assemblage.

As well as the degenerative changes, the most common condition in the palaeopathological analysis is trauma. The human bone remains were carefully dispersed in different sectors of the cave. Interestingly, cranial fragments, as well as nearly complete crania, could be found in all sectors. Four pieces show an unusual morphology. One piece was located near the entrance in sector J and the other three at the opposite side in sector B at the cave wall. These fragments were primarily from the parietal and the occipital bones, all of them showing different affections. Although they are influenced by taphonomy which further complicates examination, the morphology of these spots is reminiscent of trephination (Figure 5), a practice known since very early times. Generally, it is associated with surgery for differential reasons, resulting in the incision of the scalp followed by cutting and removing an area of the skull (Roberts and Manchester, 2010, p. 124). The traces



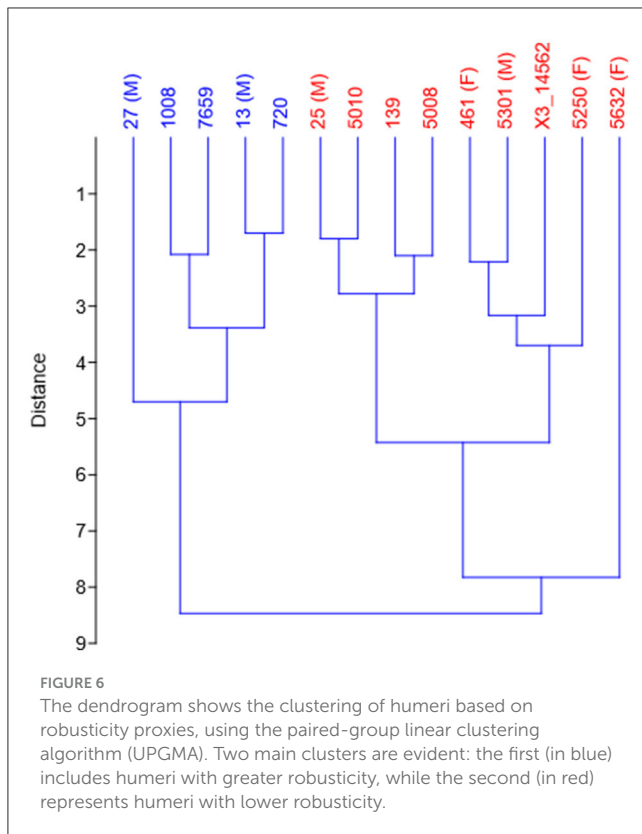
FIGURE 5
Skull from a mature individual (40–60 years old), probably female, with signs of modification compatible with trephination.

of the probable trephination were found in both sexes but mostly in older individuals and are comparable to the cases from Es Càrritx (Rihuete Herrada, 2003, p. 1999) in their appearance of the shape and the occurrence in different individuals. All circular changes that have occurred require further detailed analysis (paper in preparation).

3.2 Enteseal changes

Regarding the 3D analysis of the entheses, as explained in Materials and Methods, a total of 42 enteseal 3D areas (three entheses in 14 humeri) were digitally delineated and quantified on the 3D models using the V.E.R.A. 1.0 protocols (Karakostis and Lorenzo, 2016; Karakostis et al., 2018; Karakostis, 2023).

Subsequently, all measurements were subjected to PCA (see extensive V.E.R.A. 1.0-protocol in Karakostis, 2023), to explore multivariate patterns among entheses that may reflect differences among bones in the degree of robusticity. Although this is preliminary data, in the resulting plots, the sex of individuals was labeled using only those specimens with distinct sex scores following the application of widely used metric approaches of sex estimation. Finally, the humeri were separated into different robusticity groups, to determine whether their multivariate 3D enteseal patterns suggest different activities between robust and more gracile individuals. This categorization was attempted using three different strategies: (a) visual assessment of bone overall robusticity; (b) semi-automated K-clustering of robusticity measurements (both diameters of humeral head and epicondylar width); and (c) fully automated clustering of specimens into a blind



number of groups based on paired-group linear clustering (see Figure 6). This analysis separated specimens into two groups of robusticity. All specimens in the resulting PCA plots were colored accordingly (blue = more robust; red = more gracile). The latter categorization approach provided the most intriguing results in terms of multivariate enthesal analysis (Figures 7, 8) and was thus the one reported in this study.

