



Transformed by fire: a ritual practice dating back to the Early Neolithic in Italy. Interdisciplinary analysis of burnt bone remains in Lugo di Grezzana (Veneto), 5000 – 4850 cal BCE

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Abstract

The use of fire for the treatment of human remains in funerary rituals characterises Italian prehistory since the Neolithic, being the dominant funerary practice from the Late Bronze Age to the Early Roman period, with regional differences. New osteoarchaeological and radiometric data allow us to confirm the occasional use of fire as a transformative element for the body already in the Early Neolithic. During the excavation of the Early Neolithic settlement of Lugo di Grezzana in 2003 and 2005 (Fiorano Culture – province of Verona, Veneto, northeastern Italy), five pits were discovered, each containing burnt osteological remains. One pit, interpreted as an oven (ES 541 sector XVI), yielded numerous bones intermingled with abundant fragments of pottery and flint. Most of the bones were identified as non-human remains. However, the morphological examination revealed fragments of diaphyses with characteristics consistent with human bone. Subsequent histomorphological analysis confirmed the taxonomic identification of these fragments as belonging to the genus *Homo* and provided insights into the age distribution, indicating that they belonged to individuals spanning different age groups. The ¹⁴C analysis of charcoal and bones suggests that the use of ovens dates from 5400 to 5000 cal BCE. A new radiocarbon date of a calcined human bone fragment has been placed between 5024 and 4845 cal BCE, indicating that the oven was likely reused as funerary structure during the final phase of the site use. This discovery has increased the number of recent findings of burnt human bones within Neolithic contexts in Italy, prompting us to reflect on the significance of their presence as possible early evidence of fire rituals involving the treatment of human remains in the Italian Peninsula.

Keywords Bioarchaeology · Histology · Prehistory · Ritual · Italy · Neolithic

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Introduction

The use of fire for the funeral treatment of a corpse is a funerary practice that involves burning a deceased body or skeleton to consume the soft tissues by fire and/or to transform the bones into burnt fragments. The reconstruction and interpretation of rituals involving the cremation or burning of bodies, body parts, or already skeletonised remains is a complex theme that must consider numerous aspects that may hold symbolic and ideological value, whether arbitrary or not, and be influenced by a multitude of human and natural variables that are not fully comprehensible (Gonçalves et al. 2011; Larentis 2023a). The use of fire as a transformative element for human remains has multiple meanings and infinite facets, and this practice holds diverse significance and appears in various forms across numerous cultures and periods. It has been documented in Italian Prehistory since the Neolithic (Conati Barbaro 2019) and especially in the Copper Age (e.g., Barfield 2007; Tecchiati 2014; Quarta et al. 2014; Salzani et al. 2021), during which secondary body treatment rituals are documented, becoming predominant across most of the peninsula during the Late Bronze Age (e.g., Capuzzo and Barceló 2022; Cavazzuti et al. 2022; Crivellaro et al. 2022; Masotti et al. 2020) and the Iron Age (e.g., Larentis 2023a; Minozzi 2015). This ritual of transforming the human body gained such popularity that it was the primary choice for body treatment even during the Early Roman period. A series of findings, subject to varying degrees of debate regarding their ritual interpretation, has led to the hypothesis that such funerary practice existed in Italy since the Early Neolithic (e.g., Conati Barbaro 2019; Grifoni et al. 1978). In accordance with this interpretation, new osteoarchaeological and radiometric data support that fire-related rituals, albeit sporadic, can be traced back to that period. Insights gained from the study of the site of Lugo di Grezzana (Fig. 1a–c) of the Fiorano Culture (*Cultura di Fiorano*) (Pedrotti et al. 2015; Pessina and Tiné 2022), have enabled to enhance our understanding of Neolithic fire-related funeral treatments, conducting an in-depth review of the available data for the first time.

The Early Neolithic settlement of Lugo di Grezzana, “Campagne” locality, in the Monti Lessini area, is well-known for its prehistoric findings (e.g., Barker 1999). Since 1991, the site has been the subject of archaeological research conducted by the Superintendence for Archaeological Heritage of Veneto, in collaboration with the University of Trento from 1996 to 2005 (see Cavulli and Pedrotti 2002; Cavulli et al. 2002; Pedrotti et al. 2015). Between 2003 and 2005, five combustion pits were excavated in sector XVI (Cavulli et al. 2023; Costa et al. 2019) and their use was radiocarbon (^{14}C) dated to a time span between 5400 and 5000 cal BCE (Cavulli et al. 2023). Numerous materials,

Fig. 1 The site of Lugo di Grezzana is located in the province of Verona, Veneto Region, northeastern Italy (a); Site plan showing archaeological findings divided by excavation sectors, sector XVI is highlighted by the bold orange outline, with the location of ES 541 within the blue circle. (Costa et al. 2019) (b); Aerial photograph of the archaeological area with excavation sectors marked in Roman numerals, sector XVI is highlighted in orange (Pedrotti et al. 2015) (c)

including burnt bones, were recovered from the fill of pit ES 541 US 540 sector XVI (Fig. 1b). A radiocarbon date on a wood charcoal fragment from US 565 (DSH6739_C, 6147 ± 31 BP) has allowed for interpreting the structure's use during the last two centuries of the 6th millennium BCE (5209–5002 BCE for 2σ probability, see Costa et al. 2019). Morphological analysis of the bone fragments confirmed their almost exclusive association with non-human subjects (Maccarinelli et al. 2015). However, some elements exhibited morphological traits typical of humans, subsequently confirmed through taxonomic identification (hereinafter referred to as TI) via histomorphology. Histological analyses also allowed for the examination of the bone tissue to estimate age intervals for each analysed fragment. The Lugo di Grezzana site thus enhances our understanding of the presence of burnt human bones within Neolithic Italian sites, contributing to knowledge about the adoption and spread of cremation and body or skeletal manipulation rituals on the Italian Peninsula.

