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Title:

New insights into Mesolithic human diet in the Mediterranean from stable isotope analysis:
The sites of *Campu Stefanu* and *Torre d'Aquila*, Corsica

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Abstract

Mesolithic human remains are rare in the archaeological record of the French Mediterranean. Only the island of Corsica has so far produced relatively well preserved burials, and recent archaeological excavations have brought to light new Mesolithic human remains. The site of *Campu Stefanu*, located in Sollacaro in the southeast of the island, contained a collective burial of 7-8 individuals in a previously unobserved funerary context. A re-evaluation of collections in regional museums yielded the remains from another Mesolithic individual from the site of *Torre d'Aquila*, excavated at Pietracorbara, in the northern part of the island, at the beginning of the 1990s. These two discoveries presented the rare opportunity to obtain new radiocarbon dates and paleodietary insights from this crucial time period using stable isotope analysis ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$) on collagen. From *Campu Stefanu* one individual had sufficient collagen preserved for radiocarbon dating, revealing that it is the oldest Mesolithic human known on the island, dated to 10216-9920 cal. BP. At *Torre d'Aquila*, radiocarbon dates indicate that the individual belonged to a younger Mesolithic phase than *Campu Stefanu*, dated to 9903-9596 cal. BP. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ isotope ratios are similar between the *Campu Stefanu* and *Torre d'Aquila* individuals and indicate a diet dominated by the consumption of terrestrial animal protein, and a lack of marine resources. These findings are in contrast with the previous results from two other Mesolithic individuals from Corsica from the sites of *Araguina Sennola* and *Monte Leone*, for which about 25-30% of the consumed proteins came from a marine diet. The dietary variability recorded in Corsica is consistent with results obtained from Mesolithic human remains of Sicily and the Iberian Peninsula. We can hypothesize, that despite the nomadic lifestyle, the distance to the sea played a major role in Mesolithic food choices in Corsica.

1. Introduction

The first human occupations on the island of Corsica have been documented from archaeological excavations during the 1970s on seven Mesolithic sites (10th-9th millennium BP; Costa *et al.* 2003). Most of these sites are located close to the present day coast line and show a local exploitation of both raw material and food resources (Costa *et al.* 2003; Vigne, 2004). Corsican pika (*Prolagus sardus*), a small terrestrial herbivore, dominates the faunal assemblages, sometimes up to 80%. Other small rodents, birds, shellfish and fish make up the rest of the animal remains. Despite the proximity to the sea, marine resources are often scarce at ca. 20% (Vigne, 1995). Zooarchaeological analyses show seasonality in food resources acquisition, with fish and bird preferentially caught during spring and summer, and Corsican pika during the end of summer and autumn (Vigne, 2004).

Until 2007, Mesolithic human remains were found and studied at three sites: *Monte Leone*, and *l'Araguina Sennola*, in the southern part of the island near Bonifacio, and *Torre d'Aquila* in northern part of the island near Pietracorbara (Figure 1). At *Monte Leone* (ML), one poorly preserved female individual, two immature individuals and a few dental remains were described (David, 1999). Radiocarbon dating was performed on bones of Corsican pika, resulting in age estimates of 9533-9290 cal. BP (AA-18112), and 9126-8663 cal. BP (AA-18108) (Vigne, 1997). At *Araguina Sennola* (AS), a well preserved skeleton of a female was studied by H. Duday (1975). This individual showed specific pathological traits indicating that she was handicapped long before her death (Duday, 1975). Finally, at *Torre d'Aquila* (TA), remains from a female were found in a Mesolithic layer (Magdeleine 1995; Bouville 1995), but no radiocarbon date was obtained.