In particular, the multivariate patterns of 3D entheses identified differences between the assigned four biological males and three females in the scores of PC1 (representing 47.6% of total variation). Based on the factor loadings (Table 2 and green vectors in Figure 8), variation on PC1 represents overall enthesal size (i.e., all loadings are positive). In contrast, the relationship between PC2 (28.9% of total variation) and PC3 (23.5% of total variation) provided considerable separation in enthesal patterns between robust bones (blue dots in Figures 7, 8) and more gracile specimens (red dots in Figures 7, 8). Based on the loadings of PC2, robust individuals presented proportionally larger medial epicondyles. Nevertheless, our correlation tests showed a strong association between enthesal patterns represented by PC2 scores and the vertical head diameter of individuals (p -value > 0.01; r -value = 0.67). By contrast, PC3 scores do not seem to be associated with biological sex (see Figures 7, 8) and did not correlate with head diameters. Based on the factor loadings (Table 2 and green vectors in Figure 8), variation on PC3 reflects proportionally greater use of hand, wrist, and elbow muscles (for flexion and extension, represented by the medial and lateral epicondyles) compared to arm adduction via humeral head medial rotation (represented by the lesser tubercle).

3.3 Results of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$

The stable isotopes results show, in a first approach, the preservation of the collagen in bone through the percentages of carbon and nitrogen. Any sample showing a carbon and nitrogen percentage lower than 20% and 4% respectively was not considered for the analysis. All human and zooarchaeological samples ranged from 33.6% to 44.2% in carbon and from 12.0 to 15.6% in nitrogen. The atomic C/N ratio was 3.3 in every sample, which means that all the samples are acceptable following Van Klinken (1999) standards.

The human remains from the Biniadris cave (black dots on Figure 9) showed very narrow $\delta^{13}\text{C}$ delta values ranging from -19.9‰ to -19.1‰ and $\delta^{15}\text{N}$ values between 8.2‰ and 10.2‰. Regarding the zooarchaeological samples, they ranged between -22.1‰ to -19.7‰ for $\delta^{13}\text{C}$ and from 4.3‰ to 8.9‰ for $\delta^{15}\text{N}$. The results show a strong terrestrial diet, excluding any type of marine diet (Figure 9, Table 3). Even though there is a very slight relationship in the increase of carbon and nitrogen stable isotope values, it does not reach values that correspond with marine food. This fits logically with the zooarchaeological data published for the Balearic Islands (Ramis et al., 2017).

The stable carbon and nitrogen isotope analysis revealed a remarkable consistency across the studied samples. Both the human skeletal remains and the faunal specimens suggest a predominant terrestrial dietary pattern, primarily reliant on C_3 plants. Despite the slight dietary variability observed within the human samples, the isotopic values remain largely in line with the anticipated terrestrial signatures, suggesting the consumption of cattle, sheep/goat, and pig as seen from the domestic contexts on the island (Ramis et al., 2017). It is worth noting that the samples under scrutiny were sourced from adult individuals, and no differentiation was made based on sex, thus limiting our ability to discern potential dietary biases along gender lines. However, an exhaustive examination of the aggregated terrestrial values suggests that any segregation based on variables such as sex, skeletal robustness, or chronological considerations is unlikely to yield significant deviations within the broader terrestrial dietary spectrum (C_3).

Moreover, the consistent isotopic patterns also shed light on the population's behavioral traits concerning the utilization of marine resources in coastal communities. The lack of significant deviations from terrestrial isotopic norms underscores a consistent reliance on terrestrial food sources, despite the proximity to marine environments. This uniformity in dietary behavior, as evidenced by isotopic analysis, suggests a degree of cultural or ecological stability within these populations, with minimal adaptation to marine resource availability (Mannino et al., 2012; Salazar-García et al., 2018). Such findings contribute to our understanding of ancient human dietary habits and the socioecological dynamics influencing resource utilization patterns over time.

