

# “Celts” up and down the Alps. Insights on mobility patterns in the pre-Roman/Celtic population from Verona (NE Italy, 3rd–1st c. BCE): A multi-isotopic approach

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## Abstract

**Objectives:** The Late Iron Age in continental Europe featured complex demographic processes including, among others, the establishment of transalpine “Celtic” communities on the Italian peninsula between the 4th and 1st centuries BCE. To date, only few data are available about mobility and migration in these populations. Here we explore these topics among the Cenomani of Seminario Vescovile (SV-Verona, Italy, 3rd–1st c. BCE) through a multi-isotopic approach and test the possible associations with sex, age and funerary treatment.

**Materials and methods:** We analyzed isotopic ratios of oxygen ( $\delta^{18}\text{O}$ ) and carbon ( $\delta^{13}\text{C}$ ) from bone phosphate and collagen, respectively, of 49 individuals (23 males, 17 females, and 9 nonadults). In addition, we explored possible intraindividual lifetime changes by comparing collagen  $\delta^{13}\text{C}$  from bone and dentine of 26 individuals. We assessed nonlocality based on individual deviation of isotopic values from the population mean plus three times the median absolute deviation from the median ( $\pm 3\text{MAD}$ ). We then checked for isotopic differences between sexes and type of funerary treatment using Mann–Whitney tests.

**Results:** One individual shows isotopic values consistent with a nonlocal origin. Five more individuals may have originated from a different locality. No statistical differences separate sexes and types of funerary treatment.

**Discussion:** Results suggest a local origin of most of the individuals of SV with the few exceptions pointing especially to an Alpine origin. The low frequency of nonlocals at SV suggest a reduced mobility in this population, or the preeminence of short distance movements undetected by our analyses.

## KEYWORDS

Alps, Celtic populations, late iron age, mobility patterns, stable isotopes

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## 1 | INTRODUCTION

The reconstruction of human mobility and migration in the past is a traditional research topic in anthropology and archaeology. This is especially due to the biological, social, and cultural relevance of these processes, and the involved demographic, economic, social, cultural and political factors (Adey, 2010; Leary, 2014).

Nowadays a standard analytical tool in paleomobility studies is the application of isotopic analyses. The application of these techniques has provided various insights about human movements for a large number of archeological contexts (e.g., Bentley, 2013; Chenery et al., 2010; Fernández-Crespo et al., 2020; Francisci et al., 2020; Frei et al., 2017; Lightfoot et al., 2014; Lösch et al., 2014; Milella et al., 2019; Paladin et al., 2020; Redfern et al., 2016; Siebke et al., 2020; Stark et al., 2020 etc.). Especially during the last decade, a series of isotopic studies have explored mobility and migration in continental Europe during the Late Iron Age (ca. 4th–1st c. BCE) (Grupe et al., 2020; Hauschild et al., 2013; Knipper et al., 2014, 2018; Moghaddam et al., 2016; Moghaddam et al., 2018; Müller-Scheeßel et al., 2020; Oelze et al., 2012; Scheeres et al., 2013, 2014; Sorrentino et al., 2018). This body of research has provided important information about human mobility, especially for Central Europe. Nonetheless, our understanding of human movements and of their sociocultural correlates during this period is still fragmentary, especially for the regions to the south of the Alpine range.

The Late Iron Age (culturally denominated “La Tène”) of Continental Europe is a period characterized by intense demic and cultural exchanges between the regions north to the Alps (Transalpine areas) and those to the south of the Alpine range, like Northeastern Italy (Cisalpine area) (Kruta, 2009; Vitali, 2004, 2011). These processes are consistent with the economic relevance of the alpine areas since Pre-history (Gilck & Poschod, 2021; Hafner & Schwörer, 2018; Putzer et al., 2016), and with its role as a gateway for the transit of objects, people and ideas. For the Iron Age, this is demonstrated by the southward diffusion of material culture (e.g., La Tène swords and brooches) originating in the transalpine regions (Kruta, 2009; Vitali, 2001). Modern archeological theories are increasingly critical about traditional hypotheses about one-way mass migrations at the basis of the observed archeological patterns, rather privileging more nuanced interpretation centered on individual or small group moves and gradual processes (Ancil, 2021 and references therein; Isayev, 2017). In any case, the available data would agree with ancient Greek sources (Appianus, Dionysius of Halicarnassus) in placing the earliest important presence of “Celtic/Latenian” populations in the Italian Peninsula around the 4th century BCE (Grassi, 2009; Kruta, 1977, 1988).

Little is known about the lifestyle, cultural affiliation, and ethnic origin of the “Celtic” groups distributed in the Italian peninsula between the 4th and 1st centuries BCE. Moreover, historical, archeological, and anthropological data are available especially for some of these groups. These include the Boii, the Cenomani, and the Insubri in the North of the Italian peninsula, and the Senoni in the central regions (Grassi, 2009). These populations were characterized not only by their distinct regional distribution and cultural traditions, but also by heterogeneous relationships (conflicts, alliances, peaceful

coexistence) with indigenous Italic, Etruscan, and Roman groups (Gambacurta, 2013; Grassi, 2009). Previous anthropological studies on “Celtic” groups in the Italian Peninsula have especially focused on Boii and Cenomani. The former, distributed in nowadays Emilia Romagna region have been the subject of paleopathological analyses aimed at reconstructing patterns of health and well-being (Brasili, 1992; Brasili et al., 2000) and of paleomobility isotopic studies (Scheeres et al., 2013; Sorrentino et al., 2018). The study by Scheeres et al. (2013) focused on strontium and oxygen isotopic ratios, whereas the analysis of Sorrentino et al. (2018) included a comparison of isotopic (strontium), phenetic (dental non-metrics traits), and archeological variables (funerary variability). Both studies revealed a high proportion of male nonlocal individuals in the analyzed samples, and to several individuals who moved already during childhood. These results offer some insights into the possible socioeconomic features of these populations. Particularly, they seem to suggest (a) a dynamic situation featuring a relatively high frequency of movements, and (b) differences in the latter between sexes. These conclusions confirm expectations based on geographic, historical, and archeological data. The latter point throughout the Iron Age, to a mosaic of contacts and cultural exchanges not only between “Celtic” and local Italic populations but also between Celtic groups distributed on the two sides of the Alpine range (Butti Ronchetti, 2014; Marzatico, 2014; Ramsi, 2014; Vitali, 1996, 2001). Various causes were likely at the basis of these movements. Classical sources, for example, stress the role played by economic and commercial factors, the attraction on transalpine cultures exercised by Mediterranean products such as grapes, figs, wine, and oil, and the need to appropriate new lands for cultivation (Mansuelli, 1978; Vitali, 2011).

Among the economic drivers of mobility, one needs also to include mercenary service, an activity traditionally attributed to these groups (Hauschild, 2013; Vitali, 2011). Especially during the 3rd century BCE, individuals moved across the Alpine range in the service of third parties (Polybius II, 19, 1–4 and II, 34, 21 in Vitali, 2011).

When we shift our focus to the Northeast of the Italian Peninsula, bioarchaeological data on human movements during the late Iron Age are completely lacking. The work by Laffranchi et al. (2016) and Laffranchi and colleagues (Laffranchi et al., 2015, 2016, 2018, 2019; Laffranchi, Charisi, et al., 2020) has contributed to the reconstruction of the diet, exposure to biomechanical and nonspecific stressors, gender roles and social differentiation among the Cenomani (Verona area). From the same group, however, no data are yet available about the presence and frequency of nonlocal individuals, and about the associated mobility and migration processes.

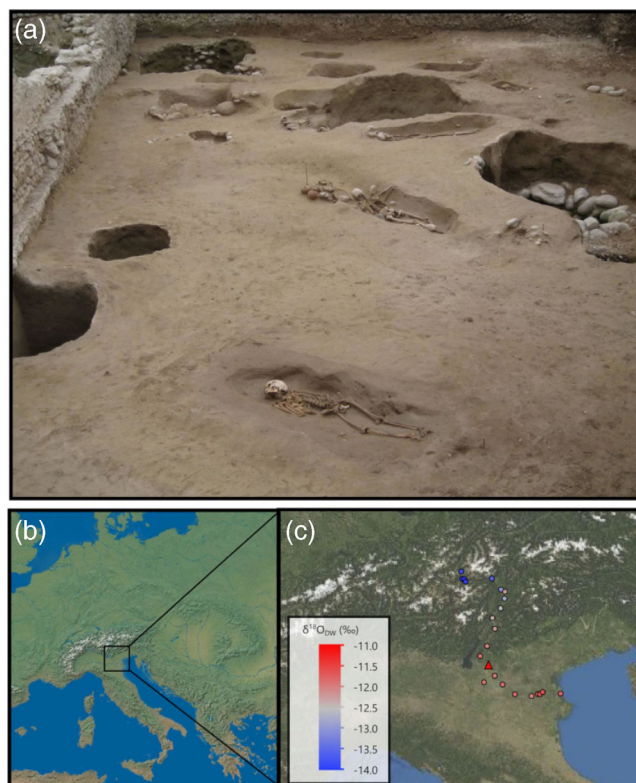
### 1.1 | Insights into past human movements from intraskeletal variability of oxygen and carbon stable isotope ratios

Together with those of strontium ( $^{87}\text{Sr}/^{86}\text{Sr}$ ), isotopic ratios of oxygen ( $\delta^{18}\text{O}$ ) are at the basis of most paleomobility research. By means of ingestion of drinking water and water contained in food, dental and

skeletal phosphate acquire during their formation the  $\delta^{18}\text{O}$  signature of the surrounding environment (D'Angela & Longinelli, 1990, 1993; Delgado Huertas et al., 1995; Longinelli, 1984). The isotopic composition of meteoric precipitation displays a strong geographical trend, being influenced by a set of variables including latitude, distance from the coast, altitude, temperature, and humidity (Lightfoot & O'Connell, 2016; Rozanski et al., 1993). Consequently, estimates of water  $\delta^{18}\text{O}$  based on phosphate isotopic composition can be used to reconstruct past human movements and/or palaeohydrological changes (D'Angela & Longinelli, 1990, 1993; Delgado Huertas et al., 1997; Lightfoot et al., 2014; Lightfoot & O'Connell, 2016; Reynard & Hedges, 2008). Specifically, a deviation in the isotopic signals of dental or skeletal tissues from those of the burial location may provide hints about the possible nonlocal origin of an individual. This interpretation, however, needs to take into account the possible effect of various factors on the  $\delta^{18}\text{O}$  values of water sources. These include, for example, evaporation of surface water and the access of humans and/or animals to rivers, groundwater, local rainwater pools preserving the isotopic signal of a different location (e.g., rivers originating at higher altitudes) (Gat, 1971; Lightfoot & O'Connell, 2016; Pederzani & Britton, 2019).

Oxygen stable isotopes in archaeology are commonly measured in tooth enamel or bone bioapatite (carbonate and phosphate). Compared with carbonate, phosphate offers the advantage of being less prone to taphonomic/diagenetic alterations (Britton et al., 2015; Delgado Huertas et al., 1997; Francisci et al., 2020; Kohn & Cerling, 2002; Luz & Kolodny, 1989). On the other hand, when compared with that from dental enamel, the isotopic composition of bone phosphate is the weighted average of the last 10–25 years of life (Longinelli, 1984; Manolagas, 2000). This plays an obvious role in the type of information that the analysis of these tissues can provide in paleomobility research. Although less frequently applied, isotopic analyses of oxygen in bone phosphate have yielded interesting results in bioarchaeology. Especially for precontact Meso and South American populations, the application of this method has provided important information about the degree of residential mobility in these contexts (Moreiras Reynaga et al., 2021; Toyne et al., 2014; Webb et al., 2013; White et al., 2000, 2004).

Stable isotopes ratios of carbon ( $\delta^{13}\text{C}$ ), although usually applied in paleodietary research, can also provide insights into paleogeography (Eerkens et al., 2014; Hakenbeck et al., 2010). Different types of plants ( $\text{C}_3$  vs.  $\text{C}_4$ ) may indeed present a variable spatial distribution because of different climatic and environmental conditions and/or different cultivation practices.  $\text{C}_3$  plants (e.g., wheat, barley, and the majority of plants and fruits) are typical of cool and wet environments, whereas  $\text{C}_4$  plants (e.g., millet, sorghum, maize, etc.) are well adapted to warm climates, and rare in Europe, with millet being the only known domesticated one during Prehistory. The relative abundance of  $\text{C}_3$  versus  $\text{C}_4$  plants is therefore highly correlated with, and therefore informative about, climatic factors (temperature, precipitation) as well as cultivation strategies (Ehleringer et al., 1997; Laffranchi et al., 2016; Lösch et al., 2006; Teeri & Stowe, 1976).  $\delta^{13}\text{C}$  ratios can also provide information about the consumption of freshwater/marine vs. terrestrial



**FIGURE 1** (a) View of SV upon excavation (photo by S. Thompson, by courtesy of SABAP-VR Soprintendenza archeologia, belle arti e paesaggio per le province di Verona, Rovigo e Vicenza); (b) estimated mean  $\delta^{18}\text{O}_{\text{DW}}$  value for SV (triangle) and mean  $\delta^{18}\text{O}$  water values from various sampling stations along the Adige river (data from Natali et al., 2016)

resources (DeNiro & Epstein, 1978; Schoeninger & DeNiro, 1984; Smith & Epstein, 1971). Individual  $\delta^{13}\text{C}$  values deviating from those of the rest of the population may point to the consumption of different foodstuffs, either due to cultural or social reasons (e.g., intrapopulation access to  $\text{C}_4$  vs.  $\text{C}_3$  plant products based on status, gender, or age) or because of a different geographic origin. The paleoecological information content of  $\delta^{13}\text{C}$ , suggested by a large literature (among others DeNiro & Epstein, 1978; Van der Merwe, 1982; Schoeninger & Moore, 1992) suggests its potential use as a complementary tool in paleomobility research.

When trying to reconstruct past diet and mobility, the interpretation of isotopic data can be informed by intraskeletal differences in collagen turnover rate. Ribs show in general a faster turnover rate than other commonly sampled bones like femur and tibia (Fahy et al., 2017; Hill & Orth, 1998; Parfitt, 2002). The turnover of dentine collagen is, conversely, extremely slow, and its isotopic signal reflects the diet during the time of dentine formation (Beaumont et al., 2013). Accordingly, the analysis of collagen from dentine and from different skeletal elements with different remodeling rates can provide information about intravital patterns in access to specific foods and/or residential patterns.