At the end of the 1990s, stable isotope ratios ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$) were measured for the first time on Prehistoric human remains from Corsica on the two adult women of ML (Pouydebat, 1997)

and AS (Bocherens, 1999), as well as on animal bones from ML (Corsican pika, grouper - Serranidae, European pilchard – *Sardina pilchardus*, sea bream – *Sparus* sp., seal – Phocidae, and dolphin – *Tursiops* sp.; Pouydebat, 1997). Isotopic results obtained on AS and ML are consistent with zooarchaeological data of these sites, indicating a protein intake based on terrestrial game (Corsican pika) and a consumption of marine food, possibly up to 30% (Pouydebat, 1997; Costa *et al.* 2003; Vigne, 2004). Archaeological studies demonstrated that the settlements were temporary occupied by small nomadic human groups, described as “trapper-fisher”, as their subsistence activities were mainly based on animal trapping and fishing (Costa *et al.* 2003).

In 2007, new archaeological discoveries in Corsica revealed additional Mesolithic human remains at the site of *Campu Stefanu* (CS) located near Sollacaro (Figure 1), at ca. 7 km from the current western coastline. Considering relative sea level change (ca. -50m; Lambeck and Bard, 2000) and bathymetric data (Pluquet, 2006), the site was not significantly further away from the shoreline during the occupation period. Excavated from 2007 to 2011, CS delivered remains of several occupations ranging from the Mesolithic to Iron Age. Among various structures (Cesari *et al.* 2008; 2011), a natural rockshelter included a burial with 7-8 individuals (Courtaud *et al.* 2014). At the bottom of the rockshelter a partially preserved human skeleton was discovered, covered by many bones of other partial individuals, including anatomical connections and scattered bones. This funerary assemblage is unknown for this period and region. In addition, no typical Mesolithic elements like seashells, or flints, were associated with the funeral deposit. Only some ochre covered the cranium of the most complete individual. Two radiocarbon dates on bone collagen from a humerus bone of the first body (CS1) deposited in the burial (lower level of the stratigraphy, layer 4 R32), revealed that it is the oldest individual found in Corsica identified so far (10216-9920 cal. BP,

Courtaud *et al.* 2014). Considering the importance of this discovery, a re-evaluation of Mesolithic human remains in Corsica was attempted and new radiocarbon dating was performed in 2014 on two human remains of TA (TA1; right M1 and right radius; rockshelter n°2, layer 9) at the Australian National University radiocarbon laboratory (Fallon *et al.* 2010). Age estimates indicate that the female of TA (TA1) belongs to a younger phase of the Mesolithic (9903-9596 cal. BP) compared to CS1, but is older than AS and ML (Table 1). Considering the scarcity of Mesolithic human remains in the French Mediterranean and the palaeodietary data already obtained from two Mesolithic women in the south of the island, we performed new stable isotope analysis on the human remains of CS1 and TA1. These new data aim at documenting hunter-gatherer behaviours in different environmental contexts (coastal vs. inland) and aim to add to our understanding of the different environmental exploitations in coastal areas from the Western and Central Mediterranean.

2. Stable isotope analysis

Carbon and nitrogen stable isotope ratios measured on bone collagen are efficient proxies to evaluate (1) the contribution of animal protein intake and (2) the environmental origin of the consumed resources. At the base of the food chain, plants have specific $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ratios according to climatic and edaphic conditions, photosynthetic pathways and species (e.g. Mariotti 1982; Virginia and Delwiche 1982; Farquhar *et al.* 1989). Plant consumers take up the specific $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ratios from the plants and this isotope ratio is incorporated into bone collagen with isotopic fractionation (e.g. Schoeller, 1999). This isotopic fractionation is considered as ca 0-1‰ for C and 3 to 5‰ for N between prey-predator bone collagen (e.g. Bocherens and Drucker 2003). $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ stable isotope ratios are efficient environmental markers and are commonly used for differentiating marine vs. terrestrial environments