Materials and methods

The burnt osteological remains

The site of Lugo di Grezzana ($45^{\circ}33'58''$ N, $10^{\circ}59'40''$ E; UTM: 32TPR558479) is divided into several areas (I–XVI), and in twelve of these, burnt bone remains have been found, numbering a minimum of 6489 fragments, with a total weight of 3017.7 g (Fig. 1c; Table 1). In sector XVI (Fig. 1b), five combustion pits and a structure divided into three areas of different size were excavated. The pits exhibit heterogeneous characteristics in terms of shape, dimension, and fill; larger structures, for example, contain few materials, while smaller pits are rich in pottery, flints, and burnt bones. One of these pits, interpreted as an oven (ES 541 sector XVI), has an oval shape and small dimensions (maximum $\varnothing = 128$ cm; minimum $\varnothing = 115$ cm; preserved depth = 27 cm) and was filled with a few charred bone fragments, some flint, and exhibited scorched walls and some fragments of fired clay (Costa et al. 2019) (Fig. 2). The central fill of the structure yielded 5695 burnt fragments with very small average dimensions, with a total weight of 2748.6 g (Table 1). From the content of the pit, ^{14}C dated with a wood charcoal fragment to 5209–5002 cal BCE at 2σ (Costa et al. 2019; Maccarinelli et al. 2015), three bone

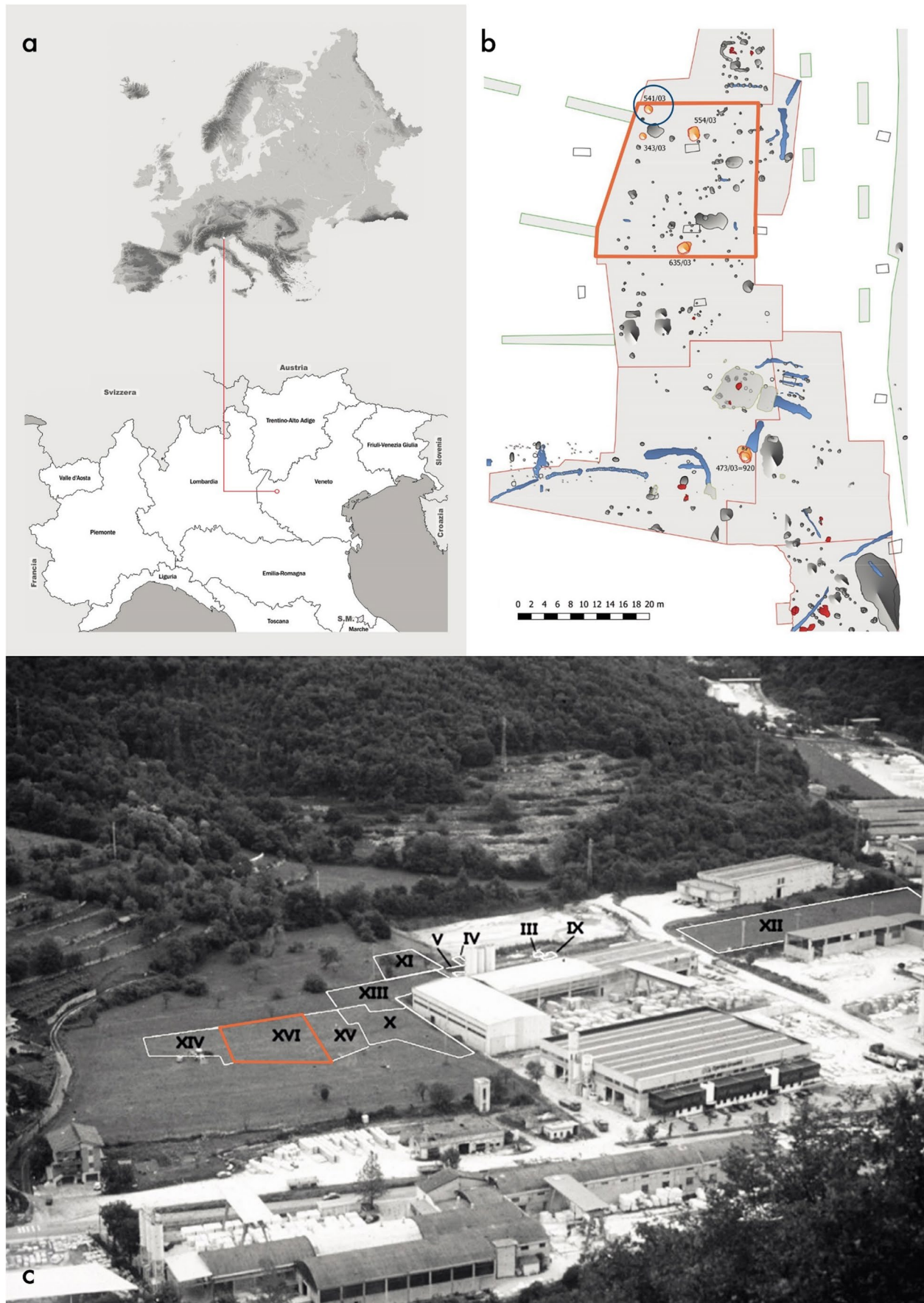


Table 1 List of excavation sectors at the Lugo Di Grezzana site where burnt bones were found; for each sector, the total number of recorded fragments and their weight in grams (g) are indicated. The data related to sector XVI, from which the materials analysed in this study originate, are highlighted in bold

Sector	Total number of fragments	Weight (g)
III	1	15.7
IV	5	1.7
IVA	8	3.1
V	16	11.6
IX	15	4.8
X	8	39.9
XA	1	0.5
XB	8	4.1
XI	5	10.2
XIB	1	0.4
XIII	726	177.5
XVI	5695	2748.6
Total	6489	3017.7

fragments, two femora and one tibia, were analysed due to their suspected human origin. Macroscopic analysis of these fragments allowed us to identify a sufficiently preserved external cortical surface (e.g., Fig. 3a). This allowed for verifying the absence of pathological processes that could have affected the histological evaluation of the sample. However, it is important to note that other variables can influence bone turnover and bone density, especially in relation to the age of the individuals (Mallorie and Shine 2022).

Morphological analyses

The materials were initially analysed from a zooarchaeological perspective. TI can be considered the central technical issue in the study of ancient osteological material, and it is based on the morphometric characteristics of the fragment, and for this reason, a comparative osteological collection of non-human specimens is necessary. For optimal comparison, such a collection should include skeletons of current and fossilised species, as the dimensional variation within the same species over time could mislead the researcher. Additionally, it should represent, for each species, the degree of interspecific variability, including elements of different ages, sexes (male, female, and possibly castrated), and breeds. In this work, we employed the zoological and zooarchaeological comparative collection housed at the Civic Museum of Rovereto, Province of Trento, Italy. To acquire the metric data of the fragments, a digital caliper I-KL-150D with a steel slide of 150 mm was used, with a precision of 0.01 mm. The weight of the remains was estimated using a high-precision laboratory scale with a ceramic load sensor, GRAM FR, with a resolution of 0.001 g.