Such an approach has already provided useful insights from a large series of archaeological contexts (Cheung et al., 2017; Cox &

Sealy, 1997; Frei et al., 2015; Hedges et al., 2007; Lamb et al., 2014; Müller et al., 2003; Pollard et al., 2012; Schroeder et al., 2009; Sealy et al., 1995; Toyne et al., 2017, 2021; Tsutaya et al., 2016; Varalli et al., 2021).

## 1.2 | Archeological and anthropological background

The necropolis of Seminario Vescovile (henceforth SV) was discovered and excavated between 2005 and 2010 in Verona (NE Italy). Preliminary typological analysis of grave goods related this context with the pre-Roman/Celtic culture of the Cenomani. The Cenomani are scarcely documented in the archeological literature, and almost no information is available regarding their geographic origin. The only historical data come from Livius (Livius, *Ab Urbe Condita*, V, 35.1), who refers to their settling in the area between the modern cities of Brescia and Verona during the 5th–4th centuries (Kruta & Manfredi, 1999; Malnati et al., 2004). Throughout the 2nd and 1st centuries BCE this population was progressively integrated into the Roman cultural and political sphere (Cavalieri Manasse, 2004; Grassi, 2009; Malnati et al., 2004). Radiocarbon datings placed the use of SV between the 3rd and 1st century BCE (Laffranchi, 2016; Laffranchi et al., 2015, 2016, 2019).

With a minimum number of 174 inhumated individuals, SV (Figure 1a and b) stands out as one of the largest and better-preserved “Celtic” necropolises in the Italian peninsula. Burials include mostly supine inhumations, with a small number of individuals either prone or on their side (see Table S1). In some cases, burials are provided with “funerary structures” represented by stones marking the edge of the pit and/or covering the burial surface (cf. Laffranchi et al., 2019 for further details).

Grave goods variability (e.g., pottery, pins, coins, rings, and few knives, but no weaponry) suggests a rather homogenous society, with no significant differences between sexes in the type and amount of grave goods, and an apparent absence of vertical social differences in burial treatment (see also Laffranchi, 2016; Laffranchi et al., 2019; Laffranchi, Charisi, et al., 2020).

An intriguing exception is US 2807, the burial of a middle adult male standing out from the rest of the population for its unique archeological and anthropological features (Laffranchi et al., 2015). These include (1) his provision with a grave good item (a probable wooden tub or barrel) that is unique at SV; (2) the oldest  $^{14}\text{C}$  datation for now at SV (2201–2137 cal. BP), and (3) the co-presence of several congenital anomalies (foot polydactyly, bipartite medial cuneiform, dental agenesis—Laffranchi et al., 2015).

A recent series of anthropological and isotopic works have revealed further details about the lifestyle and diet of this population. Patterns of enthesal changes and long bone shape and robusticity suggest differences between the sexes in the performance of daily activities and general exposure to biomechanical stress (Laffranchi, Charisi, et al., 2020). Further biocultural data have been provided by analyses of linear enamel hypoplasia, stable isotopes ratios of carbon and nitrogen, and funerary variability (Laffranchi et al., 2016, 2018, 2019). Overall, the picture emerging from these studies is that of a

population featuring a weak social differentiation and whose members were equally exposed to developmental stressors during growth (Laffranchi et al., 2019). Diet at SV was characterized by a prolonged breastfeeding period (Laffranchi et al., 2018), and almost exclusive reliance on cultivated crops ( $\text{C}_4$  plants, possibly broomcorn and foxtail millet). The diet of males featured a higher intake of animal protein, whereas that of females was characterized by a higher intake of cereals and vegetal proteins (Laffranchi et al., 2016).

Although no previous study investigated human mobility at SV, various factors (geographical, orographic, and archeological) make such an analysis worthwhile. First, the region stands at the crossroad between the Alpine range and the Southern Po Plain and is nowadays only 90 Km away from the Italian Adriatic coast. It features a relatively mild climate, fertile soils, and is crossed by an important waterway (the Adige River) which stands as a natural connection between the Cisalpine and Transalpine areas. The Adige River originates near the Reschen Pass (South Tyrol), has a course of more than 400 Km for finally flowing into the Adriatic Sea. The economic, military, and cultural relevance of the area surrounding SV is further demonstrated by the archeological traces of its occupation before, during, and after Roman times (Cavalieri Manasse, 2004; Laffranchi, 2016; Malnati et al., 2004). The archeological traces of coexistence and cultural contact between the Cenomani and the local Venetic populations, with transalpine groups, and, toward the last centuries BCE, with the Roman cultural sphere, contribute to this dynamic picture (Gambacurta & Ruta Serafini, 2019; Marinetti, 1992; Prosdoci, 1991; Vitali, 2001). All these factors make the Northeast of the Italian peninsula in general, and the region surrounding SV in particular, of great interest from a paleomobility perspective. This was further suggested by previous analyses of  $\delta^{13}\text{C}$  at SV. In the context of rather homogenous population values (mean of  $-15.3\text{‰} \pm 2.2\text{‰}$  V-PDB), some individuals indeed showed markedly depleted ratios (between  $-20$  and  $-19\text{‰}$  V-PDB), suggestive of their possible nonlocal origin (Laffranchi, 2016; Laffranchi et al., 2016). This interpretation was based on various eco-geographical and cultural factors: (a) the relative proximity of SV to subalpine and alpine regions, (b) the historically documented transalpine origin of Cenomani, and (c) the archeological traces documenting contacts between cisalpine and transalpine cultural spheres throughout the 4th–1st centuries. These considerations raise the likelihood that some individuals relocated to SV from more Northern and higher altitude areas. The latter present environmental and climatic characteristics that make them less suitable for the cultivation of millet (Ehleringer et al., 1997; Laffranchi et al., 2016; Paladin et al., 2020). One would therefore expect these nonlocals to show a comparatively depleted carbon isotopic signature, consistent with larger consumption of  $\text{C}_3$  plants. Admittedly, and lacking additional data, this has however remained an exploratory hypothesis deserving further study. Based on these premises, the aim of this work is to explore the presence of nonlocal individuals at SV by means of an analysis of stable isotopes ratio of oxygen from bone phosphate and carbon from bone and dentine collagen. Specifically, our study tries to address three main research questions:

1. What is the frequency of potential nonlocals at SV, and what does it tell about the type of human movements taking place in this population?



2. Is there any pattern among assumed nonlocals based on sex and/or age?
3. Is there an association between the isotopic signature of nonlocality and the type of funerary treatment?

## 2 | MATERIAL AND METHODS

Table 1 shows the distribution of the sample by age and sex. We analyzed 49 individuals representing both sexes and different age classes. The detailed demographic distribution of SV has been previously published by Laffranchi et al. (2016), Laffranchi et al. (2019), and Laffranchi, Charisi, et al. (2020). Adult age-at-death was estimated based on the morphological changes of the pubic symphysis, of the auricular surface of the ilium, and of the sternal end of the 4th left rib or others in case of absence (Brooks & Suchey, 1990; Buckberry & Chamberlain, 2002; İşcan et al., 1984, 1985). We estimated nonadults' age-at-death based on the development and eruption of deciduous and permanent teeth, using diaphyseal measurements, and based on the degrees of epiphyseal fusion (Schaefer et al., 2009; Scheuer & Black, 2000; Ubelaker, 1989). Sex was determined based on the morphology of pubic symphysis, coxal bones, and cranial and mandibular dimorphic traits, following standard anthropological methods collected in Buikstra and Ubelaker (1994).

Following our previous work (see Laffranchi et al., 2019), we grouped nonadults in Nal (ca. 37–42-weeks-old), Nall (0–1-year-old), NallI (>1–5-years-old), NalIV (>5–14-years-old). Adults were subdivided in Young Adults (19–34 years old) and Middle Adults (MA: 35–50 years old). Five individuals were possibly aged over 50 years old, but were included in the MA age class in order to avoid unbalances in sample sizes and associated issues during statistical testing.

### 2.1 | Stable isotopes analysis ( $\delta^{13}\text{C}$ )

Stable carbon and nitrogen isotope ratios from rib bone collagen from SV are published and discussed elsewhere (see Laffranchi et al., 2016,

2018, 2019). We refer the reader to these works for a detailed description of the applied standards and analytical protocols. This study is based on the analysis of 49 individuals for whom both carbon and oxygen data are available. Here we add data for a subsample of 26 adult individuals from whom we processed dentine collagen. The latter was obtained from the dental root (for the major part second premolars and second/third molars), sectioned transversely straight below the crown. In order to minimize the breastfeeding signal, we selected mostly premolars and second/third molars since these teeth start to mineralize during the first years of life and continue to grow until adolescence and early twenties (for M3) (Scheid, 2007; Schroeder et al., 2009). Collagen extraction followed the protocol of Bocherens et al. (1991, 1997) and the quality criteria suggested by Ambrose (1990, 1993) Van Klinken (1999), and DeNiro (1985). We included samples with >1% collagen yield, molar C:N ratio in the range of 2.9–3.6 (DeNiro, 1985), %C between 30% and 47% and %N between 11% and 17.3% (Ambrose, 1990; Van Klinken, 1999). Our aim in analyzing both bone- and dentine collagen was to explore possible isotopic differences between tissues characterized by different turnover rates and therefore informative about different times during the lifetime of an individual (Sealy et al., 1995; Toyne et al., 2017, 2021). If present, these differences may inform about dietary changes throughout an individual's lifetime. The latter, besides their possible link to cultural practices or personal preferences, may also result from individual moves between areas featuring different eco-geographical conditions (see also Eerkens et al., 2014; Hakenbeck et al., 2010; Schroeder et al., 2009). The unique features of inhumation US2807 (see Introduction) suggested to analyze two different teeth (URM2 and LLP4), in order to explore two different phases of the individual's childhood. The dentine closest to the crown margin of M2 forms around 3 years, after initial enamel calcification, followed by formation toward the pulp cavity between ~4.5 and 7.5 years. The enamel calcification of lower P4 is completed around the age of 7 years; the root (and the dentine) continues to form until the age of 14 years (Hillson, 1996; Lamb et al., 2014). The dentine isotopic values of inhumation US2807, namely URM2 and LLP4 should therefore provide information for the age periods roughly between 3 and 7.5 years and subsequently between 7 and 14 years.

Although nitrogen isotope ratios are available for all individuals, in this study we decided to focus only on  $\delta^{13}\text{C}$ . The potential bias played on  $\delta^{15}\text{N}$  by the breastfeeding signal would indeed be too elevated when comparing dentine and bone collagen isotopic values. This issue is also confirmed when screening the isotopic ratios from these two tissues (see Table S1). Our choice to focus on  $\delta^{13}\text{C}$  is also based on the use of carbon as an accessory tracer of mobility by other studies.

Henceforth, we will refer to  $\delta^{13}\text{C}$  from bone and dentine collagen as  $\delta^{13}\text{C}_{\text{bo}}$  and  $\delta^{13}\text{C}_{\text{de}}$  respectively. Analysis of nitrogen and carbon ratios was carried out by means of a Carlo Erba NC1500 (Milan, Italy) elemental analyzer on line with a Delta Plus XP (ThermoQuest, Bremen, Germany) mass spectrometer (EA-IRMS). Commercial  $\text{CO}_2$  and  $\text{N}_2$  were used as the internal standards for the carbon and nitrogen isotopic analyses (see Laffranchi et al., 2016, 2019 for more details).

**TABLE 1** Age and sex distribution of the analyzed individuals

	Females		Males		Sex: NA		Total	
	n	%	n	%	n	%	n	%
YA	9	52.9	11	47.8	0	0	20	40.8
MA	8	47.1	12	52.2	0	0	20	40.8
Nal	0	0	0	0	2	22.2	2	4.1
Nall	0	0	0	0	3	33.3	3	6.1
NallI	0	0	0	0	1	11.1	1	2.0
NalIV	0	0	0	0	3	33.3	3	6.1
Total	17	100	23	100	9	100	49	100

Note: Nal: ca. 37–42 weeks old; Nall: (0–1 year old); NallI: (>1 to 5 years old); NalIV: (>5 to 14 years old); YA: young adults (19–34 years old); MA: middle adults (35–50 years old). Sex: NA: individuals for which it was not possible to determine sex.

## 2.2 | Oxygen ( $\delta^{18}\text{O}$ ) analysis

The protocol to analyze oxygen stable isotopes in bone phosphates follows a complex chemical treatment to purify the samples and to precipitate them as silver phosphate ( $\text{Ag}_3\text{PO}_4$ ) (Crowson et al., 1991; Longinelli, 1965; Tudge, 1960). The preparation of the samples and the MS- measurements were carried out at the Stable Isotope Laboratory of the *Instituto Andaluz de Ciencias de la Tierra* (CSIC-UGR, Granada). Bone phosphate is known to be particularly resistant to diagenetic processes. This is for example demonstrated by analyses of oxygen isotopic ratios from bone phosphate of samples dating 13.000–30.000 years old (Delgado Huertas et al., 1997).