(Schoeninger and De Niro 1983) and for evaluating the relative quantity of ingested animal protein, provided that the range of values defining the local environment based on animal and/or botanical isotopic data is known (e.g. Goude and Fontugne, 2016). In human populations, an exclusively marine diet leads to a bone collagen $\delta^{13}\text{C}$ of about -13‰ and an exclusively terrestrial C_3 diet to a bone collagen $\delta^{13}\text{C}$ of about -20‰ or less (e.g. Chisholm *et al.*, 1982). Animals whose diet consisted entirely of marine resources have a $\delta^{15}\text{N}$ on average of 9‰ higher ($14.8 \pm 2.5\text{‰}$) than those with an entirely terrestrial diet ($5.9 \pm 2.2\text{‰}$), while those with a mixed diet have intermediate values according to the environment (Schoeninger *et al.* 1983). More, in depth methodological information can be found in Bocherens and Drucker (2005), Lee-Thorp (2008), Balasse *et al.* (2015), and Makarewicz and Sealy (2015). Due to the ongoing remodelling of bone, $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ stable isotope ratios of collagen provide information on the last years of life. The remodelling is faster during infancy and slows down with the passing years (Valentin 2003). In the case of adult individuals, as at TA1 and CS1, stable isotope data reflect an average of food consumed during the last 15 years before death (Hedges *et al.* 2007).

The adult of TA and four individuals buried at CS were sampled (long bone, cortical material), but for CS, only one individual (CS1) had sufficient collagen preserved to be analysed. This is the same individual as aged by radiocarbon dating. Preparation of the archaeological material was performed at the biochemical laboratory of LAMPEA using standard protocols for bone powder developed by Longin (1971) and Bocherens (1992), details also in Goude (2007). Carbon and nitrogen content and isotopic ratios were obtained from 1 mg of freeze-dried collagen by EA-IRMS (Europa Scientific 20-20 IRMS, with reproducibility below 0.1‰; Iso-Analytical Ltd, Crewe, UK). The extracted collagen analysis meets the quality criteria (Table 2; DeNiro 1985; van Klinken 1999).

3. Results and discussion

Results from the individuals from CS1 and TA1 indicate a diet based on terrestrial animal proteins (Table 2). The comparison with animal and the other Corsican human data (Table 3) reveal different subsistence strategies for the Mesolithic period. Individuals on the sea shore show as much as 30% of marine resources in their diet (Pouydebat, 1997 and Costa *et al.* 2003), while CS1 and TA1 individuals do not show any significant intake of marine fish/mammals (less than 10%, if at all). The new stable isotope data indicate a dominantly terrestrial diet and support the hypothesis of an exploitation of the nearby environment during the Mesolithic in Corsica. The observed spatially variable dietary patterns raise questions regarding the possible mobility of Mesolithic people.

Only a few excavations in the Mediterranean context have delivered Mesolithic human and animal bones allowing biochemical investigations. Using published data, we compared the Corsican data to other Mesolithic human groups in Sicily, the Iberian Peninsula and the Adriatic coast (ca. 9700-7100 cal. BP; Garcia Guixé *et al.* 2006; Lightfoot *et al.* 2011; Mannino *et al.* 2011; 2012; Fernández-López de Pablo *et al.* 2013; Salazar-García *et al.* 2014; Figure 1; Table 3). These sites are relevant for comparison as most of the human groups had access to both marine and terrestrial environments, similar to Corsica. These previous studies have shown a large variability of human $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ stable isotope data, indicating individuals with significant marine protein intake, and other individuals utilizing mainly terrestrial resources. In some cases, marine resources consumption can be linked to the ability to gain easy access to the seashore (e.g. El Collado). In other cases, the proximity to the seashore does not appear to influence the dietary habits (e.g. Grotta dell'Addaura). The dietary diversity and the generally small marine resource intake observed in Corsica is thus consistent with the general pattern defined from the Mesolithic human remains in the Mediterranean. When considering only CS1 and TA1 human samples in Corsica, the trophic

step ($\Delta^{15}\text{N}_{\text{human-herbivore}}$, computed with medians) is quite similar to what is recorded for the other Mediterranean sites (from 3.6 to 5.4‰ for nitrogen and from 1.2 to 1.4‰ for carbon; Figure 2). If we consider AS and ML human samples in Corsica, the trophic step is more similar to some individuals from El Collado, Pupićina cave or Grotta d’Oriente (>5‰ for $\delta^{15}\text{N}$). Fish, marine mammals, and molluscs are part of the diet of these individuals, but their contribution to the diet is more modest, than what we can observe in Mesolithic sites of the Atlantic coast, e.g. 44-87% of marine resources at Téviec and Hoëdic, Brittany’s islands (Schulting and Richards 2001). During the Mesolithic, terrestrial animals seem to have constituted the main food supply in the Mediterranean areas considered in this study, either as deer in Sicily (Mannino *et al.* 2012), or Corsican pika in Corsica (Vigne, 2004).