In support of the comparative collection, the discriminatory osteometric points of each species were referred to

Fig. 2 Lugo di Grezzana, pit ES 541 sector XVI during excavation, with the right portion showing the infill rich in burnt bones (a); burnt bones are concentrated in the centre of the pit, as indicated by the green elements in the plan of US 540 (b); the bones, highlighted in green in the section, mainly originate from US 540 (c); graphical elements are adapted from Costa et al. 2019

(Barone 1976; Cohen and Serjeantson 1986; Habermehl 1975; Schmid 1972). Given the large number of undetermined fragments, mainly due to the combustion process, the osteological assemblage was then assessed from an anthropological perspective to verify the presence of possible remains belonging to the genus *Homo*.

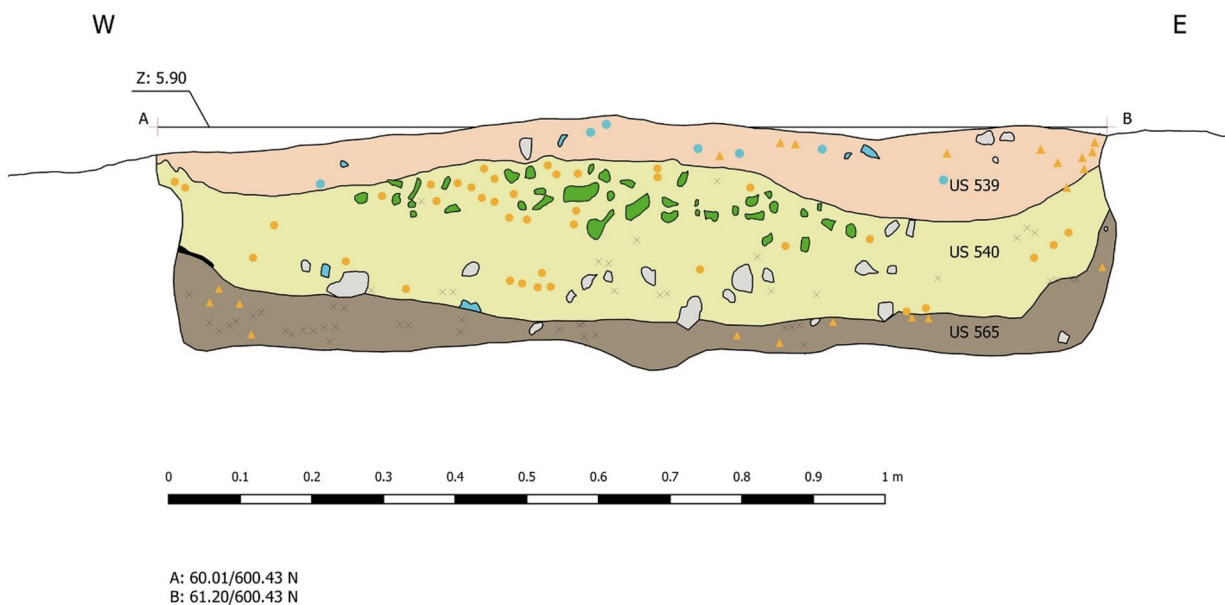
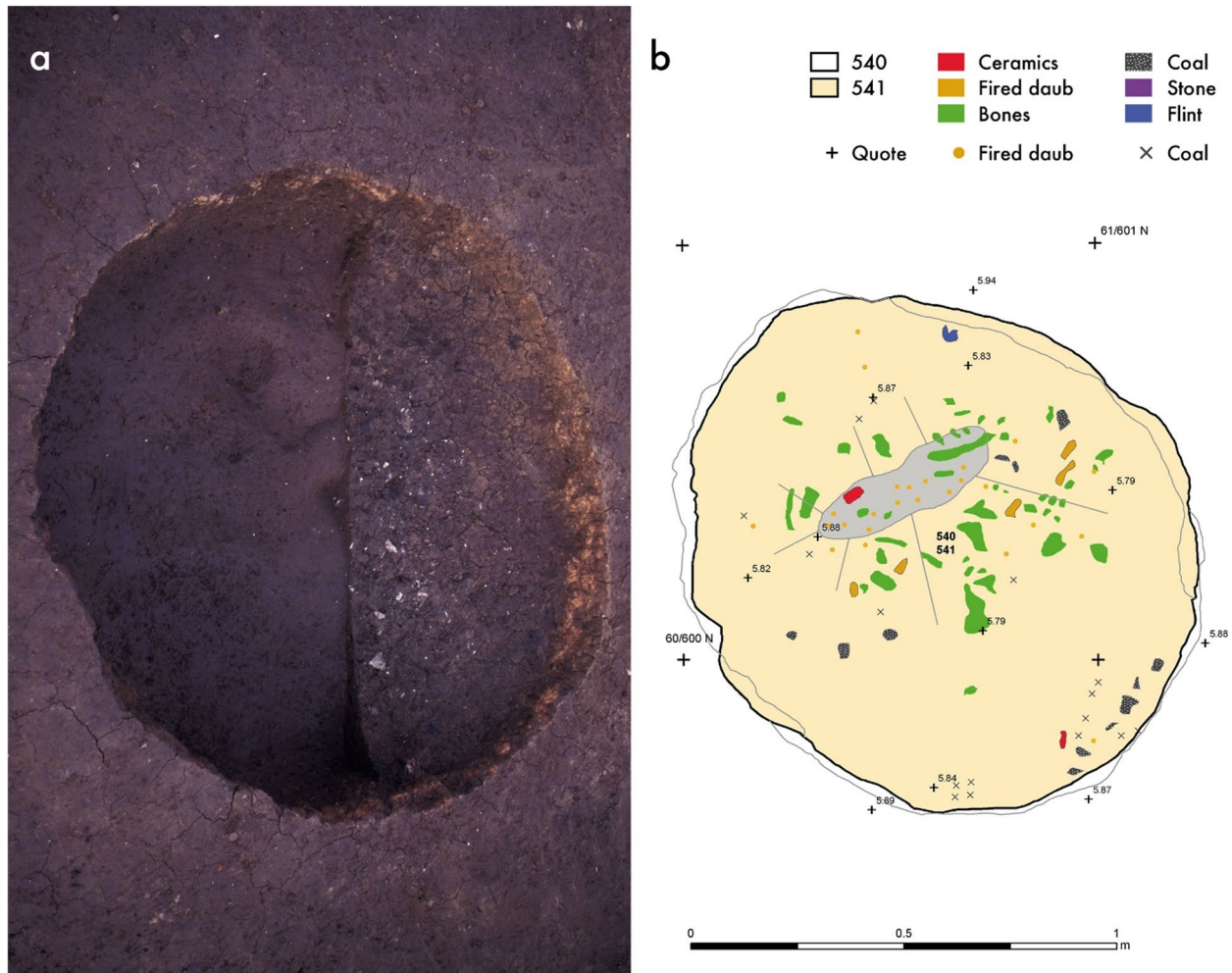
The TI of cremated human fragments relies on the same morphological principles used for unburnt bones (France 2021; White et al. 2012) and other features such as bone section, the ratio of cortical to trabecular bone, and the density of the latter (Depierre 2014; White et al. 2012). In cases where the morphological determination of fragments is uncertain, other diagnostic techniques, including histology, can be employed (Crowder and Stout 2021).