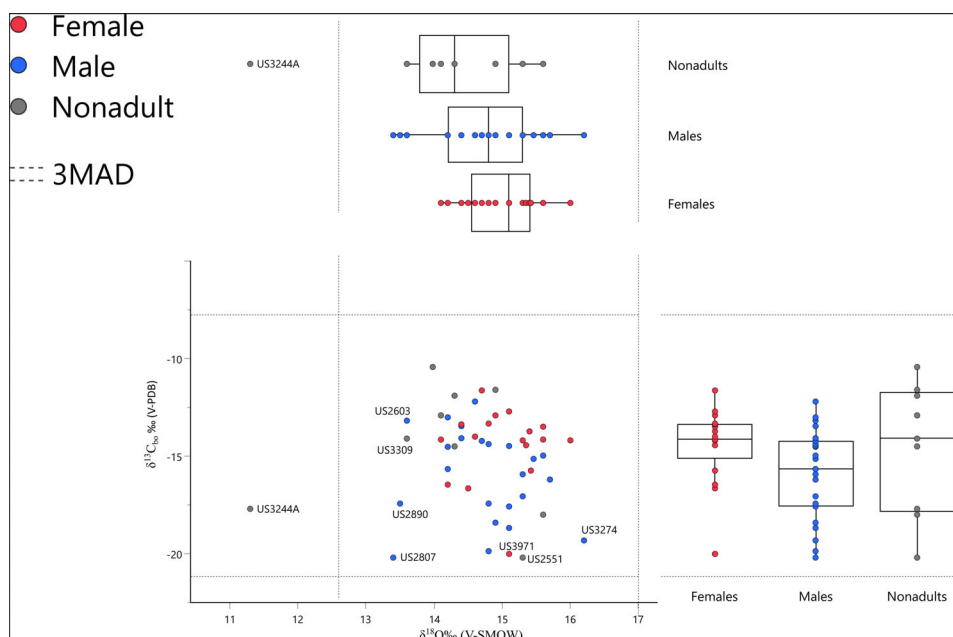
Nonetheless, in this study, we checked for different criteria in order to authenticate our phosphate isotopic values. First, we selected well-preserved bone samples from ribs showing no visual signs of dissolution or recrystallization. The good preservation of the samples, already preliminarily observed macroscopically, and attributable to the fine sand in which the skeletons were found (Laffranchi, 2016), is also suggested by their collagen isotopic data (C and N), which fit the quality criteria suggested by Ambrose (1990, 1993) and DeNiro (1985) (see Table S2).

In order to check for recrystallization processes, we then analyzed five samples by means of a PANalytical X' Pert Pro diffractometer for powder samples (XR Diffraction Unit of the *Instituto Andaluz de Ciencias de la Tierra* -CSIC-UGR, Granada). We selected for this analysis the two samples showing respectively the more positive and more negative isotopic ratios and three additional ones showing values in between these extremes.

For each sample we selected 200–300 mg of bone powder, we removed the organic matter by treating the samples with undiluted hydrogen peroxide ( $\text{H}_2\text{O}_2$ ), and left them for a week at room temperature by stirring them several times a day with a Vortex ZX Classic mixer. This process was repeated several times, renewing the  $\text{H}_2\text{O}_2$  for a few weeks until finally the samples were placed in an oven at a low temperature to

completely evaporate the  $\text{H}_2\text{O}_2$ . Successively, 2 ml of 2 M hydrofluoric acid (HF) was added, and after 24 h, the calcium fluoride ( $\text{CaF}_2$ ) was formed, leaving the  $\text{PO}_4$  in solution. After the centrifugation (to separate the solid), we added to the resulting solution (without solid) 2.2 ml of 2 M potassium hydroxide (KOH). This solution was then treated with a buffer of Silver Nitrate ( $\text{AgNO}_3$ ) + Ammonium Nitrate ( $\text{NH}_4\text{NO}_3$ ) + Ammonium Hydroxide ( $\text{NH}_4\text{OH}$ ) and put into a thermostatic bath (Julabo sw23) at a constant temperature of  $50^\circ$  (increasable up to  $70^\circ$ ). During this process,  $\text{NH}_3$  is released and the phosphates crystallize ( $\text{Ag}_3\text{PO}_4$ ), afterward the samples (pH less than 7.5 but not less than 6.8) were filtered and dried. An internal standard of bone phosphate, magmatic apatite, and phosphorite with known isotopic composition was precipitated (following the same process described above) to verify that no isotopic fractionation has occurred during the precipitation process.

Samples ( $\text{Ag}_3\text{PO}_4$ ) mixed with graphite were placed in silver capsules that fall onto a ceramic column containing a glassy carbon tube at  $1450^\circ\text{C}$  to produce CO (Sharp et al., 2001); this system is coupled on-line via a ConFlo IV interface to a Delta V Plus isotope ratio mass spectrometer (Thermo-Finnigan, Bremen). The CO was separated by chromatography using a helium carrier gas stream. Commercial CO and five different internal and international standards were used for the oxygen isotopic analyses. To avoid memory effects, each sample was analyzed six times. We discarded the first three analyses and calculated the average of the last three. For oxygen 12 internal standards (organic and inorganic material, including  $\text{Ag}_3\text{PO}_4$ ) ranging between  $-27.93\%$  and  $+71.4\%$  (V-SMOW), contrasted with the IAEA international references, IAEA-NO-3, IAEA-C3, NBS-127, USGS35 and USGS34 are commonly used. For this study three internal standards of  $+30.2\%$ ,  $+8.7$ , and  $-27.93\%$  (V-SMOW) have been used. After correction of the mass spectrometer daily drift, the calculated precision from standards systematically interspersed in analytical batches was better than  $\pm 0.2\%$  for phosphate oxygen. The standard for reporting oxygen is V-SMOW.



**FIGURE 2** Plot of the analyzed individuals along  $\delta^{18}\text{O}_{\text{bo}}$  and  $\delta^{13}\text{C}_{\text{bo}}$ , and distribution of adults and nonadults for each isotopic ratio. Dotted lines indicate the upper and lower 3MAD isotopic ranges. US numbers indicate the individuals discussed in the text

To approach the geographical localization of the burials, phosphate  $\delta^{18}\text{O}_{\text{bo}}$  values (V-SMOW) were subsequently converted to the oxygen isotopic composition of drinking water, also referred to as meteoric water ( $\delta^{18}\text{O}_{\text{dw}}$  vs. V-SMOW). For this, we used the equation provided by Daux et al. (2008):  $\delta^{18}\text{O}_{\text{dw}} = 1.54 (\pm 0.09) \times \delta^{18}\text{O}_{\text{p}} - 33.72 (\pm 1.51)$ . These values were then compared with published  $\delta^{18}\text{O}$  water data from the river Adige (D'Angela & Longinelli, 1993; Müller et al., 2003; Natali et al., 2016; Toncala et al., 2017), from precipitation across Italy (Bowen, 2021; Giustini et al., 2016; IAEA/WMO, 2015; Longinelli & Selmo, 2003), and with isotopic ratios obtained from the sampling of local waters. Specifically, we analyzed  $\delta^{18}\text{O}$  (and  $\delta\text{D}$ ) from ten water samples representing two different altitudinal points along the course of the Adige river, three tributaries of the Adige near Verona, as well as local water sources, well- and tap waters from the surroundings of SV (Table S3). The isotopic analyses of the water samples were carried out by injecting 1.8 microliters into a Picarro L-2140i. The replications of internal standards (contrasted with IAEA international standards) indicate errors of less than 0.1‰ and 0.5‰ for  $\delta^{18}\text{O}$  and  $\delta\text{D}$ , respectively.

## 2.3 | Statistical protocol

We first screened our data for the presence of isotopic outliers in  $\delta^{18}\text{O}_{\text{bo}}$ ,  $\delta^{13}\text{C}_{\text{bo}}$ , and  $\delta^{13}\text{C}_{\text{de}}$ , by using as criterion the burial communities median added and subtracted three times the median absolute deviation from the median (henceforth 3MAD) (Lightfoot & O'Connell, 2016; Milella et al., 2019). We performed the same procedure focusing on the difference between  $\delta^{13}\text{C}_{\text{bo}}$  and  $\delta^{13}\text{C}_{\text{de}}$  (henceforth  $\Delta^{13}\text{C}_{\text{bo-de}}$ ). We also tested

for differences between  $\delta^{13}\text{C}$  from bone and dentine collagen comparing the two datasets with a Mann–Whitney  $U$  test.

Previous analyses highlighted a significant difference in  $\delta^{13}\text{C}_{\text{bo}}$  between sexes, a result pointing to a higher contribution of cereals and vegetal proteins to the diet of females (see Laffranchi et al., 2016). To minimize the possible bias of dietary differences on our data, we, therefore, decided to compare sexes for  $\delta^{18}\text{O}_{\text{bo}}$  and  $\Delta^{13}\text{C}_{\text{bo-de}}$  using Mann–Whitney  $U$  tests.

We then grouped all individuals according to the presence or absence of three basic funerary variables: the presence or absence of grave goods, the position of the skeleton (supine or not), and the presence of funerary structures (see introduction).

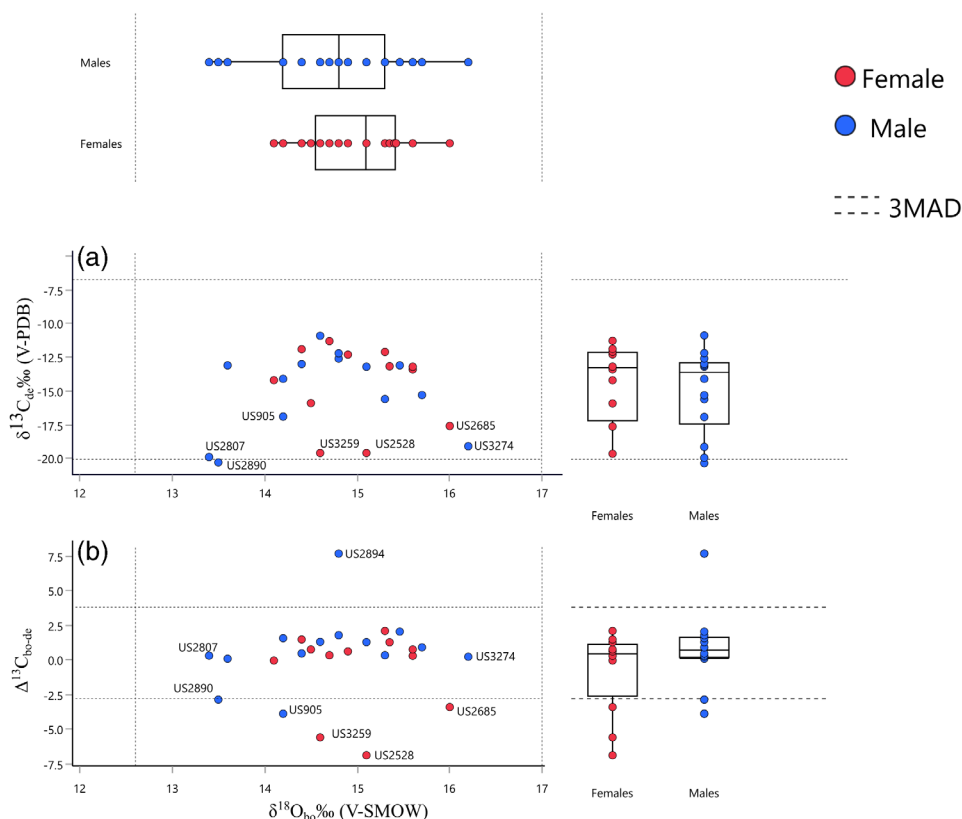
We then compared the resulting groups for  $\delta^{18}\text{O}_{\text{bo}}$  and  $\Delta^{13}\text{C}_{\text{bo-de}}$  through Mann–Whitney  $U$  tests. We performed all analyses and plots in JMP, setting alpha = 0.05.

## 3 | RESULTS

Table S1 presents all demographic, isotopic, and funerary data. Figures 2 and 3 plot the ranges of  $\delta^{18}\text{O}_{\text{bo}}$ ,  $\delta^{13}\text{C}_{\text{bo}}$ ,  $\delta^{13}\text{C}_{\text{de}}$ , and  $\Delta^{13}\text{C}_{\text{bo-de}}$ .

### 3.1 | Assessment of sample preservation

All carbon and nitrogen isotopic values fit the quality criteria and these are presented in Table S2, as recommended by Szpak et al. (2017). Individuals US3274 and US3244A show the more positive and more



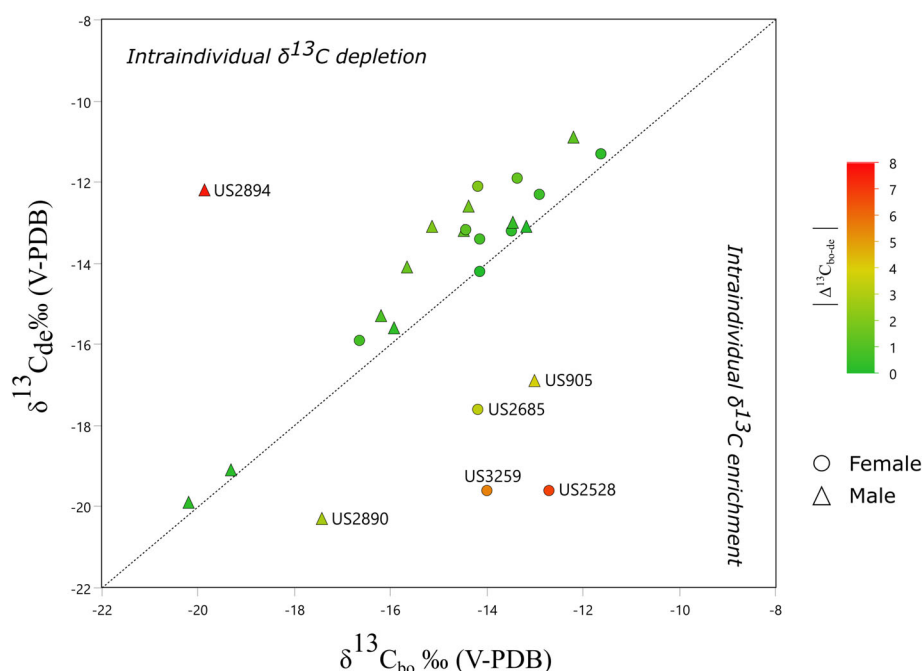
**FIGURE 3** Plot of  $\delta^{18}\text{O}_{\text{bo}}$  versus  $\delta^{13}\text{C}_{\text{de}}$  (a), and  $\Delta^{13}\text{C}_{\text{bo-de}}$  (difference between  $\delta^{13}\text{C}$  values from bone and dentine collagen) (b). Boxplots visualize the distribution of each isotopic variable according to sex. Dotted lines indicate the upper and lower 3MAD isotopic ranges. US numbers indicate the individuals discussed in the text

negative  $\delta^{18}\text{O}_{\text{bo}}$  values, respectively. The X-ray diffraction patterns of these samples and the additional three (US 2807, US 3309, and US 3243) selected from those falling inside this range do not show the presence of recrystallization processes (see Figure S1).