Dietary dichotomy observed between Atlantic and Mediterranean Mesolithic coastal settlements could be linked to the availability of nearby food resources, particularly in marine ecosystem, and to environmental parameters, such as tidal amplitudes (Fa, 2008). These results further document the geographical difference of the subsistence shift (or lack thereof) during the Mesolithic-Neolithic transition (e.g. Richards and Schulting, 2003). The poor preservation of bone organic matter in these sites makes it challenging, but our findings indicate that it is worthwhile to attempt new analyses (e.g. $\delta^{34}\text{S}$, amino acid). Further investigation on Mesolithic diet in a Mediterranean area such as Corsica is essential to understand the role and influence of different ecosystems on resources acquisition with the aim to better interpret the dietary shift occurring with the advance of agriculture and its socioeconomic consequences.

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Understanding the migrations of prehistoric populations through direct dating and isotopic tracking of their mobility patterns.

Accepted Article

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Table 1a. AMS radiocarbon dates from Mesolithic sites in Corsica. Calibration was carried out in OxCal v4.2 (Bronk Ramsey, 1995, 2001) against IntCal13 (Reimer et al., 2013). All radiocarbon dates of bone are on collagen. Collagen from S-ANU was purified using an ultrafiltration protocol (as described in Wood *et al.* 2014).

Laboratory number	Context	Sample material	¹⁴ C date (BP)	Calibrated ¹⁴ C date (cal. BP, 95.4% range)	Reference
Campu Stefanu (CS)					
Beta 318791	Individual CS1,	Human humerus	8940±40	10216-9920	Courtaud <i>et al.</i> 2014
Poz 44201	layer 4 R32		8970±60		
Torre d'Aquila (TA)					
S-ANU 38010	Individual TA1,	Human 1 st molar	8790±50	9903-9596	This study
S-ANU 38011	rockshelter n°2, layer 9	Human right distal radius	8715±50		
Araguina Sennola					
GIF 2705	layer XVIIIa	Charcoal	8520±150	9891-9150	de Lanfranchi, 1973
Monte Leone					
AA 18112	layers 5 to 2a	<i>Prolagus sardus</i> bone	8415±65	9533-9290	Vigne, 1997, Costa <i>et al.</i> 2003
AA 18108	layers 5 to 2a	<i>Prolagus sardus</i> bone	8050±60		

Table 1b. Quality assurance data for bone collagen extracted for radiocarbon dating.

Laboratory number	Collagen yield (mg)	Collagen yield (%)	$\delta^{13}\text{C}$ (deltaPDB)	$\delta^{15}\text{N}$ (deltaAIR)	%C	C:N
S-ANU 38010	13.2	2.0	-20.2	8.9	43.9	3.3
S-ANU 38011	15.2	2.9	-20.2	8.0	39.7	3.4

Table 2. Stable isotope ratios and collagen quality criteria of Corsican human bone collagen analysed in this study for palaeodiet.

Location	Site	Context	Bone	Yield (%)	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	%C	%N	C/N	Current distance to the sea
Corsica - South	Campu Stefanu	Individual CS1, layer 4 R32	Long bone	1.5	-20.4	8.9	35.9	13.1	3.2	ca. 7 km
Corsica - North	Torre d'Aquila	Individual TA1, rockshelter n°2, layer 9	Long bone	NA	-20.3	8.1	34.9	11.7	3.5	ca. 4 km

Table 3. Published stable isotope ratios of Corsican Mesolithic humans, as well as Mesolithic herbivores and humans from other Mediterranean/Adriatic sites.