In this study, we employed the terms diagenesis and taphonomy to refer to different aspects of post-mortem processes. Specifically, diagenesis is used to describe the range of chemical and physical alterations affecting bone components in response to burial conditions, often influenced by soil chemistry (i.e. Del Valle et al. 2025). Taphonomy, on the other hand, encompasses all modifications that occur to bones after the individual's death (i.e. White et al. 2012; Buikstra 2019). Although taphonomy, broadly defined, includes diagenetic processes, we chose to treat these two aspects separately in our analysis.

Histological analyses

Microscopic analysis of cremated bone has various scientific applications, including determining the human or non-human origin of the analysed fragment (Caccia et al. 2016; Cattaneo et al. 2009). Histology is particularly useful in this regard, but it requires the production of thin sections (hereafter TS) of good quality. Many authors have proposed procedures for preparing TS of cremated bone, mainly aiming to facilitate production and reduce costs (De Boer and Maat 2012; García-Donas et al. 2017).

In this study, a TS preparation protocol is proposed for the histological analysis of bone tissue, focusing on its structure and measurements such as the diameter of the Haversian canal, density, and the diameter of the Haversian system (Hillier and Bell 2007). Additionally, it is used to estimate the skeletal age of individuals through the osteon count method applied to the cremated remains (Kerley and Ubelaker 1978; Wolf et al. 2017). For each fragment, three sampling points were selected, aiming to avoid the cortical



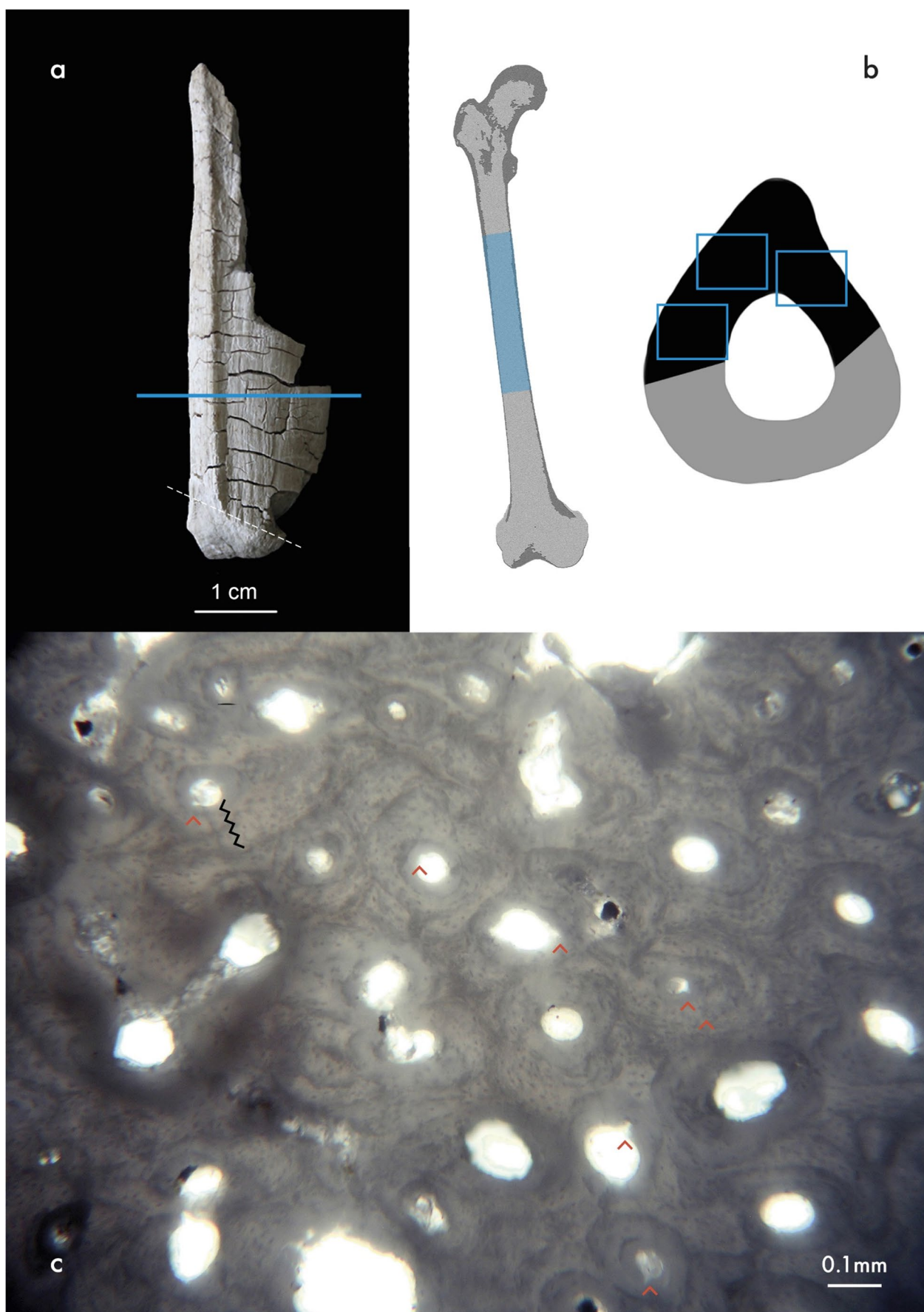


Fig. 3 Sample ES 541 US 540 sector XVI_1. (a) Transverse section of the femur taken along the plane represented by the blue line, the dotted line indicates a fracture probably linked to the burning of the fragment; (b) Representation of the transverse section of the femur, with the black area indicating the section of bone present and the blue rectangles marking the evaluated areas; (c) Transmitted light acquisition of the TS of the cortical tissue, in which the osteon structure is clearly visible. Small cracks of the Haversian canal (orange arrows) related to the heating process and small fractures likely due to diagenetic and taphonomic events (black zigzag line) are present. The dotted line indicates a fracture probably linked to the burning of the fragment. The area shown in image (c) is the one indicated by the blue rectangle at the bottom left of image (b)

area and those near the *linea aspera* (10x magnification, 2.2 mm² area). The acquisition of measurements was performed using the digital image processing software ImageJ.