### 3.2 | Oxygen isotopic ratios

$\delta^{18}\text{O}_{\text{bo}}$  ranges from 16.2‰ to 11.3 ‰ (mean:  $14.7 \pm 0.8\%$  V-SMOW). Only one individual (US3244A, Nall) with a markedly

depleted isotopic signature (11.0‰ V-SMOW), falls outside the  $\pm 3\text{MAD}$  range, (Figure 2). Even though not statistical outliers, four additional individuals (US2603, 2807, 2890, and 3309) present particularly depleted values. These include three males (one young adult and two middle adults) and one infant of 2–3 months. Another male (US3274: middle adult) presents the most enriched  $\delta^{18}\text{O}_{\text{bo}}$  value (16.0 ‰) (Figure 2). When converted to  $\delta^{18}\text{O}_{\text{Dw}}$  these values correspond to a sample average of  $-11.03 \pm 1.3\%$ . Converted values for individuals US3244A, 2603, 2807, 2890, 3309, and 3274 are  $-16.3\%$ ,  $-12.8\%$ ,  $-13.1\%$ ,  $-12.9\%$ ,  $-12.8\%$ , and  $-8.8\%$  V-SMOW, respectively.



**FIGURE 4** Plot of  $\delta^{13}\text{C}_{\text{bo}}$  versus  $\delta^{13}\text{C}_{\text{de}}$ . Male and females are indicated by triangles and circles, respectively. Individual deviations from a theoretical perfect positive correlation between  $\delta^{13}\text{C}_{\text{bo}}$  and  $\delta^{13}\text{C}_{\text{de}}$  are further highlighted by means of a color code expressing the absolute difference between variables

**TABLE 2** Results of Mann–Whitney tests for the comparison of  $\delta^{18}\text{O}_{\text{bo}}$  and  $\delta^{13}\text{C}_{\text{bo-de}}$  between sexes (a) and funerary treatment (b–d)

(a)	Females				Males				<i>p</i> (Mann–Whitney <i>U</i> test)
	<i>n</i>	Mean	Median	SD	<i>n</i>	Mean	Median	SD	
$\delta^{18}\text{O}_{\text{bo}}$	17	15.0	15.1	0.5	23	14.8	14.8	0.7	0.29
$\Delta^{13}\text{C}_{\text{bo-de}}$ <sup>a</sup>	12	−0.7	0.5	2.9	14	0.8	0.7	2.6	0.33
(b)	Supine				Prone or on the side				<i>p</i> (Mann–Whitney <i>U</i> test)
	<i>n</i>	Mean	Median	SD	<i>n</i>	Mean	Median	SD	
$\delta^{18}\text{O}_{\text{bo}}$	39	14.7	14.8	0.8	10	14.9	15.0	0.8	0.71
$\Delta^{13}\text{C}_{\text{bo-de}}$ <sup>a</sup>	22	0.0	0.4	3.0	4	0.8	0.8	0.6	0.64
(c)	Without grave goods				With grave goods				<i>p</i> (Mann–Whitney <i>U</i> test)
	<i>n</i>	Mean	Median	SD	<i>n</i>	Mean	Median	SD	
$\delta^{18}\text{O}_{\text{bo}}$	9	14.3	14.7	1.2	40	14.8	14.9	0.7	0.18
$\Delta^{13}\text{C}_{\text{bo-de}}$ <sup>a</sup>	2	−2.6	−2.6	4.2	24	0.3	0.7	2.7	0.21
(d)	Burial without structure				Burial with structure				<i>p</i> (Mann–Whitney <i>U</i> test)
	<i>n</i>	Mean	Median	SD	<i>n</i>	Mean	Median	SD	
$\delta^{18}\text{O}_{\text{bo}}$	42	14.7	14.8	0.8	7	15.0	15.1	0.7	0.50
$\Delta^{13}\text{C}_{\text{bo-de}}$ <sup>a</sup>	21	0.2	0.8	2.0	5	−0.4	0.3	5.4	0.31

Note: *n*: number of individuals; SD: standard deviation. Data on  $\delta^{13}\text{C}_{\text{bo-de}}$  are available only for adults.

<sup>a</sup>Only adult individuals.



Oxygen isotopic ratios from our water samples range from  $-7.7\text{‰}$  (Avesa stream, Verona) to  $-12\text{‰}$  (Adige River, upper course Adige River) (Figure S2 and Table S3).

### 3.3 | Carbon isotopic ratios

$\delta^{13}\text{C}_{\text{bo}}$  and  $\delta^{13}\text{C}_{\text{de}}$  range respectively from  $-21.2\text{‰}$  to  $-7.7\text{‰}$  (mean:  $-15.15 \pm 2.8\text{‰}$  V-PDB), and from  $-20.3\text{‰}$  to  $-6.7\text{‰}$  (mean:  $-14.7 \pm 3.4\text{‰}$  V-PDB). We do not find outliers for  $\delta^{13}\text{C}_{\text{bo}}$  although we point out four individuals, with particularly depleted  $\delta^{13}\text{C}_{\text{bo}}$  values. These are US3971 (young adult female), US2551 (nonadult, NaIV), and US2807 (middle adult male) (Figure 2). The only outlier for  $\delta^{13}\text{C}_{\text{de}}$  with a particularly depleted isotopic value ( $-20.3\text{‰}$  V-PDB) is US2890 (young adult male) (Figure 3a).

Males and females show similar ranges for  $\delta^{13}\text{C}_{\text{de}}$ , whereas for  $\delta^{13}\text{C}_{\text{bo}}$  females show less dispersed values, with one individual (US3971, young adult female) falling well outside the isotopic range for this sex ( $-20.0\text{‰}$  V-PDB).

Individual  $\Delta^{13}\text{C}_{\text{bo-de}}$  values present an interesting variability (Figure 3b and 4). First, most of the sample falls in a rather narrow range (mean:  $0.1 \pm 2.8$ ), pointing to, on average, a minimal isotopic shift between bone and dentine. This is further demonstrated by the lack of statistically significant differences between the two types of samples for  $\delta^{13}\text{C}$  (Table S4). Three individuals, however, stand out for their large  $\Delta^{13}\text{C}_{\text{bo-de}}$  values. Two females (US3259 and US2528, both young adults) show  $\delta^{13}\text{C}_{\text{bo}}$  values that are enriched compared with their  $\delta^{13}\text{C}_{\text{de}}$  values (Figures 3b and 4). The opposite situation ( $\delta^{13}\text{C}_{\text{bo}}$  depleted compared with  $\delta^{13}\text{C}_{\text{de}}$ ) characterizes the middle adult male US2894. Smaller values of  $\Delta^{13}\text{C}_{\text{bo-de}}$  are also shown by US2890 and US905 (young adult males) and US2685 (middle adult female) (Figures 3b and 4).

Formal statistical tests show no significant difference between sexes or funerary features for  $\Delta^{13}\text{C}_{\text{bo-de}}$  and  $\delta^{18}\text{O}_{\text{bo}}$  (Table 2).

Finally, the comparison of  $\delta^{13}\text{C}_{\text{de}}$  from the two teeth of the “funerary/paleopathological outlier” US2807 highlights a minimal shift ( $0.2\text{‰}$ ) from URM2 ( $-20.1\text{‰}$  V-PDB) to LLP4 ( $-19.9\text{‰}$  V-PDB).

## 4 | DISCUSSION

Before discussing our results, it is worth mentioning some issues affecting our analyses. These relate to the size and demographic composition of our sample, and the analyzed elements and tissues.

Our sample size is admittedly small, and this becomes important when evaluating the power of our statistical analyses. This cautionary note seems particularly important when considering the sex bias in our sample (17 females and 23 males). Having larger subsamples of sexed individuals would allow a more solid exploration of the possible links between mobility, sex, and gender. Finally, the inclusion of other stable isotope elements and different skeletal tissues (e.g.,  $\delta^{18}\text{O}$  and  $^{87}\text{Sr}/^{86}\text{Sr}$  from tooth enamel,  $\delta^{34}\text{S}$  from bone collagen) may allow refining the picture emerged from this study.

### 4.1 | What is the frequency of potential nonlocals at SV, and what does it tell about the type of human movements in this population?

Oxygen isotopic values at SV show a low variability and indicate a source of drinking water featuring relatively constant and homogeneous isotopic characteristics.

Based on the position of the site, and the water isotopic data, it is plausible to identify this source with the Adige river. This, in turn, suggests that most of the individuals spent their adult life in the surrounding of SV. The only individual showing a clearly different  $\delta^{18}\text{O}_{\text{bo}}$  value is US 3244A. This 3–6-months-old nonadult was likely breastfed at the time of death (as further suggested by the elevated nitrogen isotopic ratio) (also see Laffranchi et al., 2018). On the other end, the breastfeeding effect seems not to be reflected in the observed  $\delta^{18}\text{O}_{\text{bo}}$  value (Britton et al., 2015) which is the lowest one in the analyzed sample. The observed  $\delta^{18}\text{O}_{\text{bo}}$  value would therefore reflect that of the mother. Either this infant was born “locally” (i.e., in the surrounding of SV) from a nonlocal woman, or both arrived at SV from somewhere else. Although indicating a specific geographic location based on isotopic values is notoriously difficult (cf. Lightfoot & O'Connell, 2016; Milella et al., 2019), some insight may be obtained by comparing calculated  $\delta^{18}\text{O}_{\text{dw}}$  with modern data from rivers, springs, and rainwater. The conversion of  $\delta^{18}\text{O}_{\text{ph}}$  to  $\delta^{18}\text{O}_{\text{dw}}$  for US3244A results in a value of  $-16\text{‰}$  V-SMOW (Table S1), which indicates a higher altitude (mountain) environment, versus a mean value for the rest of the burial community of  $-10.9 \pm 1\text{‰}$  V-SMOW. The latter range is consistent with local waters (Figure S2) and published  $\delta^{18}\text{O}$  values for the Adige river in the area of Verona (average:  $-11.9 \pm 0.6$  considering the measurements from Parona, 6 km north from SV– Natali et al., 2016), although slightly different from rainfall  $\delta^{18}\text{O}$  values for the same area ( $-7.7\text{‰} \pm 2\text{‰}$ –Longinelli & Selmo, 2003 and  $-7.1\text{‰} \pm 3.1\text{‰}$ –Bowen & Revenaugh, 2003; Bowen, 2021, <http://www.waterisotopes.org>). Giustini et al. (2016) highlight homogenous rainfall oxygen isotopic values (between  $-7\text{‰}$  and  $-8\text{‰}$ ) for the Northeastern Po plain (Verona:  $-7.65\text{‰}$ ) (see figure 8 and supplementary data in Giustini et al., 2016). Conversely, the isotopic ratio of US3244A (and/or its mother we probably did not detect in our burial community) would point to a location featuring high altitude (Giustini et al., 2016; Natali et al., 2016). Particularly depleted isotopic values suggestive of mountain environments are also shown by US2603, 2807, 2890, and 3309 (three adult males and one infant of 2–3 months). The particularly negative  $\delta^{18}\text{O}$  values of these samples allow excluding a diagenetic effect. Phosphate recrystallization in equilibrium with local meteoric waters (whose  $\delta^{18}\text{O}$  ranges between  $-6$  and  $-8$ –Giustini et al., 2016) and annual soil temperature of  $15^\circ\text{C}$  would make us expect higher or less negative values than those observed. These results further confirm therefore the good quality of our samples.

Regarding the location of these high-altitude environments, the most likely hypothesis is that these individuals arrived at SV from a location in the Alpine area. Published  $\delta^{18}\text{O}$  values for the upper stretch of the Adige river (elevation above 180 m) are indeed on average  $-12.9 \pm 0.7$  V-SMOW, with the most depleted values found at

sampling locations above 880 m (Figures 1c and S2b) (Natali et al., 2016). The inverse correlation between elevation and  $\delta^{18}\text{O}$  is further demonstrated by our water sample from the upper stretch of the Adige (Bolzano, 262 m:  $-12.27\text{‰}$ , Figure S2a). Similarly, published rainfall  $\delta^{18}\text{O}$  values show the more negative values in the Alpine area and, for isolated locations, the Central Apennines (Giustini et al., 2016). Compared with the alpine area the Apennines seem, however, an unlikely place of origin for US3244A, US2603, 2807, 2890, and 3309 based on the geographic location and the archeological features of the analyzed necropolis. First, SV is closer to the Alps, to which it is connected by a main waterway (Adige). Second, the available archeological data (still under study) point to a connection (at least cultural) between SV and transalpine areas. This is for example suggested by the presence of pins of transalpine typologies and ceramics carrying Rhaetian Lepontian inscriptions (Marchesini & Stifter, 2018; Solinas, 2015).

Another male (US3274: middle adult) presents the most enriched  $\delta^{18}\text{O}_{\text{bo}}$  value (16.0 ‰). When combined with his depleted  $\delta^{13}\text{C}_{\text{bo}}$  and  $\delta^{13}\text{C}_{\text{de}}$  values this may cautiously suggest his origin from an area lacking rivers with high-elevation recharge areas, that is, an area of plains, surrounded by mountains of low altitude (e.g., more southern regions—cf. Milella et al., 2019; Prowse et al., 2004). We want to stress that, given the large 3MAD range at SV, and the large error associated with the use of  $\delta^{18}\text{O}_{\text{pw}}$  for indicating a geographic origin (Lightfoot & O'Connell, 2016) these hypotheses need to be considered with caution. Furthermore, our interpretation needs to take into account a series of factors, besides geographic origin, potentially influencing the observed  $\delta^{18}\text{O}_{\text{bo}}$  values. These include food preparation techniques (e.g., cooking), consumption of imported foodstuff, physiological, and metabolic factors, such as body size, nutritional stress, disease, amount of water in the diet (Brettell et al., 2012; Lightfoot & O'Connell, 2016; Moreiras Reynaga et al., 2021; Pederzani & Britton, 2019; White et al., 2000).