3.4 Results of the radiocarbon ^{14}C - AMS analysis

A Single Contiguous Phase Bayesian Model (Figure 10, A_{model} 107.3 and A_{overall} 107.2) determined a continuous temporal

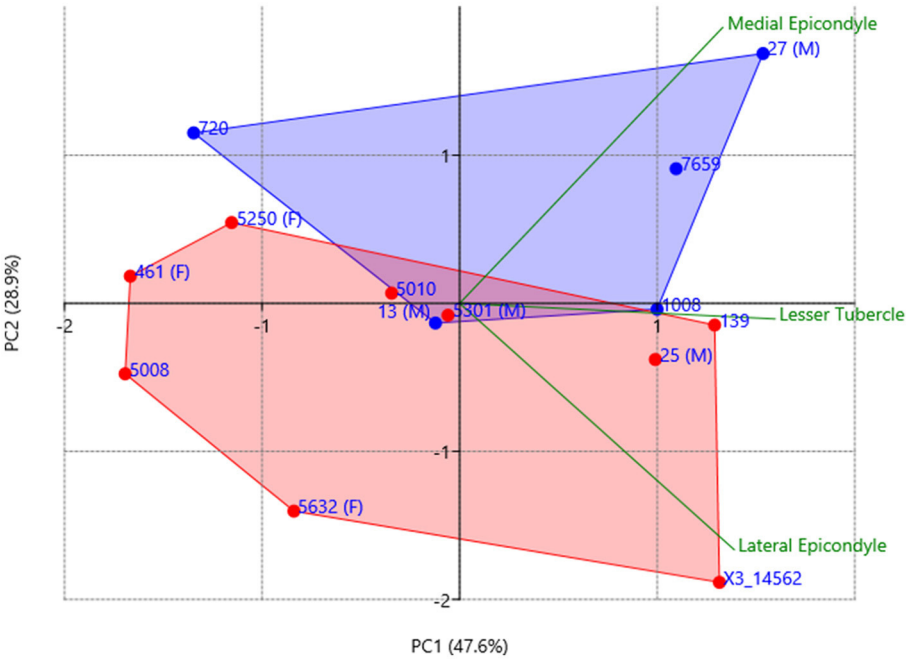


FIGURE 7
Principal component analysis (PCA) plot displaying the first two principal components (PC1 and PC2), using all three humeral enthesal 3D measurements as variables. The plot highlights the key patterns and differences between more robust (blue) and more gracile (red) individuals, color-labeled following the clustering process presented in Figure 4. The specimen labels indicate the few bones with assessed biological sex as males (M) or females (F).