Sample Preparation

The sample undergoes a slow dehydration process in a series of alcoholic solutions with increasing concentration until absolute alcohol is reached. Subsequently, it is placed in a solution composed of 50% absolute alcohol and 50% photo-polymerisable resin based on methacrylate and, finally, in pure resin. The impregnated sample is then placed in a plastic mould filled with resin for polymerisation using an Exakt polymeriser. The block is later detached from the mould, glued to a plastic microscope slide, and abraded with abrasive paper discs mounted on an Exakt grinding machine to achieve a smooth surface. A cover glass is then attached to the smooth surface using a glass coverslip. Using the Exakt 300 CP cutting unit, a section is made near the second coverslip. The obtained section undergoes thinning and vitrification through abrasive discs to achieve a perfectly smooth section approximately 100 µm thick. The section is finally ready for observation under a microscope in normal transmitted light.

Radiocarbon dating

One sample of fully calcined human bone from pit ES 541 US 540 sector XVI corresponding to a fragment of diaphysis (femur) of 0.85 g, was submitted for radiocarbon dating at the Royal Institute for Cultural Heritage (KIK-IRPA) in Brussels, Belgium. The other human bone fragments did not reach the minimum weight required for ¹⁴C dating. The applied protocol for the pre-treatment of cremated bone and the subsequent processes (CO₂ extraction and graphitisation) is described in Wojcieszak and colleagues (2020). The ¹⁴C/¹²C ratio in the graphite was measured with the AMS type MICADAS, mini carbon dating system, at the KIK-IRPA (Lab-code: RICH) (Boudin et al. 2015) and converted into a radiocarbon age (expressed in years BP), after correction for isotope fractionation, using the δ¹³C AMS

measurement. Calibration of this radiocarbon age (BP) and all dates cited in the text into calendar years (BCE) was performed using the software OxCal 4.4 (Bronk Ramsey 2009) and the atmospheric calibration curve IntCal20 (Reimer et al. 2020).

Limitations of the study

From a morphological perspective, the obvious challenge arises from the difficulty of TI in cases of high fragmentation (Larentis 2023b). Moreover, heat-induced fractures do not seem to be, in this case, a decisive factor to determine the human or non-human TI of the remains (Gonçalves et al. 2011). The colour of the fragments is traditionally attributed to the temperature reached during combustion (Holck 1986). However, recent literature questions this interpretation, as the colour of burnt bones is primarily attributed to the amount of oxygen available in the combustion micro-environment (Rosa et al. 2023). The coexistence of colours ranging from black to white, passing through various shades of grey, does not allow for hypotheses about the treatment of the remains or the processes that led to the formation of the deposit. Another limitation is the inability to verify whether the remains result from a single episode or multiple burning events (Cavulli et al. 2023; Costa et al. 2019).

From an anthropological perspective, given the high fragmentation of the bones, the only way to assess the representativeness of human remains within the total elements would be to sample a statistically significant number of pieces and perform histological analysis on all of them. The long analysis times, costs, and the loss of a significant portion of the available sample necessitate caution in making this choice. Furthermore, as suggested by Wolf and colleagues (2017), the method used to estimate the age of cremated individuals encounters substantial difficulties due to factors such as the degree of tissue shrinkage. Therefore, histological analysis can be useful to hypothesise the presence of subjects with a substantial difference in quantitative values acquired through osteon counting, but not to estimate an age range with a high degree of confidence. The need to adopt these methods arose from the impossibility of conducting ZooMS analysis on the fragments, as this technique cannot be applied to cremated bone (McGrath et al. 2019).

Results

Zooarchaeological analysis was conducted on the 5695 bone fragments recovered from US 540 ES 541 Sector XVI, of which osteometric evaluation and TI allowed for species identification of 46 remains (Table 2). *Bos taurus* appears

Table 2 List of the number of identified specimens (NISP) from US 540 ES 541 sector XVI at Lugo Di Grezzana

Sector	ES	US	TI	NISP
XVI	541	540	<i>Bos taurus</i>	22
			<i>Cervus elaphus</i>	3
			<i>Sus scrofa</i>	1
			<i>Bos taurus/Cervus elaphus</i>	9
			<i>Bos taurus/Sus scrofa</i>	1
			<i>Capra hircus/Ovis aries</i>	1
			<i>Bos taurus</i> (?)	5
			<i>Cervus elaphus</i> (?)	1
			<i>Homo sapiens</i>	3
Total				46

to be the most well represented species, with one fragment displaying cut marks on the outer cortical surface.

Among all these, TI of three burnt fragments suggests they may be human, attributed to the femur in two cases (Figs. 3a and 4a) and a tibia in another (Fig. 5a). In particular, a fragment of the femur was identified by the presence of the *linea aspera*, which, even from a macroscopic perspective, suggests a human origin for the specimen. Specifically, this corresponds to the central portion of the diaphysis, where, in the human femur, the *linea aspera* is flanked by two ridges: the *labium mediale* and the *labium laterale* (Fig. 3a) (cortical thickness = 7.9 mm cortical thickness at the *linea aspera* = 11.7 mm). Due to fire-induced deformation and the fragment's small size, determining the laterality of the element was not possible.

A second case is represented by what appears to be another femoral fragment, originating from the proximal diaphysis, specifically in the region of the spiral line, which serves as the attachment site for the *vastus medialis* muscle (Fig. 4a) (cortical thickness = 7.6 mm). The position of this feature allows for the identification of the femur as belonging to the right side.

The final fragment has been hypothesised to be part of the anterior crest of the tibia, based on cortical thickness (cortical thickness at the cresta = 9.4 mm) and the triangular shape that this structure typically assumes in our species (Fig. 5a). However, due to fire-induced deformation, it was not possible to determine the laterality of this bone.

The morphological analysis of bone tissue in TS consistently revealed the presence of osteon banding and the absence of plexiform structure, as noted by Mulhern and Ubelaker (2001). Subsequent morphometric evaluation indicated that the osteon measurements fell within the expected ranges for human tissue reported in the literature (Table 3).