As mentioned, the choice to (cautiously) consider  $\delta^{13}\text{C}$  as a potential marker of mobility is suggested by the correlation between this variable and environmental factors. In the case of SV, the cultivation of millet, although possible only during spring–summer, resulted in a strong  $\text{C}_4$  signal in this population (Laffranchi, 2016; Laffranchi et al., 2016). The cultivation of millet in the Po plain is documented since the Bronze Age (Tafuri et al., 2009; Tafuri et al., 2018; Varalli et al., 2016) and continued to be practiced during Late Antiquity and early Middle Ages (Ganzarolli et al., 2018; Laffranchi, Mazzucchi, et al., 2020; Marinato, 2016, 2017, 2019; Maxwell, 2019). In contrast, the low minimum temperatures characterizing mountain areas make the latter incompatible with the cultivation of  $\text{C}_4$  plants (Teeri & Stowe, 1976). This is further confirmed by a recent isotopic analysis of Early medieval contexts from the Italian Alps showing a substantial reliance on  $\text{C}_3$  plants, and, in general, more depleted carbon isotopic ratios at higher altitudes (Paladin et al., 2020).

Clearly,  $\delta^{13}\text{C}$  values per se cannot point unambiguously to an individual's nonlocal origin, since they may be related to personal dietary preferences and/or cultural customs. However, in those cases where both oxygen and carbon isotopic ratios fall outside (or on the edge) of

the sample range, we may try to postulate some more explicit hypotheses. This is the case, for example, of two of the potential nonlocal males based on  $\delta^{18}\text{O}_{\text{bo}}$  (US2807 and 2890), who also show some of the more depleted  $\delta^{13}\text{C}_{\text{de}}$  values (for US 2807 also for  $\delta^{13}\text{C}_{\text{bo}}$ ) in the sample. Both oxygen and carbon isotopic ratios would support therefore a nonlocal origin of these individuals.

The differences between carbon isotopic values from bone and dentine collagen deserve some further consideration. We recall that our aim in comparing these types of data was exploring intraindividual lifetime differences potentially related to changes in diet and/or mobility. A change in diet between infancy and late adulthood is indeed suggested for three males (US 905, 2890, and 2894) and three females (US 2528, 2685, and 3259). Of these six cases, three females' and two males'  $\Delta^{13}\text{C}_{\text{bo-de}}$  values are consistent with a shift toward a higher dietary contribution of  $\text{C}_4$  plants. Previous analyses of SV highlighted the important dietary contribution of  $\text{C}_4$  plants (likely millet) in this population (see Laffranchi et al., 2016). Furthermore, all inhumations at SV have shown a certain variability in  $\delta^{13}\text{C}$  from bone collagen with an absolute mean difference of minimal 0.4, and maximal 2.7 (see Laffranchi et al., 2018). In contrast, the  $\Delta^{13}\text{C}_{\text{bo-de}}$  values for the five individuals discussed here show an absolute difference of minimum 3 and maximum 8. Considering these data, the depleted dentine values of these individuals may be related to them having spent their infancy in a location featuring less availability of  $\text{C}_4$  plants followed by their movement (at least during the last years before death) to SV. A lack of relocation during the last years before death is also suggested by the fact that  $\Delta^{13}\text{C}_{\text{bo-de}}$  outliers tend to fall in the  $\delta^{18}\text{O}$  range of the population. The discussion of the isotopic values of the middle adult male US2894 with a largely positive  $\Delta^{13}\text{C}_{\text{bo-de}}$  (depleted bone isotopic value) is more difficult. This result may be related to a specific diet during infancy (e.g., during the weaning process) including a high contribution of  $\text{C}_4$  plant products, followed by an adult diet more based on  $\text{C}_3$  resources. We cannot establish if this was due to dietary preferences, high consumption of proteins from animals feeding on  $\text{C}_3$  plants (note that the same individual also shows the highest nitrogen isotopic value among adults at SV), a recent movement to SV from somewhere else, or to a combination of these factors.

Boiling down these considerations to actual numbers, and applying a parsimonious approach, the frequency of nonlocals would be somewhere between 1/49 (2%) and 6/49 (12%). Comparative data for continental European Late Iron Age contexts are available for Nebringen (Germany, 400–250 BCE), the Glauberg (Germany, ca. 400 BCE), Monte Biele (Italy, 5th–3rd c. BCE), Monterenzio Vecchio (Italy, 4th–3rd c. BCE), Münsingen Rain (Switzerland, ca. 450–150 BCE), Basel Gasfabrik (Switzerland, 200–80 BCE), Radovesice I, Radovesice II and Kutná Hora (Bohemia, 380–250 BCE) (Hauschild et al., 2013; Knipper et al., 2014, 2018; Moghaddam et al., 2016; Scheeres et al., 2013, 2014; Sorrentino et al., 2018). It should be noted however that none of these studies used the same approach employed here. Rather, they usually include the analysis of strontium and oxygen isotopic ratios from dental enamel, and/or sulfur from bone collagen. The criteria used to define local isotopic

ranges also differ from those employed in our study (3MAD). All these considerations make it clear that we can only loosely compare our results with those from these studies, and just in terms of the relative numerosity of nonlocals. Frequencies of nonlocals range from a minimum of ca. 11% (4/35) in Radovesice (Scheeres et al., 2014) to higher frequencies like the 42% (8/19) at the princely seat of Glauberg (Knipper et al., 2014) and 57% (13/23) at Monterenzio Vecchio (Sorrentino et al., 2018). SV would therefore lie in the lower range of these percentages, a result for which we can propose various, and not mutually exclusive explanations. The aforementioned methodological differences are important and likely to influence the relative frequency of isotopic outliers in a sample. Differences between the demographic and the economic composition of analyzed population may also play a role, especially if the sex, age, and/or social standing and profession of an individual made them more (or less) likely to move. The type of network each population is part of (economic, cultural, etc.) is also likely to influence the degree of mobility of its members. We also need to question the reliability of our analytical approach in capturing various scales of human movement. In particular, an important point to consider is the difference between mobility and migration (Kern, 2012; Nehlich et al., 2009; Tilly, 1978), two terms that are often used as synonyms although they indicate different phenomena. We consider mobility processes those involving regional and periodic moves in one's home region, whereas migrations would include discrete relocation over long distances (Nehlich et al., 2009; Tilly, 1978). Climatic similarities make it possible that a large part of short-distance mobility at SV was left undetected by our analyses, which would be more sensitive to long-distance movements. The picture emerging from this study would therefore be an underestimation of the actual frequency of mobility in the analyzed population.

As mentioned when discussing the limitation of our study, we plan to extend our analyses by including other elements (strontium, sulfur) and  $\delta^{18}\text{O}$  from dental enamel. Besides providing a better basis for comparison with other studies, these data would allow more insights about the types of mobility in this context.

## 4.2 | Is there any pattern among assumed nonlocals based on sex and/or age?

At both Nebringen and Monte Biele nonlocals or mobile individuals were mainly males (Scheeres et al., 2013), and a similar conclusion was reached for Radovesice and Kutná Hora (Scheeres et al., 2014). For Münsigen Rain (Hauschild et al., 2013; Moghaddam et al., 2016) the frequency of nonlocals is relatively low (14.7% according to Hauschild et al., 2013) with an equal distribution between the sexes. Conversely, data from the Glauberg and Basel Gasfabrik highlight a higher female mobility (Knipper et al., 2014, 2018). At SV, the four adults with  $\delta^{18}\text{O}_{\text{bo}}$  values deviating from the rest of the burial community are males, whereas the six individuals showing large deviations between dentine and bone collagen include an equal number of both sexes (three males and three females). Taken together, these results suggest a slightly higher mobility for males. Our previous works on

entheseal changes (Laffranchi, Charisi, et al., 2020) at SV pointed at differences between sexes in physical activity. Males appear to have experienced higher levels of biomechanical stress than females, likely due to the presence in this society of a sex subdivision of labor. The involvement of males in different professions and activities may in turn have influenced their relative likelihood to move.

## 4.3 | Is there an association between the isotopic signature of postulated nonlocality and the type of funerary treatment (body position, presence of grave goods)?

Our analyses did not highlight any association between isotopic data and the three selected funerary variables. This in turn suggests a lack of association between geographic origin and funerary treatment. Our result is not surprising since social status is unlikely to follow a simplistic dichotomy between “locals” and “nonlocals.” Additional factors, such as specific geographic origin, the timing of movement, kinship relationship, in conjunction with processes of cultural integration are likely to lead to complex, fluid, and heterogeneous scenarios (Eckardt, 2010; Laffranchi et al., 2019; Levitt, 2018; Milella et al., 2019).

The unsuitability of simplistic categories and the need for nuanced interpretation are well exemplified by the “funerary outlier male” US2807. The isotopic ratios from bones and teeth depict in this case a diachronic enrichment in  $\delta^{13}\text{C}$ . Furthermore, he stands out for presenting the most depleted  $\delta^{13}\text{C}_{\text{bo}}$  at SV, and one of the more depleted  $\delta^{18}\text{O}_{\text{bo}}$ . The preliminary archeological interpretation of the wooden container associated with this burial is of a small tub or barrel, an object undocumented so far in other necropolises of La Tène chronology in the Italian peninsula (Laffranchi et al., 2015). According to ancient Roman and Greek sources (Pliny, Strabo, and Caesar), the wooden barrel was a container largely used among “Celtic” populations (e.g., for storing wine—Plin., Nat. Hist. XIV, 132). Interestingly, archeological remains of barrels have been found along the courses of the rivers Rhine, Danube, and Rhone, in Switzerland, along the French Mediterranean coast, and in Great Britain, and all date back to the 1st–3rd century AD (Baratta, 1994). The wooden object associated with the middle adult male (US 2807) may therefore represent not only a *unicum* for the Italian peninsula but also one of the earliest documented barrels in Continental Europe. Further typological and archeological analyses are needed to corroborate this preliminary hypothesis, and the study of this particular object as well as the grave goods typology of SV is ongoing (Salzani, Personal communication).

Comparing this information with the isotopic and radiocarbon data, it is tempting to propose a specific “residential history” of this individual. It is possible that the male (US2807) originated from a high altitude, possibly Alpine region ( $\delta^{18}\text{O}_{\text{bo}}$  and  $\delta^{13}\text{C}$  data), and was among the first “Celtic” settlers in the area of Verona ( $^{14}\text{C}$  data), where he died relatively shortly after his arrival (intraskeletal and intertooth  $\delta^{13}\text{C}$  data;  $\Delta^{13}\text{C}_{\text{bo-de}}$  data). Naturally, although suggestive, this is only a preliminary hypothesis that will have to be explored more

extensively through biogeochemical and biomolecular analyses (additional isotopic analyses, additional radiocarbon dating, and ancient DNA), and by more detailed scrutiny of the different typological phases of the necropolis.

## 5 | CONCLUSIONS

In this study, we investigated the presence of nonlocals at Seminario Vescovile (Northeastern Italy, 3rd–1st century BCE) by means of an analysis of  $\delta^{13}\text{C}$  from bone and dentine collagen and  $\delta^{18}\text{O}$  from bone phosphate. Results suggest a nonlocal origin for one individual, and possibly for other five, with no significant pattern according to sex or funerary treatment. With one exception, nonlocals appear to have moved to SV from a higher altitude, possibly an alpine environment. Overall, our results depict a population featuring reduced levels of residential mobility or mostly short-distance movements. At the same time, the possible alpine origin of the nonlocal individuals confirms expectations based on historical sources and archeological data about the pre-Roman populations of Northern Italy. This study is the first to explore residential mobility in a “Celtic” population in the northeast of the Italian peninsula, a crucial area for the cultural and demic exchanges between Mediterranean and central European territories. Accordingly, our data contribute to a better understanding of the heterogeneous processes shaping the cultural and biological variability of the Italian peninsula during the last centuries BCE.

This research opens various research questions. These include (a) what kind of movements (long-vs. short distance mobility, frequency of nonlocals, sex and age patterns) characterized the entire burial community of SV? (b) What genetic variation characterized SV, and what genetic relationships linked this population with other, transalpine “Celtic” groups? (c) What kind of relationship linked mobility, kinship patterns, and social organization in this context, and how do these patterns compare with other, transalpine populations? Planned isotopic, aDNA, and archeological analyses will provide the opportunity to address these questions.

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## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

## DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article.

## AUTHOR CONTRIBUTIONS

**Zita Laffranchi:** Conceptualization (lead); data curation (lead); formal analysis (equal); funding acquisition (equal); investigation (lead); methodology (equal); project administration (equal); resources (equal); validation (equal); visualization (equal); writing – original draft (lead); writing – review and editing (lead). **Arsenio Granados-Torres:** Conceptualization (supporting); data curation (equal); formal analysis (supporting); investigation (supporting); methodology (equal); validation (supporting); writing – review and editing (supporting). **Sandra Lösch:** Conceptualization (supporting); funding acquisition (supporting); investigation (supporting); methodology (supporting); writing – review and editing (equal). **Albert Zink:** Conceptualization (supporting); funding acquisition (lead); project administration (lead); supervision (equal); writing – review and editing (supporting). **Irene Dori:** Writing – review and editing (supporting). **Antonio Delgado-Huertas:** Conceptualization (equal); data curation (equal); funding acquisition (lead); investigation (equal); methodology (lead); project administration (equal); resources (lead); software (equal); supervision (equal); validation (equal); writing – original draft (equal); writing – review and editing (equal). **Marco Milella:** Conceptualization (equal); data curation (equal); formal analysis (lead); funding acquisition (lead); investigation (lead); methodology (lead); project administration (lead); resources (equal); software (equal); supervision (lead); validation (equal); visualization (lead); writing – original draft (lead); writing – review and editing (lead).