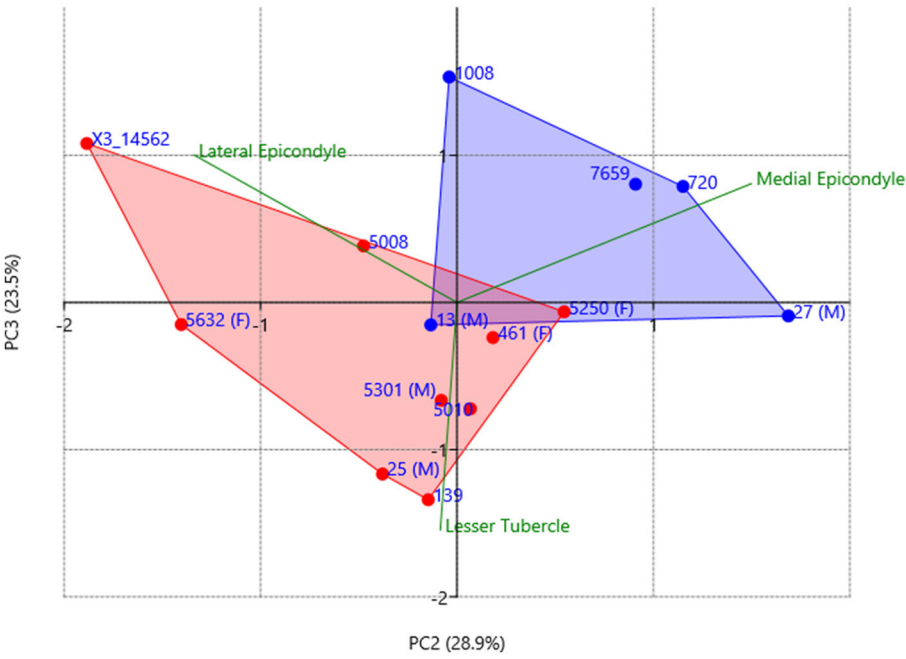
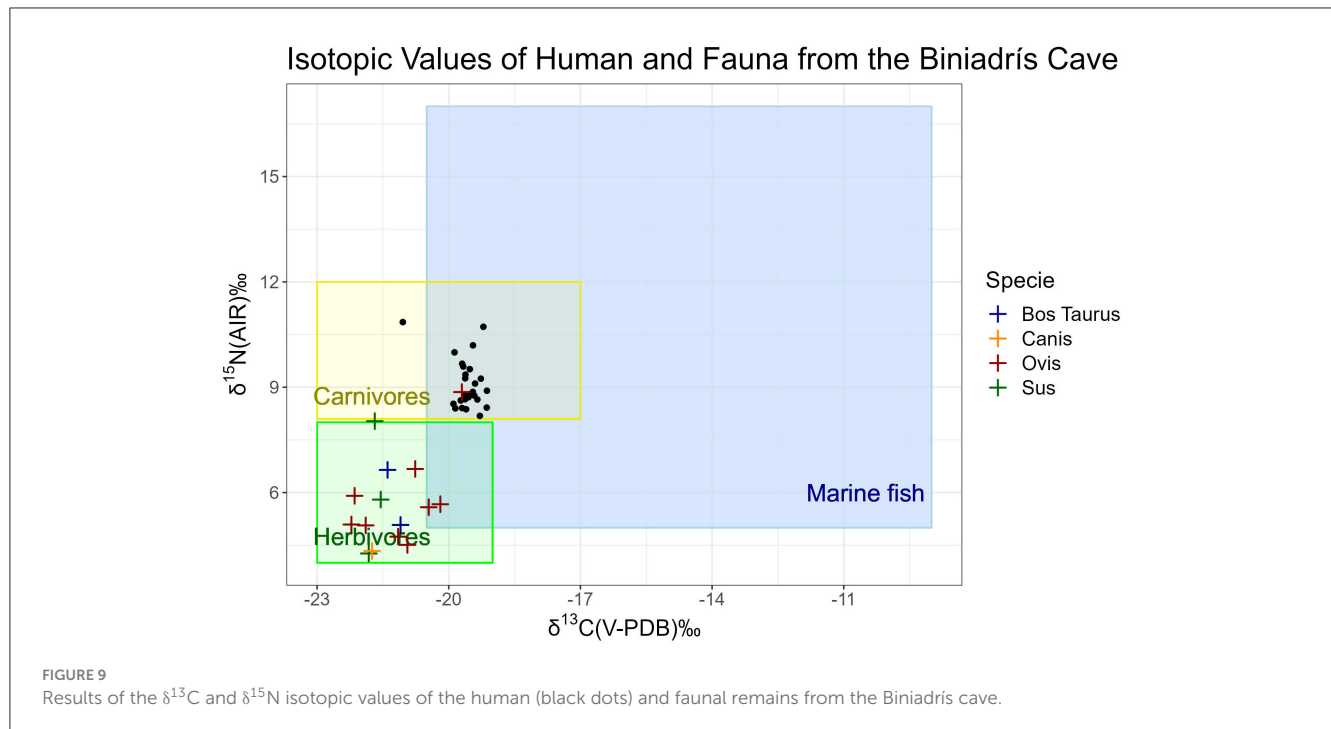


FIGURE 8
Principal component analysis (PCA) plot displaying the second and third principal components (PC2 and PC3), using all three humeral enthesal measurements as variables. The plot highlights the key patterns and differences between more robust (blue) and more Gracile (red) individuals, color-labeled following the clustering process presented in Figure 4. The specimen labels indicate the few bones with assessed biological sex as males (M) or females (F).