Location	Site	Species (N)	$\delta^{13}\text{C}$ (‰) median	$\delta^{15}\text{N}$ (‰) median	Current distance to the sea	Reference
Corsica - South	Araguina Sennola	Human (1)	-18.8	10.6	seashore	Bocherens 1999
Corsica - South	Monte Leone	Human (1)	-18.0	9.9	seashore	Pouydebat 1997
Corsica - South	Monte Leone	<i>Prolagus sardus</i> (5)	-21.6	4.1	seashore	Pouydebat 1997
Iberian Peninsula-	El Collado, C. Corona, C. Santa Maira, P. Comptador, C. Mas Nou	Human (22)	-18.5	9.2	From ca. 3 to 46 km	Garcia-Guixé <i>et al.</i> 2006; Fernández- López de Pablo <i>et al.</i> 2013; Salazar-Garcia <i>et al.</i> 2014
Iberian Peninsula-	C. Santa Maira, P. Comptador, C. Mas Nou	Herbivores (19)	-19.8	3.8	From ca. 3 to 46 km	Salazar-Garcia <i>et al.</i> 2014
Sicilian island	G. Oriente, G. Addaura, G. Molara, G. Uzzo	Human (11)	-19.5	10.4	Less than 2 km	Francalacci, 1988; Mannino <i>et al.</i> 2011; 2012
Sicilian island	G. Oriente, G. Addaura, G. Molara	Herbivores (15)	-20.9	6.4	Less than 2 km	Mannino <i>et al.</i> 2011; 2012
Adriatic coast	Vela Spilja- Vela Luka, Pupicina	Human (4)	-19.2	9.7	From seashore to ca. 7 km	Lightfoot <i>et al.</i> 2011
Adriatic coast	Vela Spilja- Vela Luka	Herbivores (8)	-20.4	6.1	From seashore to ca. 7 km	Lightfoot <i>et al.</i> 2011