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## REFERENCES

- Adey, P. (2010). *Mobility*. Routledge.
- Ambrose, S. H. (1990). Preparation and characterization of bone and tooth collagen for isotopic analysis. *Journal of Archaeological Science*, 17, 431–451. [https://doi.org/10.1016/0305-4403\(90\)90007-R](https://doi.org/10.1016/0305-4403(90)90007-R)
- Ambrose, S. H. (1993). Isotopic analysis of paleodiets: Methodological and interpretive considerations. In M. K. Sanford (Ed.), *Investigations of*



- ancient human tissue – *Chemical analyses in anthropology* (pp. 59–130). Gordon and Breach.
- Ancil, M. J. (2021). Ancient celts: A reconsideration of Celtic identity through dental nonmetric trait analysis. (Unpublished doctoral dissertation) John Moores University, Liverpool (UK). <http://researchonline.ljmu.ac.uk/id/eprint/14244/>
- Baratta, G. (1994). Circa Alpes ligneis vasis condunt circulisque cingunt. *Archeologia Classica*, 46, 233–260. L'Erma di Bretschneider. <https://www.jstor.org/stable/44365781>
- 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(2), 277–295. <https://doi.org/10.1111/j.1475-4754.2012.00682.x>
- Bentley, R. A. (2013). Mobility and the diversity of early Neolithic lives: Isotopic evidence from skeletons. *Journal of Anthropological Archaeology*, 32(3), 303–312. <https://doi.org/10.1016/j.jaa.2012.01.009>
- Bocherens, H., Biliou, D., Patou-Mathis, M., Bonjean, D., Otte, M., & Mariotti, A. (1997). Paleobiological implications of the isotopic signatures ( $^{13}\text{C}$ ,  $^{15}\text{N}$ ) of fossil mammal collagen in Scladina cave (Sclayn, Belgium). *Quaternary Research*, 48(3), 370–380. <https://doi.org/10.1006/qres.1997.1927>
- Bocherens, H., Fizet, M., Mariotti, A., Lange-Badre, B., Vandermeersch, B., Bore, J. P., & Bellon, G. (1991). Isotopic biogeochemistry ( $^{13}\text{C}$ ,  $^{15}\text{N}$ ) of fossil vertebrate collagen: Application to the study of a past food web including Neanderthal man. *Journal of Human Evolution*, 20, 481–492. [https://doi.org/10.1016/0047-2484\(91\)90021-M](https://doi.org/10.1016/0047-2484(91)90021-M)
- Bowen, G. J. (2021). The online isotopes in precipitation calculator, version X.X. <http://www.waterisotopes.org>.
- Bowen, G. J., & Revenaugh, J. (2003). Interpolating the isotopic composition of modern meteoric precipitation. *Water Resources Research*, 39(10), 1299. <https://doi.org/10.1029/2003WR002086>
- Brasili, P. (1992). Food habits and dental disease in an iron-age population. *Anthropologischer Anzeiger*, 50, 67–82.
- Brasili, P., Mariotti, V., Facchini, F., & Neretti, K. (2000). Nutritional habits of the Celtic population of Casalecchio di Reno (Bologna, Italy) (4th–3rd c. B.C.) inferred from dental conditions. *Homo*, 51, 200–219.
- Brettell, R., Montgomery, J., & Evans, J. (2012). Brewing and stewing: The effect of culturally mediated behavior on the oxygen isotope composition of ingested fluids and the implications for human provenance studies. *Journal of Analytical Atomic Spectrometry*, 27, 778–785. <https://doi.org/10.1039/C2JA10335D>
- Britton, K., Fuller, B. T., Tütken, T., Mays, S., & Richards, M. P. (2015). Oxygen isotope analysis of human bone phosphate evidences weaning age in archaeological populations. *American Journal of Physical Anthropology*, 157(2), 226–241. <https://doi.org/10.1002/ajpa.22704>
- Brooks, S., & Suchey, J. M. (1990). Skeletal age determination based on the os pubis: A comparison of the Acsádi & Nemeskéri and Suchey-Brooks methods. *Human Evolution*, 5, 227–238. <https://doi.org/10.1007/BF02437238>
- Buckberry, J. L., & Chamberlain, A. T. (2002). Age estimation from the auricular surface of the ilium: A revised method. *American Journal of Physical Anthropology*, 119, 231–239. <https://doi.org/10.1002/ajpa.10130>
- Buikstra, J. E., & Ubelaker, D. H. (1994). *Standards for data collection from human skeletal remains*. Arkansas Archaeological Survey.
- Butti Ronchetti, F. (2014). Mobilità nelle Alpi centrali, tra fine dell'Età del Ferro e prima Romanità: alcuni esempi. In P. Barral, J. P. Guillaumet, M.-J. Roulière-Lambert, M. Saracino, & D. Vitali (Eds.), *Les Celtes et le Nord de l'Italie. Premier et Second Âges du Fer. Atti XXXVI coll. AFEAF, Verona (17–20 May 2012)* (pp. 653–658). RAE Suppl. 36.
- Cavaliere Manasse, G. (2004). L'Italia romana delle Regione. Regio X Venetia et Histria: Verona. In *Enciclopedia archeologica Europa* (pp. 722–729). Istituto della Enciclopedia Italiana Giovanni Treccani S.p.A.
- Chenery, C., Müldner, G., Evans, J., Eckardt, H., & Lewis, M. (2010). Strontium and stable isotope evidence for diet and mobility in Roman Gloucester, UK. *Journal of Archaeological Science*, 37(1), 150–163. <https://doi.org/10.1016/j.jas.2009.09.025>
- Cheung, C., Jing, Z., Tang, J., Weston, D. A., & Richards, M. P. (2017). Diets, social roles, and geographical origins of sacrificial victims at the royal cemetery at Yinxi, Shang China: New evidence from stable carbon, nitrogen, and sulfur isotope analysis. *Journal of Anthropological Archaeology*, 48, 28–45. <https://doi.org/10.1016/j.jaa.2017.05.006>
- Cox, G., & Sealy, J. (1997). Investigating identity and life history: Isotopic analysis and historical documentation of slave skeletons found in the Cape Town foreshore, South Africa. *International Journal of Historical Archaeology*, 1, 207–224. <https://doi.org/10.1023/A:1027349115474>
- Crowson, R. A., Showers, W. J., Wright, E. K., & Hoering, T. C. (1991). Preparation of phosphate samples for oxygen isotope analysis. *Analytical Chemistry*, 63, 2397–2400. <https://doi.org/10.1021/ac00020a038>
- D'Angela, D., & Longinelli, A. (1990). Oxygen isotopes in living mammals' bone phosphate: Further results. *Chemical Geology: Isotope Geoscience Section*, 86, 75–82. [https://doi.org/10.1016/0168-9622\(90\)90007-Y](https://doi.org/10.1016/0168-9622(90)90007-Y)
- D'Angela, D., & Longinelli, A. (1993). Oxygen isotopic composition of fossil mammal bones of Holocene age: Palaeoclimatological considerations. *Chemical Geology: Isotope Geoscience Section*, 103, 171–179. [https://doi.org/10.1016/0009-2541\(93\)90299-X](https://doi.org/10.1016/0009-2541(93)90299-X)
- Daux, V., Lécuyer, C., Hérán, M. A., Amiot, R., Simon, L., Fourel, F., Martineau, F., Lynnerup, N., Reyher, H., & Escarguel, G. (2008). Oxygen isotope fractionation between human phosphate and water revisited. *Journal of Human Evolution*, 55(6), 1138–1147. <https://doi.org/10.1016/j.jhevol.2008.06.006>
- Delgado Huertas, A., Iacumin, P., & Longinelli, A. (1997). A stable isotope study of fossil mammal remains from the Paglicci cave, southern Italy, 13 to 33 ka BP: Palaeoclimatological considerations. *Chemical Geology*, 141, 211–223.
- Delgado Huertas, A., Iacumin, P., Steni, B., Chillon, B., & Longinelli, A. (1995). Oxygen-isotope variations of phosphate in mammalian bone and tooth enamel. *Geochimica et Cosmochimica Acta*, 59, 4299–4305.
- DeNiro, M. J. (1985). Postmortem preservation and alteration of in vivo bone-collagen isotope ratios in relation to paleodietary reconstruction. *Nature*, 317, 806–809. <https://doi.org/10.1038/317806a0>
- DeNiro, M. J., & Epstein, S. (1978). Influence of diet on the distribution of carbon isotopes in animals. *Geochimica et Cosmochimica Acta*, 42(5), 495–506. [https://doi.org/10.1016/0016-7037\(78\)90199-0](https://doi.org/10.1016/0016-7037(78)90199-0)
- Eckardt, H. (2010). Roman diasporas: archaeological approaches to mobility and diversity in the Roman empire. *Journal of Roman Archaeology Supplementary Series*, 78. Portsmouth, R.I. *Journal of Roman Archaeology*.
- Eerkens, J. W., Barford, G. H., Jorgenson, G. A., & Peske, C. (2014). Tracing the mobility of individuals using stable isotope signatures in biological tissues: “locals” and “non-locals” in an ancient case of violent death from Central California. *Journal of Archaeological Science*, 41, 474–481. <https://doi.org/10.1016/j.jas.2013.09.014>
- Ehleringer, J. R., Cerling, T. E., & Helliker, B. R. (1997). C4 photosynthesis, atmospheric CO<sub>2</sub>, and climate. *Oecologia*, 112, 285–299. <https://doi.org/10.1007/s004420050311>
- Fahy, G. E., Deter, C., Pitfield, R., Miszkiewicz, J. J., & Mahoney, P. (2017). Bone deep: Variation in stable isotope ratios and histomorphometric measurements of bone remodelling within adult humans. *Journal of Archaeological Science*, 87, 10–16. <https://doi.org/10.1016/j.jas.2017.09.009>
- Fernández-Crespo, T., Snoeck, C., Ordoño, J., de Winter, N. J., Czermak, A., Mattioli, N., Lee-Thorp, J. A., & Schulting, R. J. (2020). Multi-isotope evidence for the emergence of cultural alterity in late Neolithic Europe. *Science Advances*, 6(4), eaay2169. <https://doi.org/10.1126/sciadv.aay2169>
- Francisci, G., Micarelli, I., Iacumin, P., Castorina, F., Di Vincenzo, F., Di Matteo, M., Giostra, C., Manzi, G., & Tafuri, M. A. (2020). Strontium and oxygen isotopes as indicators of Longobards mobility in Italy: An