Osteon counting allowed for the estimation of skeletal ages for the samples under examination. It is possible that ES 541 US 540 structure XVI_1 is a fragment of femoral diaphysis of an individual in his/her fifth-seventh decade of life, ES 541 US 540 structure XVI_2 is a similar anatomical

Fig. 4 Sample ES 541 US 540 sector XVI_2. (a) Transverse section of the femur taken along the plane represented by the blue line; (b) Representation of the transverse section of the femur, with the black area indicating the section of bone present and the blue rectangles marking the evaluated areas; (c) Transmitted light acquisition of the TS of the cortical tissue, in which the osteon structure is less visible in the lower portion (orange rectangle). The compact cortical bone is characterised by small taphonomic fractures (black zigzag lines). The area shown in image (c) is the one indicated by the blue rectangle at the bottom right of image (b)

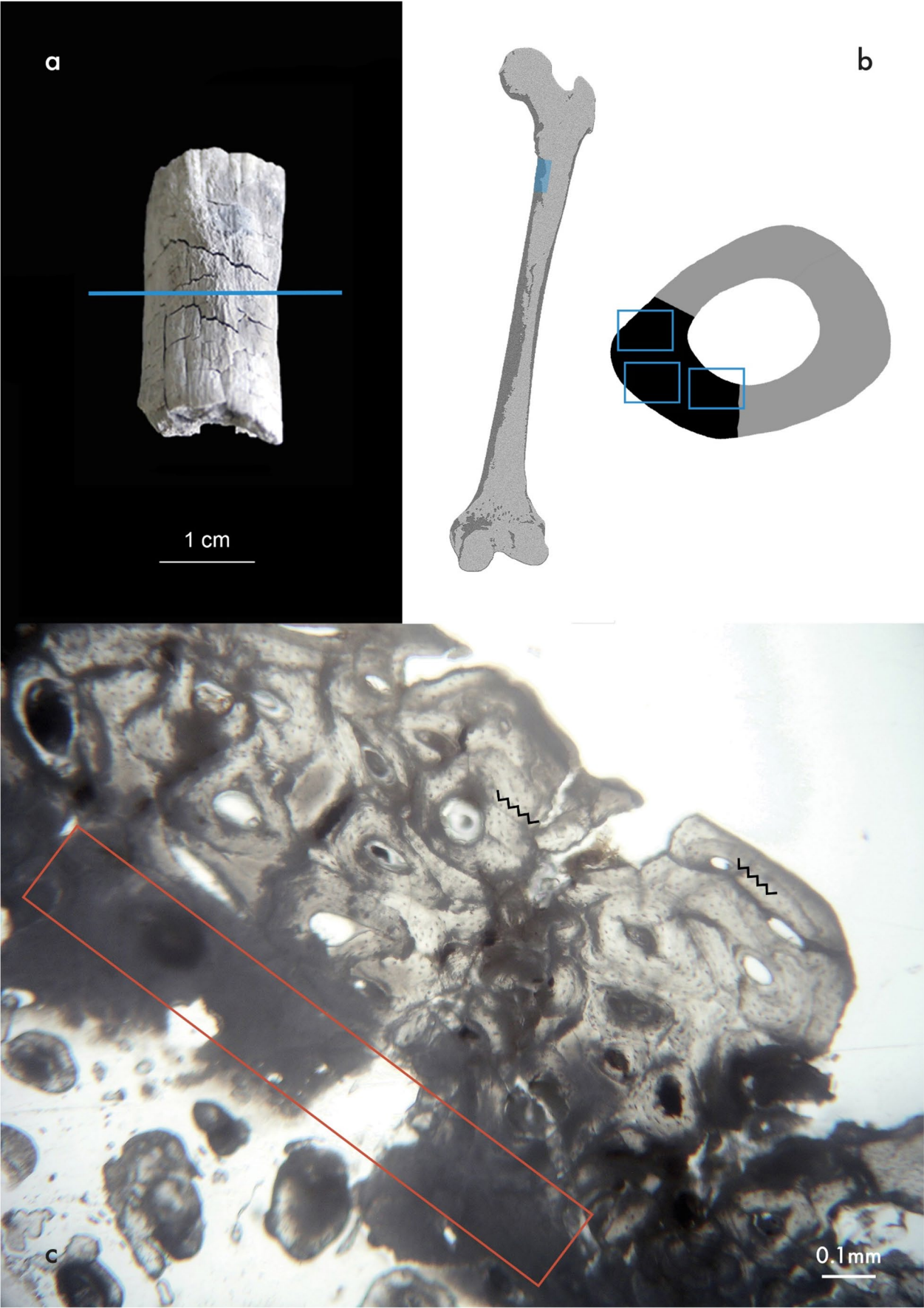
portion of an individual in his/her third-sixth decade, and ES 541 US 540 structure XVI_3 is a fragment of the tibia of an individual likely in his/her first-second decade (Table 4).

The fragment of calcined femoral diaphysis from pit ES 541 US 540 sector XVI (Fig. 3a), yielded a radiocarbon date (RICH-35214) of 6044 ± 26 BP, calibrated to: 4993–4905 BCE (1σ) or 5024–4845 BCE (2σ) (Fig. 6; Table 5). The low carbon content (0.18%) and the complete calcination of the sample (i.e., fully white) confirm the loss of organic carbon and the preservation of only bioapatite carbonate (Hüls et al. 2010; Van Strydonck et al. 2010), thereby ensuring the reliability of the sample for radiocarbon dating. The resulting date corresponds to the end of the Fiorano Culture and the emergence of the Square-Mouthed Vases Culture (*Cultura dei Vasi a Bocca Quadrata*) in the Po Valley (Pedrotti et al. 2015).

Discussion

From a methodological perspective related to osteological analysis, this study emphasises the importance of interdisciplinary analysis of burnt osteological remains, regardless of the context of their discovery. Macroscopic and microscopic zooarchaeological and anthropological analyses have highlighted the presence of burnt human bones within the pit ES 541 sector XVI at the Early Neolithic site of Lugo di Grezzana. Zooarchaeological analysis allowed the TI of numerous bones, all with traces of burning, among which those attributable to *Bos taurus* stood out due to their number and the presence of cut marks (Maccarinelli et al. 2015). The higher abundance of *Bos taurus* compared to other taxa may be attributed to various factors. The bones of large animals, such as *Bos taurus*, may have been less affected by fire processes due to their greater robustness compared, for example, to those of caprines. This could have led to better overall preservation of the more robust bones and, in particular, of the areas useful for macroscopic taxonomic identification.