distribution of the cave's inhumations between 1295 and 1175 cal BC and 750–520 cal BC (95% probability) with a span of 445–675 years (95% probability). The radiocarbon results were examined using a χ^2 test (Ward and Wilson, 1978), which resulted in seven groups of dates that could have been contemporary (Figure 11). If the groups indicate pulses of use, the oldest one occurred in 1195–1120 cal BC (95% probability; 53.33% of the dated graves, A_{comb} 191.6), the second one 1190–1055 cal BC (95% probability; 40%, A_{comb} 174.1), the third one in 1110–1005 cal BC (95% probability; 13.33%, A_{comb} 85.2), the fourth in 1010–915 cal BC (95% probability; 6.66%, A_{comb} 67.4), the fifth one in 805–780 cal BC (95% probability; 6.66%, A_{comb} 75.4), the sixth in 790–590 cal BC (95% probability; 10%, A_{comb} 121.7) and, the last one in 770–570 cal BC (95% probability; 23.33%, A_{comb} 106.1).

4 Discussion

During the Late Bronze Age (c. 1,400–800 BC) the funerary ritual at Biniadrís cave is linked to the changes observed in the archaeological record and the habitational and funerary spaces in the Balearic Islands but particularly in Menorca (Lull et al., 1999). During this period, different types of spaces coexisted with different distributions across the Balearics, such as boat-shaped structures known as “navetas,” which initially served as habitational structures but later were used exclusively for collective funerary purposes. Examples include Biniac-L'Argentina (Plantalamor Massanet, 1991), Es Tudons (Fernández-Miranda, 1991), and Rafal Rubí (Roselló-Bordoy, 1979). These navetas were contemporaneous with natural caves or shelters used for similar purposes, such as Cova dels Ossos de Mongofre Nou, Cova de Es

Càrritx (Lull et al., 1999; Lull and Micó Pérez, 1999), Cova des Mussol (Lull et al., 1999; Lull and Micó Pérez, 1999), Cova des Pas (Fullola et al., 2008), Biniadrís, and Torre del Ram (Plantalamor Massanet, 1997). The concept of collective burial, evolving from individual burials within an organized and structured deposit, is exemplified at the Biniadrís cave, which contains a human bone collection of over 150 individuals buried in this context. The equal representation of female and male with the inclusion of a large non-adult group is one of the main features of the Biniadrís community. In addition, the results of our preliminary enthesal analysis suggest that the robust humeri of Menorca belonged to relatively larger individuals (represented by high PC2 scores correlating with our body size proxy; see Results) whose habitual upper arm activities involved extensive use of elbows and hands (represented by high PC3 scores; see Table 2). Interestingly, most relatively gracile individuals presented an enthesal pattern reflecting proportionally greater adduction and medial rotation of the arm (reflected in low PC3 scores). Further studies will follow the advanced iteration of the original V.E.R.A. 1.0, which is a semi-automated protocol (using primary MeshLab), and will be helpful to analyse in depth the enthesal changes in the Biniadrís bones (Karakostis, 2024).

Of special importance and one of the main features of the funerary caves, shelters, and hypogea is the site selection. It seems to have played a significant role before the start of their use, with inaccessibility and location, usually far from the settlements, being key components. The interiors are small, circular or oval in shape, with monumentalised entrances, such as the one still preserved at Biniadrís, that are also known from Menorcan settlements. There is a specific burial treatment such as the dyeing of the hair, where the red pigment is characteristic and has been used also