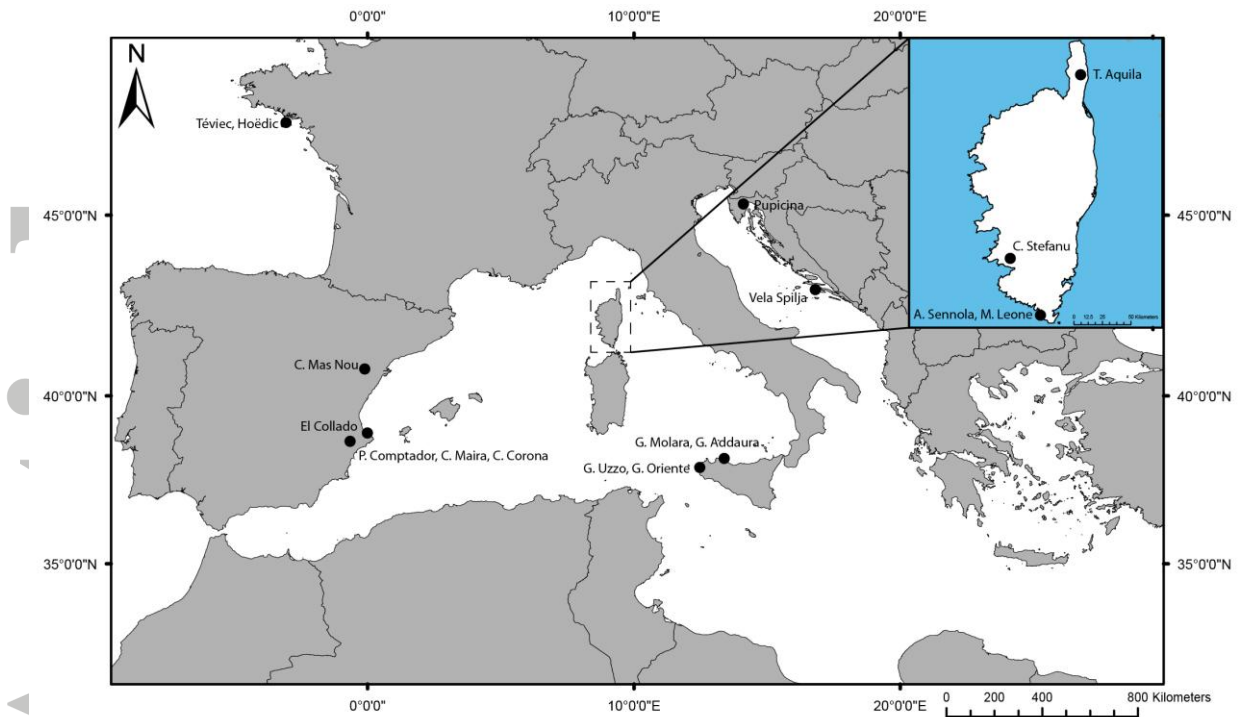


Figure 1. Location of the Mesolithic sites with human stable isotope data in Mediterranean and Adriatic coast.

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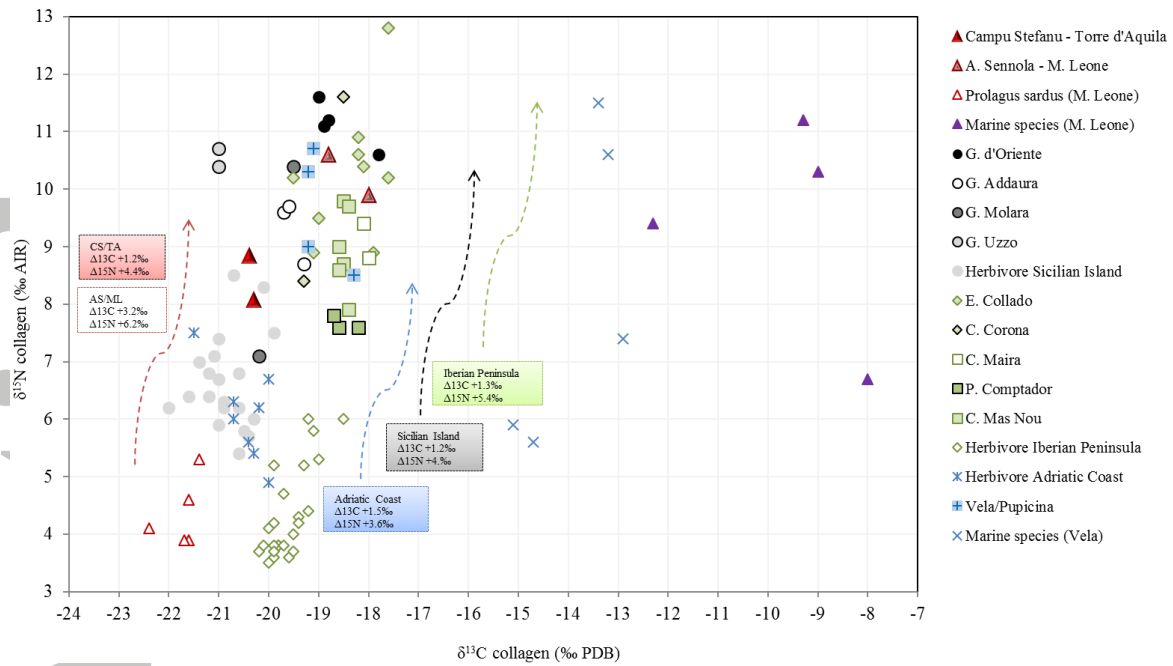


Figure 2. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ stable isotope distribution for Mesolithic remains located on coastal environments. Corsica: this study, Pouydebat, 1997; Bocherens, 1999; Sicily: Mannino *et al.* 2011, 2012; Croatia: Lightfoot *et al.* 2011; Spain: Garcia-Guixé *et al.* 2006; Fernández-López de Pablo *et al.* 2013; Salazar-Garcia *et al.* 2014. For human samples, only individuals over 3 years of age were included. Arrows represent the isotopic enrichment (median) between the human group and herbivores of the corresponding area.