A series of ^{14}C dates obtained on fragments of charcoal frame the use of these pits and the oven between 5465 and 5007 cal BCE (Costa et al. 2019). On one hand, the presence of numerous non-human fragments allowed the



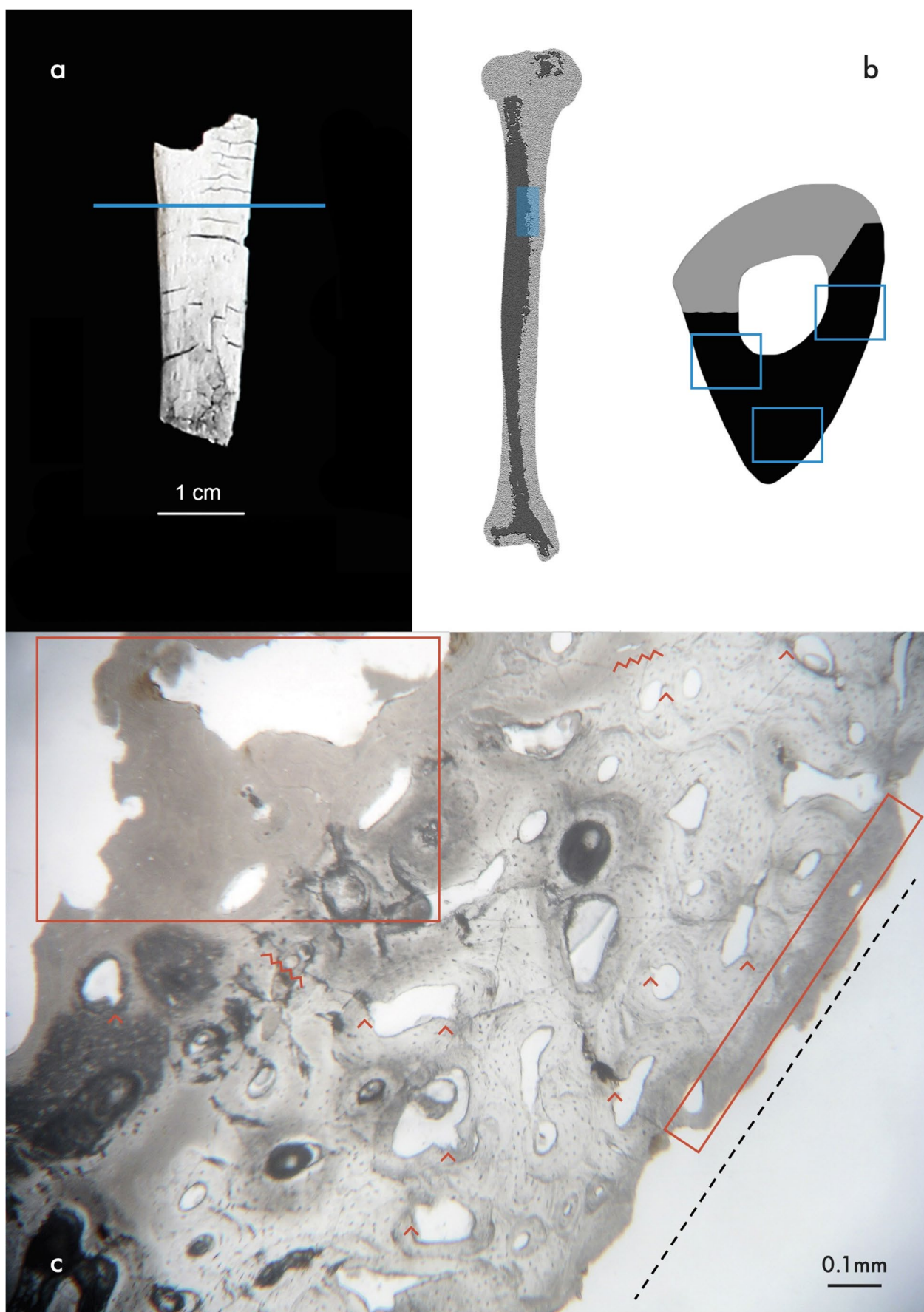


Fig. 5 Sample ES 541 US 540 sector XVI_3. (a) Transverse section of the tibia taken along the plane represented by the blue line; (b) Representation of the transverse section of the tibia, with the black area indicating the section of bone present and the blue rectangles marking the evaluated areas; (c) Transmitted light acquisition of the TS of the cortical tissue, in which the osteon structure is clearly visible in its central portion, while the periosteal and endosteal surfaces are less readable, as shown in the orange rectangles. The black dashed white line follows an erosion front due to diagenesis or taphonomy. The sample shows numerous cracks in the Haversian canals (orange arrows), sometimes continuing into fractures passing through the osteon structures (orange zigzag lines). The area shown in image (c) is the one indicated by the blue rectangle at the top right of image (b)

interpretation of the structure ES 541 sector XVI as an oven for cooking food containing meat or butchering residues (Cavulli et al. 2023; Costa et al. 2019; Maccarinelli et al. 2015); on the other hand, the overall study of these pits and of the oven led to their generic identification as combustion structures based on morphological criteria, given the difficulty in their functional interpretation (Cavulli et al. 2023; Costa et al. 2019).

Macroscopic anthropological analysis suggested the possible TI of three bone fragments within the genus *Homo* (Table 2). This was possible thanks to the identification of specific anatomical landmarks typical of the human skeleton, such as the *linea aspera* (*vastus medialis* muscle insertion) and the anterior tibial crest. The hypothesis of TI was integrated through the morphometric analysis in TS of the fragments (Figs. 3a, 4a and 5a). Firstly, the absence of plexiform tissue, characteristic of non-human bone sample, was evident (Crescimanno and Stout 2012; Mulhern and Ubelaker 2001). Further consideration comes from the average measurements of the Haversian canal diameter, the Haversian system diameter, and the Haversian system density (Table 3). These variables are among the most useful for TI (Hillier and Bell 2007), and even considering a possible dimensional reduction likely linked to the grey areas where the tissue is not observable, we can hypothesise a very advanced stage of the combustion process that resulted in bone calcination. This is indicated by both the white colour of the fragments and the poorly preserved periosteal and endosteal surfaces, a sign that the inversion process (500/700–1100 °C) was likely underway (Mayne Correia 1997; Thompson 2004, 2005). Even considering a reduction in bone tissue of about 10%, as proposed by Buikstra

and Swegle (1989), due to the combustion process, the values still fall within the expected range for unburnt human bone. The potential overlap between human and non-human values is observed in the Haversian canal diameter. Human values typically range from 30 to 175 µm, while goat, sheep, and cow values partially overlap within these ranges (goat = 15–70 µm, sheep = 20–120 µm, cow = 15–55 µm; from Hillier and Bell 2007). In our sample, values range from 115 to 170 µm. Even without considering the volumetric reduction due to calcination, the overlap is minimal, allowing us to confidently exclude species other than humans.