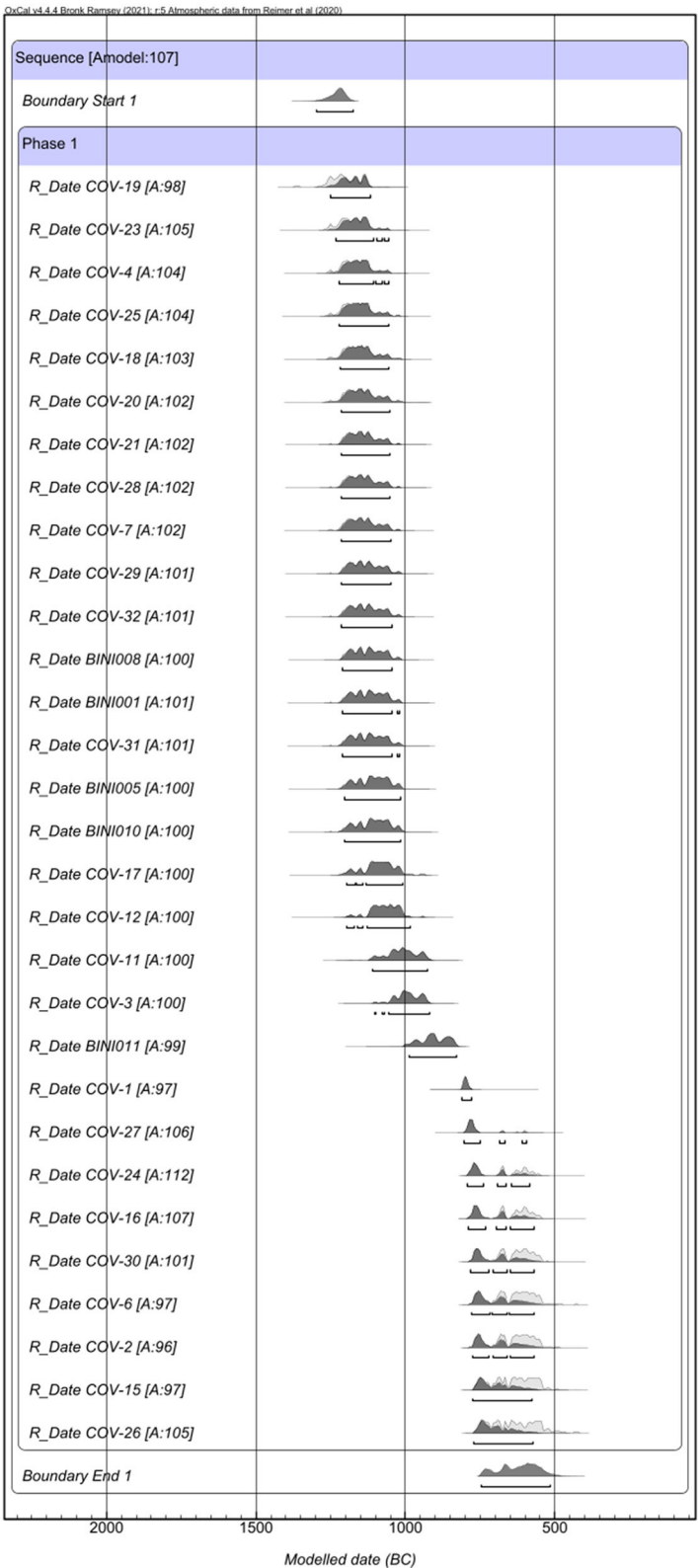