- investigation at Povegliano Veronese. *Scientific Reports*, 10, 11678. <https://doi.org/10.1038/s41598-020-67480-x>
- Frei, K., Mannering, U., Kristiansen, K., Allentoft, M. E., Wilson, A. S., Skals, I., Tridico, S., Nosch, M. L., Willerslev, E., Clarke, L., & Frei, R. (2015). Tracing the dynamic life story of a bronze age female. *Scientific Reports*, 5, 10431. <https://doi.org/10.1038/srep10431>
- Frei, K. M., Villa, C., Jørkov, M. L., Allentoft, M. E., Kaul, F., Ethelberg, P., Reiter, S. S., Wilson, A. S., Taube, M., Olsen, J., Lynnerup, N., Willerslev, E., Kristiansen, K., & Frei, R. (2017). A matter of months: High precision migration chronology of a bronze age female. *PLoS One*, 12(6), e0178834. <https://doi.org/10.1371/journal.pone.0178834>
- Gambacurta, G. (2013). I Celti e il Veneto. *Etudes Celtiques*, XXXIX, 31–40.
- Gambacurta, G., & Ruta Serafini, A. (2019). *I Celti e il Veneto. Storie di cultura a confronto*. Antequem S.r.l.
- Ganzarolli, G., Alexander, M., Chavarria Arnau, A., & Craig, O. E. (2018). Direct evidence from lipid residue analysis for the routine consumption of millet in early medieval Italy. *Journal of Archaeological Science*, 96, 124–130. <https://doi.org/10.1016/j.jas.2018.06.007>
- Gat, J. R. (1971). Comments on stable isotope method in regional groundwater investigations. *Water Resources Research*, 7(4), 980–993.
- Gilck, F., & Poschold, P. (2021). The history of human land use activities in the Northern Alps since the Neolithic age. A reconstruction of vegetation and fire history in the Mangfall Mountains (Bavaria, Germany). *The Holocene*, 3(4), 579–591. <https://doi.org/10.1177/0959683620981701>
- Giustini, F., Brilli, M., & Patera, A. (2016). Mapping oxygen stable isotopes of precipitation in Italy. *Journal of Hydrology: Regional Studies*, 8, 162–181. <https://doi.org/10.1016/j.ejrh.2016.04.001>
- Grassi, M. T. (2009). *I Celti in Italia. Biblioteca di Archeologia* (Vol. 16). Longanesi.
- Grupe, G., Klaut, D., Otto, L., Mauder, M., Lohrer, J., Kroger, P., & Lang, A. (2020). The genesis and spread of the early Fritzens-Sanzeno culture (5th/4th cent. BCE): Stable isotope analysis of cremated and uncremated skeletal finds. *Journal of Archaeological Science: Reports*, 29, 102121. <https://doi.org/10.1016/j.jasrep.2019.102121>
- Hafner, A., & Schwörer, C. (2018). Vertical mobility around the highalpine Schnidejoch pass. Indications of Neolithic and bronze age pastoralism in the Swiss Alps from paleoecological and archaeological sources. *Quaternary International*, 484, 3–18. <https://doi.org/10.1016/j.quaint.2016.12.049>
- Hakenbeck, S., McManus, E., Geisler, H., Grupe, G., & O'Connell, T. (2010). Diet and mobility in early medieval Bavaria: A study of carbon and nitrogen stable isotopes. *American Journal of Physical Anthropology*, 143(2), 235–249. <https://doi.org/10.1002/ajpa.21309>
- Hauschild, M., Schönfelder, M., Scheeres, M., Knipper, C., Alt, K. W., & Pare, C. (2013). Nebringen, Münsingen und Monte Bibele – Zum archäologischen und bioarchäometrischen Nachweis von Mobilität im 4./3. Jahrhundert v. Chr. *Archäologisches Korrespondenzblatt*, 43, 345–364.
- Hedges, R., Clement, J., Thomas, C., & O'Connell, T. (2007). Collagen turnover in the adult femoral mid-shaft: Modeled from anthropogenic radiocarbon tracer measurements. *American Journal of Physical Anthropology*, 133, 808–816. <https://doi.org/10.1002/ajpa.20598>
- Hill, P. A., & Orth, M. (1998). Bone remodeling. *British Journal of Orthodontics*, 25, 101–107. <https://doi.org/10.1093/ortho.25.2.101>
- Hillson, S. (1996). *Dental anthropology* (1st ed.). Cambridge University Press.
- IAEA/WMO. (2015). Global Network of Isotopes in Precipitation. *The GNIP Database*. Accessible at: <https://nucleus.iaea.org/wiser>.
- Isayev, E. (2017). *Migration, mobility and place in ancient Italy*. Cambridge University Press.
- İşcan, M. Y., Loth, S. R., & Wright, R. K. (1984). Age estimation from the rib by phase analysis: White males. *Journal of Forensic Sciences*, 29, 1094–1104 PMID: 6502109.
- İşcan, M. Y., Loth, S. R., & Wright, R. K. (1985). Age estimation from the rib by phase analysis: White females. *Journal of Forensic Sciences*, 30, 853–863.
- Kern, D. (2012). Migration and mobility in the latest Neolithic of the Traisen valley, Lower Austria: Archaeology. In E. Kaiser, J. Burger, & W. Schier (Eds.), *Population dynamics in prehistory and early history. New approaches using stable isotopes and genetics* (pp. 213–224). de Gruyter GmbH & Co.. <https://doi.org/10.1515/9783110266306.213>
- Knipper, C., Meyer, C., Jacobi, F., Roth, C., Fecher, M., Stephan, E., Schatz, K., Hansen, L., Posluschny, A., Hoppner, B., Maus, M., Pare, C. F. E., & Alt, K. W. (2014). Social differentiation and land use at an early iron age “princely seat”: Bioarchaeological investigations at the Glauberg (Germany). *Journal of Archaeological Science*, 41, 818–835. <https://doi.org/10.1016/j.jas.2013.09.019>
- Knipper, C., Pichler, S. L., Bronnimann, D., Rissanen, H., Rosner, M., Spichtig, N., Stopp, B., Rentzel, P., Roder, B., Schibler, J., Lassau, G., & Alt, K. W. (2018). A knot in a network: Residential mobility at the late iron age proto-urban Centre of Basel-Gasfabrik (Switzerland) revealed by isotope analyses. *Journal of Archaeological Science: Reports*, 17, 735–753. <https://doi.org/10.1016/j.jasrep.2017.12.001>
- Kohn, M. J., & Cerling, T. E. (2002). Stable isotope compositions of biological apatite. In M. J. Kohn, J. F. Rakovan, & J. M. Hughes (Eds.), *Phosphates: Geochemical, geobiological, and materials importance* (pp. 455–488). Mineralogical Society of America.
- Kruta, V. (1977). *Los Celtas*. Biblioteca Edef.
- Kruta, V. (1988). In C. Liguri, U. Piconi, & C. e. I. Latini (Eds.), *I Celti. In Italia omnium terrarum alumna. La civiltà dei Veneti, Reti* (pp. 263–311). Libri Scheiwiller.
- Kruta, V. (2009). *La grande storia dei Celti*. Newton & Compton editori s.r.l.
- Kruta, V., & Manfredi, V. (1999). *I Celti in Italia*. Mondadori.
- Laffranchi, Z. (2016). *Antropología de la población Pre-Romana de Verona (Italia)*, (Unpublished doctoral dissertation) University of Granada, Granada. <http://hdl.handle.net/10481/40234>
- Laffranchi, Z., Cavalieri Manasse, G., Salzani, L., & Milella, M. (2019). Patterns of funerary variability, diet, and developmental stress in a Celtic population from NE Italy (3rd-1st c BC). *PLoS ONE*, 14, e0214372. <https://doi.org/10.1371/journal.pone.0214372>
- Laffranchi, Z., Charisi, D., Jiménez Brobeil, S. A., & Milella, M. (2020). Gendered division of labor in a Celtic community? A comparison of sex differences in enthesal changes and long bone shape and robusticity in the pre-Roman population of Verona (Italy, third-first century BC). *American Journal of Physical Anthropology*, 173, 568–588. <https://doi.org/10.1002/ajpa.24111>
- Laffranchi, Z., Delgado Huertas, A. D., Jiménez Brobeil, S. A., Granados Torres, A. G., & Riquelme Cantal, J. A. (2016). Stable C & N isotopes in 2100 Year-B.P. human bone collagen indicate rare dietary dominance of C4 plants in NE-Italy. *Scientific Reports*, 6, 38817. <https://doi.org/10.1038/srep38817>
- Laffranchi, Z., Jiménez Brobeil, S. A., Delgado Huertas, A., Granados Torres, A., & Miranda, M. T. (2018). Infant feeding practices in a pre-Roman/Celtic population from Verona (Italy). *Journal of Archaeological Science: Reports*, 17, 30–38. <https://doi.org/10.1016/j.jasrep.2017.10.040>
- Laffranchi, Z., Martín Flórez, J. S., Jiménez Brobeil, S. A., & Castellani, V. (2015). Foot polydactyly and bipartite medial cuneiform: A case of co-occurrence in a Celtic skeleton from Verona (Italy). *Homo*, 66, 216–228. <https://doi.org/10.1016/j.jchb.2015.01.003>
- Laffranchi, Z., Mazzucchi, A., Thompson, S., Delgado Huertas, A., Granados Torres, A., & Milella, M. (2020). Funerary reuse of a Roman amphitheatre: Palaeodietary and osteological study of early middle ages burials (8th and 9th centuries AD) discovered in the arena of Verona (northeastern Italy). *International Journal of Osteoarchaeology*, 30, 435–448. <https://doi.org/10.1002/oa.2872>
- Lamb, A. L., Evans, J. E., Buckley, R., & Appleby, J. (2014). Multi-isotope analysis demonstrates significant lifestyle changes in King Richard III.

- Journal of Archaeological Science*, 50, 559–565. <https://doi.org/10.1016/j.jas.2014.06.021>
- Leary, J. (2014). *Past mobility*. Routledge.
- Levitt, P. (2018). Social remittances: Migration driven local-level forms of cultural diffusion. *International Migration Review*, 32(4), 926–948. <https://doi.org/10.2307/2547666>
- Lightfoot, E., & O'Connell, T. C. (2016). On the use of biomineral oxygen isotope data to identify human migrants in the archaeological record: Intra-sample variation, statistical methods and geographical considerations. *PLoS One*, 11(4), e0153850. <https://doi.org/10.1371/journal.pone.0153850>
- Lightfoot, E., Slaus, M., & O'Connell, T. C. (2014). Water consumption in iron age, Roman, and early medieval Croatia. *American Journal of Physical Anthropology*, 154(4), 535–543. <https://doi.org/10.1002/ajpa.22544>
- Longinelli, A. (1965). Oxygen isotopic composition of orthophosphate from shells of living marine organisms. *Nature*, 207, 716–719. <https://doi.org/10.1038/207716a0>
- Longinelli, A. (1984). Oxygen isotopes in mammal bone phosphate: a new tool for paleohydrological and paleoclimatological research. *Geochimica et Cosmochimica Acta*, 48, 385–390. [https://doi.org/10.1016/0016-7037\(84\)90259-X](https://doi.org/10.1016/0016-7037(84)90259-X)
- Longinelli, A., & Selmo, E. (2003). Isotopic composition of precipitation in Italy: A first overall map. *Journal of Hydrology*, 270, 75–88. [https://doi.org/10.1016/S0022-1694\(02\)00281-0](https://doi.org/10.1016/S0022-1694(02)00281-0)
- Lösche, S., Grupe, G., & Peters, J. (2006). Stable isotopes and dietary adaptations in humans and animals at pre-pottery Neolithic Nevalı Çori, Southeast Anatolia. *American Journal of Physical Anthropology*, 131(2), 181–193. <https://doi.org/10.1002/ajpa.20395>
- Lösche, S., Moghaddam, N., Grossschmidt, K., Risser, D. U., & Kanz, F. (2014). Stable isotope and trace element studies on gladiators and contemporary romans from Ephesus (Turkey, 2nd and 3rd Ct. AD): Implications for differences in diet. *PLoS ONE*, 9(10), e110489. <https://doi.org/10.1371/journal.pone.0110489>
- Luz, B., & Kolodny, Y. (1989). Oxygen isotope variation in bone phosphate. *Applied Geochemistry*, 4, 317–323. [https://doi.org/10.1016/0883-2927\(89\)90035-8](https://doi.org/10.1016/0883-2927(89)90035-8)
- Malnati, L., Salzani, L., & Cavalieri Manasse, G. (2004). Verona la formazione della città. In *Des Iberes aux Venetes* (pp. 347–377). Roma.
- Manolagas, S. C. (2000). Birth and death of bone cells: Basic regulatory mechanisms and implications for the pathogenesis and treatment of osteoporosis. *Endocrine Review*, 21, 115–137. <https://doi.org/10.1210/er.21.2.115>
- Mansuelli, G. A. (1978). Le fonti storiche sui Celti Cisalpini. In P. Santoro (Ed.), *I Galli e l'Italia* (pp. 71–75). Catalogo della mostra di Roma.
- Marchesini, S., & Stifter, D. (2018). Inscriptions from Italo-Celtic burials in the Seminario Maggiore (Verona). In J. Tabolli (Ed.), *From invisible to visible. New methods and data for the archaeology of infant and child burials in pre-Roman Italy and beyond* (pp. 143–154). Astrom Editions.
- Marinato, M. (2016). Isotopic analyses and bioarchaeology as sources for the study of the population between late antiquity and early middle ages in northern Italy. *Data from Bergamo, Modena and Verona provinces* (Unpublished doctoral dissertation). University of Padova, Padova. <http://paduaresearch.cab.unipd.it/9445/>
- Marinato, M. (2017). Analisi degli isotopi stabili sulle sepolture altomedievali. In A. A. Chavarria (Ed.), *Ricerche sul centro episcopale di Padova. Scavi 2011–2012* (pp. 151–154). SAP Società Archeologica srl.
- Marinato, M. (2019). Alimentazione, salute e mobilità della popolazione in Italia settentrionale tra IV e VIII secolo. In *Approcci bioarcheologici*. SAP Società Archeologica srl.
- Marinetti, A. (1992). Este preromana, epigrafia e lingua. In *Este antica dalla preistoria alla età Romana* (pp. 127–169). Este.
- Marzatico, F. (2014). Il mondo retico fra Etruschi e Celti. In P. Barral, J. P. Guillaumet, M.-J. Roulière-Lambert, M. Saracino, & D. Vitali (Eds.), *Les Celtes et le Nord de l'Italie. Premier et Second Âges du Fer. Atti XXXVI coll. AFEAF, Verona (17–20 May 2012)* (pp. 189–210). RAE.
- Maxwell, A.B. (2019). Exploring variations in diet and migration from late antiquity to the early medieval period in the Veneto, Italy: A biochemical analysis. (unpublished doctoral dissertation). Tampa: University of South Florida. <https://www.proquest.com/docview/2239956364?pq-origsite=gscholar&fromopenview=true>
- Milella, M., Gerling, C., Doppler, T., Kuhn, T., Cooper, M., Mariotti, V., Belcastro, M. G., Ponce de León, M. S., & Zollikofer, C. P. E. (2019). Different in death: Different in life? Diet and mobility correlates of irregular burials in a Roman necropolis from Bologna (northern Italy, 1st–4th century CE). *Journal of Archaeological Science: Reports*, 27, 101926. <https://doi.org/10.1016/j.jasrep.2019.101926>
- Moghaddam, N., Müller, F., Hafner, A., & Lösche, S. (2016). Social stratigraphy in late iron age Switzerland: Stable carbon, nitrogen and Sulphur isotope analysis of human remains from Münsingen. *Archaeological and Anthropological Sciences*, 8(1), 149–160. <https://doi.org/10.1007/s12520-014-0221-4>
- Moghaddam, N., Müller, F., & Lösche, S. (2018). A bioarchaeological approach to the iron age in Switzerland: Stable isotope analyses ( $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ ,  $\delta^{34}\text{S}$ ) of human remains. *Archaeological and Anthropological Sciences*, 10(5), 1067–1085. <https://doi.org/10.1007/s12520-016-0441-x>
- Moreiras Reynaga, D. K., Millaire, J. F., Chávez Balderas, X., Román Berrelleza, J. A., López Luján, L., & Longstaffe, F. J. (2021). Residential patterns of Mexica human sacrifices at Mexico-Tenochtitlan and Mexico-Tlatelolco: Evidence from phosphate oxygen isotopes. *Journal of Anthropological Archaeology*, 62, 101296. <https://doi.org/10.1016/j.jaa.2021.101296>
- Müller, W., Fricke, H., Halliday, A. N., McCulloch, M. T., & Wartho, J. A. (2003). Origin and migration of the alpine iceman. *Science*, 302(5646), 862–866. <https://doi.org/10.1126/science.1089837>
- Müller-Scheeßel, N., Grupe, G., Mühldorfer, B., & Tütken, T. (2020). The dead of the Dietersberg cave, Germany: New insights into burial practices of the iron age from 14C-dates and stable isotope (C, N, O, and Sr) analyses of human bones and teeth. *Archaeological and Anthropological Sciences*, 12, 68. <https://doi.org/10.1007/s12520-020-01025-1>
- Natali, C., Bianchini, G., Marchina, C., & Knöller, K. (2016). Geochemistry of the Adige River water from the Eastern Alps to the Adriatic Sea (Italy): Evidences for distinct hydrological components and water-rock interactions. *Environmental Science and Pollution Research*, 23, 11677–11694. <https://doi.org/10.1007/s11356-016-6356-3>
- Nehlich, O., Montgomery, J., Evans, J., Schade-Lindig, S., Pichler, S. L., Richards, M. P., & Alt, K. W. (2009). Mobility or migration: A case study from the Neolithic settlement of Nieder-Mörlen (Hessen, Germany). *Journal of Archaeological Science*, 36, 1791–1799. <https://doi.org/10.1016/j.jas.2009.04.008>
- Oelze, V. M., Koch, J. K., Kupke, K., Nehlich, O., Zauner, S., Wahl, J., Weise, S. M., Rieckhoff, S., & Richards, M. P. (2012). Multi-isotopic analysis reveals individual mobility and diet at the early iron age monumental tumulus of Magdalenenberg, Germany. *American Journal of Physical Anthropology*, 148(3), 406–421. <https://doi.org/10.1002/ajpa.22063>
- Paladin, A., Moghaddam, N., Stawinoga, A. E., Siebke, I., Depellegrin, V., Tecchiati, U., Lösche, S., & Zink, A. (2020). Early medieval Italian Alps: Reconstructing diet and mobility in the valleys. *Archaeological Anthropological Sciences*, 12, 82. <https://doi.org/10.1007/s12520-019-00982-6>
- Parfitt, A. M. (2002). Misconceptions (2): Turnover is always higher in cancellous than in cortical bone. *Bone*, 30(6), 807–809. [https://doi.org/10.1016/S8756-3282\(02\)00735-4](https://doi.org/10.1016/S8756-3282(02)00735-4)
- Pederzani, S., & Britton, K. (2019). Oxygen isotopes in bioarchaeology: Principles and applications, challenges and opportunities. *Earth-Science Reviews*, 188, 77–107. <https://doi.org/10.1016/j.earscirev.2018.11.005>
- Pollard, A. M., Ditchfield, P., Piva, E., Wallis, S., Falys, C., & Ford, S. (2012). 'Sprouting like cockle amongst the wheat': The St Brice's day