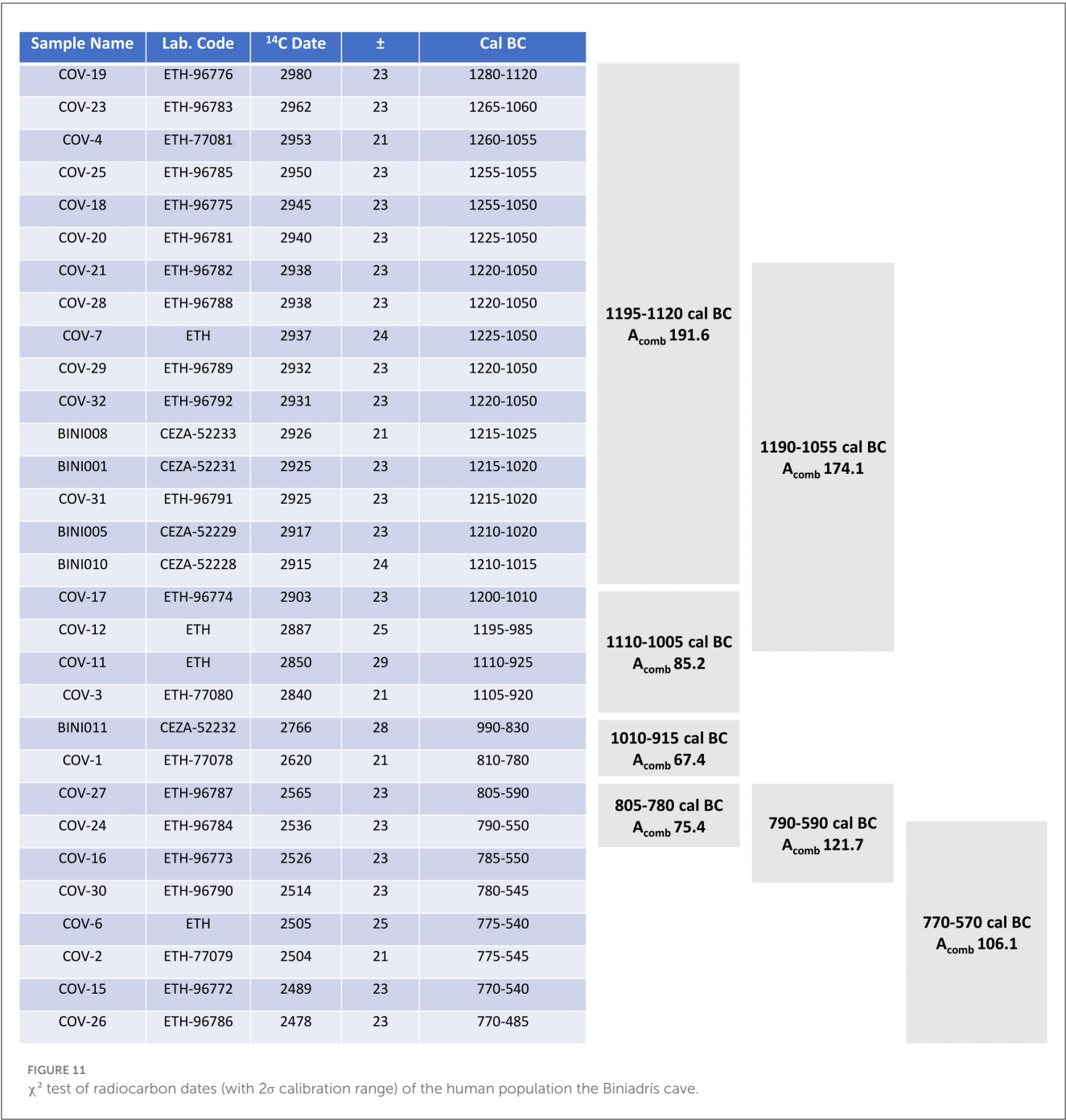


FIGURE 10 Radiocarbon dates (with 2σ calibration range) for the human population of the Biniadrís cave.

in other caves (Lull et al., 1999; Lull and Micó Pérez, 1999; Lull et al., 2014; Rihuete Herrada, 2000). In addition, the cutting of the hair and its deposition in special containers, made this ritual

quite elaborate and specific. The funerary ritual is accompanied by the use of plants that seem to be exclusive to some ritual spaces (Guerra-Doce et al., 2023; Riera Mora et al., 2018). There



also appears to have been some selection in the production of associated ceramics. Personal belongings accompanying the bodies of the deceased persons are made of metal but also of bone, such as the V-shaped buttons (Altamirano García and Alarcón García, 2018), which is also a recurrent feature that has been found in the western Mediterranean.

These Late Bronze Age communities were attached to their landscape and made good use of their resources (Díaz-Zorita Bonilla et al., 2025), mainly land-based terrestrial sources, practicing agricultural and herding strategies. The scientific

analyses applied to the study of subsistence practices showed a human diet clearly based on terrestrial resources of animal and plant proteins, and excluding any appreciable marine component. Similar patterns have been documented at Cova des Pas, where an identical archaeological record and terrestrial-based diets were observed (Sotiriadou et al., 2023).

The 700 years of use of the cave should be understood in a *longue durée* perspective, especially considering that access to the cave is concealed and difficult, which reinforces the intentionality, strong ties, and collective knowledge and identity

of the community that has cared for the funerary space through time. The archaeological record shows a very long use of the cave, where the funerary memory has been preserved for centuries. It is not only the preservation of this memory that is important, but also the archaeological record, which has been organized with great care, with fragmentation kept to a minimum. It is now possible to observe the organization of the community and the reconstruction of group identity, the interaction between its members and the modification of space and objects over time (Hernando, 2002; Sánchez Romero, 2005, 2007; Querol, 2001; Alarcón García et al., 2020). Since the main archaeological material found in the Biniadrís cave is human remains, our research focuses on the human body while also considering everything else that encompasses the ritual understanding of the body as cultural elements (Sánchez Romero, 2008, 2009). The prolonged use of the cave and the longevity of the ritual practices can also be interpreted in terms of place-attachment and place-related identity, a feature of small islands arising from their more bounded character and strong sense of place (Dawson, 2019).

Similarly, the evidence for healing and care among the individuals buried in the cave is a strong indication of a close-knit and autonomous population, as is to be expected on an island. The absence of indicators for a marine diet suggests limited engagement with the sea and greater exploitation of the land, through agriculture and animal husbandry, which “left their mark on the bodies” (Díaz-Zorita Bonilla et al., 2025, p. 128). This is not to say that the community at Biniadrís was completely isolated or inward-looking. While still under study and not included in this paper, the material evidence found at the cave, ranging from organic (e.g., flax, V-perforated bone buttons) to inorganic material (e.g., carnelian beads), points to connections to the Iberian mainland as well as the wider Mediterranean. Alternating phases of increased isolation and connectivity are bound to have occurred over 700 years; thus, the continuity in the use of the same ritual space over seven centuries represents a conscious expression of community identity. The absence of contemporary settlement evidence makes it difficult to evaluate whether Biniadrís cave served one or more communities and where the individuals buried there lived. Nonetheless, its longevity underscores the considerable effort that went into maintaining it as a focal point in a shifting landscape. The sharing of a limited space, practices, and resources is an important factor in the development of a unique community identity within an island setting. Moreover, the evidence indicates a stable, well-organized, adapted, and cared-for community, managing well at the interface between isolation and connectivity. The development of a collective identity at Biniadrís, which we understand as the expression of community belonging and place-attachment, can be traced from its shared and continued practices and appears amplified by insularity (Calvo-Trias, 2024; Dawson, 2020).

5 Conclusions

The Biniadrís cave represents a sacred space shared by all members of the community, whose actions further reinforced their

identity as reflected in the care of their ancestors according to a specific funerary programme. The fact that individuals of all ages, especially young non-adults, had the right to be inhumed in the same space, and the equal representation of female and male adults and the absence of evidence for gendered divisions of labor in the osteological record, attest to the inclusion of all members of the community in the daily activities and also in the funerary world. Additionally, the palaeopathological analysis showed the implementation of care in the past, which along with the setting of the ritual, reinforces the agency and identity of the community through time and space. This *longue durée* can be further explained by the insular setting of this community, with its limited space and resources, which would reinforce community cohesion. Biniadrís thus provides significant insights into the changing nature of insularity, as seen from our ongoing study of long-term environmental and cultural dynamics at the island and archipelago scale. The exceptional preservation in Biniadrís cave, including the remarkable condition of the human remains, combined with its enduring funerary memory spanning over seven centuries, makes it a remarkable site for understanding the life and death of Menorcan communities during the late prehistoric period in Europe.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

MDZB: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. MT: Formal analysis, Writing – review & editing. MM: Formal analysis, Writing – review & editing. AM: Writing – review & editing. EA: Writing – review & editing. AK: Formal analysis, Software, Writing – review & editing. JE: Writing – review & editing. LA: Writing – review & editing. SR: Writing – review & editing. BM: Formal analysis, Writing – review & editing. DH: Writing – review & editing. HD: Writing – review & editing. FC: Writing – review & editing. MB: Writing – review & editing. JB: Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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