- massacre and the isotopic analysis of human bones from Sr Johns College, Oxford. *Oxford Journal of Archaeology*, 31, 83–102. <https://doi.org/10.1111/j.1468-0092.2011.00380.x>
- Prosdocimi, A. L. (1991). Note sul Celtico in Italia. *Studi Etruschi*, 57, 139–177.
- Prowse, T., Schwarcz, H. P., Saunders, S., Macchiarelli, R., & Bondioli, L. (2004). Isotopic paleodiet studies of skeletons from the Imperial Roman-age cemetery of Isola Sacra, Rome, Italy. *Journal of Archaeological Science*, 31(3), 259–272. <https://doi.org/10.1016/j.jas.2003.08.008>
- Putzer, A., Festi, D., Edlmair, S., & Oegg, K. (2016). The development of human activity in the high altitudes of the Schnals Valley (South Tyrol/Italy) from the Mesolithic to modern periods. *Journal of Archaeological Science: Reports*, 6, 136–147. <https://doi.org/10.1016/j.jasrep.2016.01.025>
- Rams, P. (2014). The relationship between Austrian and North-Italian sites in the Iron Age. In P. Barral, J. P. Guillaumet, M.-J. Roulière-Lambert, M. Saracino, & D. Vitali (Eds.), *Les Celtes et le Nord de l'Italie. Premier et Second Âges du Fer. Atti XXXVI coll. AFEAF, Verona (17-20 May 2012)* (pp. 179–188). RAE.
- Redfern, R. C., Gröcke, D. R., Millard, A. R., Ridgeway, V., Johnson, L., & Hefner, J. T. (2016). Going south of the river: A multidisciplinary analysis of ancestry, mobility and diet in a population from Roman Southwark, London. *Journal of Archaeological Science*, 74, 11–22. <https://doi.org/10.1016/j.jas.2016.07.016>
- Reynard, L. M., & Hedges, R. E. M. (2008). Stable hydrogen isotopes of bone collagen in palaeodietary and palaeoenvironmental reconstruction. *Journal of Archaeological Science*, 35(7), 1934–1942. <https://doi.org/10.1016/j.jas.2007.12.004>
- Rozanski, K., Araguas-Araguas, L., & Gonfiantini, R. (1993). Isotopic patterns in modern global precipitation. *Geophysical Monograph Series*, 78, 1–36. <https://doi.org/10.1029/GM078p0001>
- Schaefer, M., Black, S., & Scheuer, L. (2009). *Juvenile osteology. A laboratory and field manual*. Academic Press.
- Scheeres, M., Knipper, C., Hauschild, M., Schonfelder, M., Siebel, W., Pare, C., & Alt, K. W. (2014). “Celtic migrations”: Fact or fiction? Strontium and oxygen isotope analysis of the Czech cemeteries of Radovesice and Kutna Hora in Bohemia. *American Journal of Physical Anthropology*, 155, 496–512. <https://doi.org/10.1002/ajpa.22597>
- Scheeres, M., Knipper, C., Hauschild, M., Schonfelder, M., Siebel, W., Vitali, D., Pare, C., & Alt, K. W. (2013). Evidence for “Celtic migrations”? Strontium isotope analysis at the early La Tène (LT B) cemeteries of Nebringen (Germany) and Monte Bibele (Italy). *Journal of Archaeological Science*, 40, 3614–3625. <https://doi.org/10.1016/j.jas.2013.05.003>
- Scheid, R. C. (2007). *Woelfel's dental anatomy: Its relevance to dentistry*. Lippincott, Williams & Wilkins.
- Scheuer, L., & Black, S. (2000). *Developmental juvenile osteology*. Academic Press.
- Schoeninger, M. J., & DeNiro, M. J. (1984). Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochimica et Cosmochimica Acta*, 48(4), 625–639. [https://doi.org/10.1016/0016-7037\(84\)90091-7](https://doi.org/10.1016/0016-7037(84)90091-7)
- Schoeninger, M. J., & Moore, K. (1992). Bone stable isotope studies in archaeology. *Journal of World Prehistory*, 6(2), 247–296. <https://www.jstor.org/stable/25800615>
- Schroeder, H., O'Connell, T. C., Evans, J. A., Shuler, K. A., & Hedges, R. E. M. (2009). TransAtlantic slavery: Isotopic evidence for forced migration to Barbados. *American Journal of Physical Anthropology*, 139, 547–557. <https://doi.org/10.1002/ajpa.21019>
- Sealy, J., Armstrong, R., & Schrire, C. (1995). Beyond lifetime averages: Tracing life histories through isotopic analysis of different calcified tissues from archaeological human skeletons. *Antiquity*, 69(263), 290–300. <https://doi.org/10.1017/S0003598X0006469>
- Sharp, Z. D., Atudorei, V., & Durakiewicz, T. (2001). A rapid method for determination of hydrogen and oxygen isotope ratios from water and hydrous minerals. *Chemical Geology*, 178, 197–210.
- Siebek, I., Furtwängler, A., Steuri, N., Hafner, A., Ramstein, M., Krause, J., & Lösch, S. (2020). Crops vs. animals: Regional differences in subsistence strategies of Swiss Neolithic farmers revealed by stable isotopes. *Archaeological and Anthropological Sciences*, 12(10), 1–30. <https://doi.org/10.1007/s12520-020-01122-1>
- Smith, B. N., & Epstein, S. (1971). Two categories of  $^{13}\text{C}/^{12}\text{C}$  ratios for higher plants. *Plant Physiology*, 47, 380–384. <https://doi.org/10.1104/pp.47.3.380>
- Solinas, P. (2015). Le iscrizioni in alfabeto leponzio dalla necropoli del Seminario Maggiore. *Studi Etruschi*, 78, 373–379.
- Sorrentino, R., Bortolini, E., Lugli, F., Mancuso, G., Buti, L., Oxilia, G., Vazzana, A., Figus, C., Serrangeli, M. C., Margherita, C., Penzo, A., Gruppioni, G., Gottarelli, A., Jochum, K. P., Belcastro, M. G., Cipriani, A., Feeney, R. N. M., & Benazzi, S. (2018). Unravelling bio-cultural population structure in 4th/3rd century BC Monterenzio Vecchio (Bologna, Italy) through a comparative analysis of strontium isotopes, non-metric dental evidence, and funerary practices. *PLoS One*, 13, e0193796. <https://doi.org/10.1371/journal.pone.0193796>
- Stark, R. J., Emery, M. V., Schwarcz, H., Sperduti, A., Bondioli, L., Craig, O. E., & Prowse, T. (2020). Imperial Roman mobility and migration at Velia (1st to 2nd c. CE) in southern Italy. *Journal of Archaeological Science: Reports*, 30, 102217. <https://doi.org/10.1016/j.jasrep.2020.102217>
- Szpak, P., Metcalfe, J. Z., & Macdonald, R. A. (2017). Best practices for calibrating and reporting stable isotope measurements in archaeology. *Journal of Archaeological Science: Reports*, 13, 609–616. <https://doi.org/10.1016/j.jasrep.2017.05.007>
- Tafuri, M. A., Craig, O. E., & Canci, A. (2009). Stable isotope evidence for the consumption of millet and other plants in bronze age Italy. *American Journal of Physical Anthropology*, 139(2), 146–153. <https://doi.org/10.1002/ajpa.20955>
- Tafuri, M. A., Rottoli, M., Cupitò, M., Pulcini, M. L., Tasca, G., Carrara, N., Bonfanti, F., Salzani, L., & Canci, A. (2018). Estimating  $\text{C}_4$  plant consumption in bronze age Northeastern Italy through stable carbon and nitrogen isotopes in bone collagen. *International Journal of Osteoarchaeology*, 28, 131–142. <https://doi.org/10.1002/oa.2639>
- Teeri, J. A., & Stowe, L. G. (1976). Climatic patterns and the distribution of  $\text{C}_4$  grasses in North America. *Oecologia*, 23, 1–12. <https://doi.org/10.1007/BF00351210>
- Tilly, C. (1978). Migration in modern European history. In W. McNeill & R. Adams (Eds.), *Human migration: Patterns and policies* (pp. 48–74). Indiana University Press.
- Toncala, A., Sollner, F., Mayr, C., Holz, S., Heck, K., Wycisk, D., & Grupe, G. (2017). Isotopic map of the Inn-Eisack-Adige-Brenner passage and its application to prehistoric human cremations. In G. Grupe, A. Grigat, & G. C. McGlynn (Eds.), *Across the Alps in prehistory. Isotopic mapping of the Brenner passage by bioarchaeology* (pp. 127–227). Springer International Publishing. [https://doi.org/10.1007/978-3-319-41550-5\\_6](https://doi.org/10.1007/978-3-319-41550-5_6)
- Toyne, J. M., Čelhar, M., & Nystrom, K. C. (2021). Liburnian lunches: New stable isotope data for the iron age community of Nadin-Gradina, Croatia. *International Journal of Osteoarchaeology*, 1–17, 241–257. <https://doi.org/10.1002/oa.3059>
- Toyne, J. M., Church, W. B., Coronado Tello, J. L., & Morales Gamarra, R. (2017). Exploring imperial expansion using an isotopic analysis of paleodietary and paleomobility indicators in Chachapoyas, Peru. *American Journal of Physical Anthropology*, 162(1), 51–72. <https://doi.org/10.1002/ajpa.23085>
- Toyne, J. M., White, C. D., Verano, J. W., Uceda Castillo, S., Millaire, J. F., & Longstaffe, F. J. (2014). Residential histories of elites and sacrificial victims at Huacas de Moche, Peru, as reconstructed from oxygen isotopes. *Journal of Archaeological Science* 42, 15–28. <https://doi.org/10.1016/j.jas.2013.10.036>

- Tsutaya, T., Miyamoto, H., Uno, H., Omori, T., Gakuhari, T., Inahara, A., Nagaoka, T., Abe, M., & Yoneda, M. (2016). From cradle to grave: Multi-isotopic investigations on the life history of a higher-status female from Edo-period Japan. *Anthropological Science*, 124(3), 185–197. <https://doi.org/10.1537/ase.161029>
- Tudge, A. P. (1960). A method of analysis of oxygen isotopes in orthophosphate-its use in the measurement of paleotemperatures. *Geochimica et Cosmochimica Acta*, 18, 81–93. [https://doi.org/10.1016/0016-7037\(60\)90019-3](https://doi.org/10.1016/0016-7037(60)90019-3)
- Ubelaker, D. H. (1989). *Human skeletal remains. Excavation, analysis, interpretation* (2nd ed.). Taraxacum.
- Van der Merwe, N. J. (1982). Carbon isotopes, photosynthesis, and archaeology: Different pathways of photosynthesis cause characteristic changes in carbon isotope ratios that make possible the study of prehistoric human diets. *American Scientist*, 70(6), 596–606. <https://www.jstor.org/stable/27851731>
- Van Klinken, G. J. (1999). Bone collagen quality indicators for palaeodietary and radiocarbon measurements. *Journal of Archaeological Science*, 26(6), 687–695. <https://doi.org/10.1006/jasc.1998.0385>
- Varalli, A., Desideri, J., David-Elbiali, M., Goude, G., Honegger, M., & Besse, M. (2021). Bronze age innovations and impact on human diet: A multi-isotopic and multi-proxy study of western Switzerland. *PLoS One*, 16(1), e0245726. <https://doi.org/10.1371/journal.pone.0245726>
- Varalli, A., Moggi-Cecchi, J., Dori, I., Boccone, S., Bortoluzzi, S., Salzani, P., & Tafuri, M. A. (2016). Dietary continuity vs. discontinuity in bronze age Italy. The isotopic evidence from Arano di Cellere (Illasi, Verona, Italy). *Journal of Archaeological Science: Reports*, 7, 104–113. <https://doi.org/10.1016/j.jasrep.2016.03.047>
- Vitali, D. (1996). Celtes cisalpins, celtes transalpins: quelques réflexions sur le rôle de l'Italie du nord dans l'origine des oppida. In M. Groenen (Ed.), *La Préhistoire au Quotidien* (pp. 323–345). Mélanges offerts à Pierre Bonenfant.
- Vitali, D. (2001). I Celti a Sud del Po. In *I Celti nell'Alto Adriatico (Antichità Altoadriatiche XLVIII)* (pp. 227–239). EUT Edizioni Università di Trieste.
- Vitali, D. (2004). La Cispadana tra IV e II secolo a.C. In *Des Ibères aux Vénètes* (Vol. 328, pp. 277–292). Rome: Collection de l'École française de Rome 328.
- Vitali, D. (2011). I Celti in Italia tra scambi e movimenti migratori. In F. Marzatico, R. Gebhard, & P. Glairscher (Eds.), *Le grandi vie della civiltà, relazioni e scambi fra il Mediterraneo ed il centro Europa dalla Preistoria alla Romanità* (pp. 287–289). Castello del Buonconsiglio.
- Webb, E. C., White, C. D., & Longstaffe, F. J. (2013). Exploring geographic origins at Cahuachi using stable isotopic analysis of archaeological human tissues and modern environmental waters. *International Journal of Osteoarchaeology*, 23, 698–715. <https://doi.org/10.1002/oa.1298>
- White, C. D., Spence, M. W., Longstaffe, F. J., & Law, K. R. (2000). Testing the nature of Teotihuacán imperialism at Kaminaljuyú using phosphate oxygen isotope ratios. *Journal of Anthropological Research*, 56(4), 535–558. <http://www.jstor.org/stable/3630930>
- White, C. D., Spence, M. W., Longstaffe, F. J., & Law, K. R. (2004). Demography and ethnic continuity in the Tlailotlacan enclave of Teotihuacan: The evidence from stable oxygen isotopes. *Journal of Anthropological Archaeology*, 23(4), 385–403. <https://doi.org/10.1016/j.jaa.2004.08.002>

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