The analysis of bone tissue via TS was also useful in formulating hypotheses about the age of the individuals. The chosen method is the one proposed by Kerley and Ubelaker (1978), which, although presenting some issues related to burnt remains (such as the degree of bone shrinkage and areas of poor visibility), allowed the estimation of different skeletal ages for the three analysed fragments. This evidence indicates that the oven served as a place where the community, or perhaps an individual, chose to deposit the remains of multiple individuals, whether these were perceived as remnants of a secondary ritual or as the primary actors within the ceremony itself. Although the interpretation remains challenging, given the possibility that the remains derive from a single ritual event, it is plausible to suggest that the deposition of multiple individuals within such a unique context was a common practice within the cultural sphere of those who carried it out. The radiocarbon analysis of ES 541 US 540 sector XVI_1 (Fig. 3a) provided a date between 5024 and 4845 cal BCE, which appears to be later compared to the use of the pits as ovens. During the burning process an exchange of carbon, which can be up to 95%, between the bone bioapatite and the fuel takes place (Hüls et al. 2010; Olsen et al. 2013; Snoeck et al. 2014; Zazzo et al. 2009, 2012). This implies that radiocarbon dates on calcined bone might potentially be affected by an old-wood effect. If the individual was burnt with older wood, it might result in a ¹⁴C date older than the actual event. The date on the human bone fragment from pit ES 541 US 540 sector XVI aligns with the stratigraphic information. Two radiocarbon measurements, DSH-461 (5959 ± 48 BP, 4984–4719 cal BCE) and DSH-462 (5946 ± 24 BP, 4901–4726 cal BCE), date

Table 3 Measurements obtained from the histological analysis of ES 541 US 540 sector XVI_1–3 (Figs. 3b, 4b and 5b). Expected range in the human sample (ER, from Hillier and Bell 2007) and mean of the measurements acquired in the Lugo Di Grezzana sample; measurements are expressed in µm, and density in mm³

Measure	ER	ES 541 US 540 structure XVI_1			ES 541 US 540 structure XVI_2			ES 541 US 540 structure XVI_3		
		1	2	3	1	2	3	1	2	3
Haversian canal diameter	30–175	150	125	140	115	135	160	155	170	130
Haversian system diameter	190–320	260	210	285	245	220	275	310	280	295
Haversian system density	5–40	30	15	35	20	25	30	40	35	40

Table 4 The values inserted into the Hillier and Bell regression formulas (2007) are the average number of osteons counted per analysed area (Figs. 3b, 4b and 5b). The figures are rounded to the second decimal place, and after the estimated age, we have included the values adjusted by subtracting (RMSR-) or adding (RMSR+) the root mean square residual value (RMSR)

Regression Equation	Value	Estimated Age	RMSR-	RMSR+
ES 541 US 540 structure XVI_1 (femur)				
Osteons	122	58.73	49.54	67.92
Osteon Fragments	50	54.44	47.46	61.42
% Lamellar Bone	7	63.05	50.53	75.57
Non-haversian	5	44.00	31.88	56.12
ES 541 US 540 structure XVI_2 (femur)				
Osteons	89	36.82	27.63	46.01
Osteon Fragments	39	42.05	35.07	49.03
% Lamellar Bone	13	53.67	41.15	66.19
Non-haversian	17	20.64	8.52	32.76
ES 541 US 540 structure XVI_3 (tibia)				
Osteons	46	16.94	6.41	27.47
Osteon Fragments	21	19.35	10.93	27.77
% Lamellar Bone	51	14.02	-0.26	28.30
Non-haversian	41	8.33	-1.86	18.52

the last occupation of the site and provide a *terminus ante quem* for the colluvium covering the pits (Angelucci 2002; Cavulli et al. 2002; Pedrotti et al. 2015; Rottoli et al. 2015). Consequently, an old-wood effect in the radiocarbon date is unlikely or negligible.

Regarding the formation of the archaeological deposit, several considerations are necessary. First, it would be important to estimate the deposition timing of human fragments relative to non-human ones. During the excavation of ES 541 US 540 sector XVI, carried out by the Soprintendenza Archeologica per il Veneto, no individual identification numbers were assigned to each recovered bone element, nor were their spatial coordinates or orientation recorded. Collecting such data is time-consuming and is typically reserved for contexts that, prior to analysis, appear particularly significant or pose archaeological questions that can only be addressed through the acquisition of spatial data. In hindsight, gathering this information would have been crucial for chronologically defining possible deposition events of the bones, which unfortunately remain unknown. The combustion patterns, including colour, fractures, and fragment sizes, also do not aid in reconstructing the formation dynamics of the deposit as during the excavation and recovery much information that would have been useful to create a microstratigraphy of the context was not acquired. Therefore, it was not possible to determine whether the deposit resulted from a single or multiple burning events occurring in situ, or if the remains were deposited in the oven all at once or at different times following their combustion elsewhere. The fragments are mostly calcined and vary in size, conditions that leave little room for further hypotheses.

These new data prompted a holistic interpretation of the archaeological context and the funerary aspects that likely characterised its final phase. From the perspective of

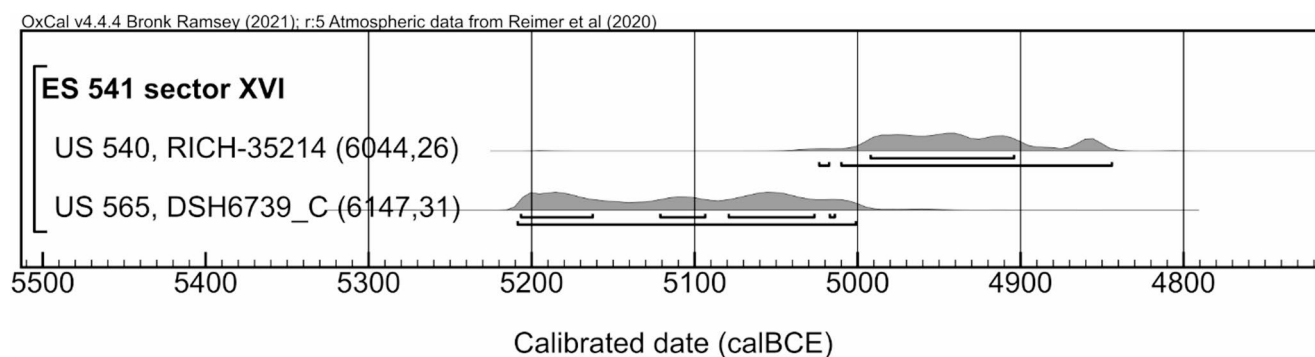


Fig. 6 OxCal plot showing the calibrated radiocarbon dates on a fragment of charcoal (DSH6739_C) and on a fragment of calcined human bone (RICH-35214) from pit ES 541 sector XVI in Lugo di Grezzana

Table 5 Radiocarbon dates on calcined bone from Early Neolithic contexts that yielded burnt bone human remains. The dates have been calibrated using the atmospheric calibration curve IntCal20 (Reimer et al. 2020)

Site	Feature	Material	¹⁴ C Lab-code	¹⁴ C Age BP ± σ	Age cal BCE (2σ)	Weight	% C	AMS δ ¹³ C‰	References
Lugo di Grezzana	ES 541 US 540	Calcined bone	RICH-35214	6044 ± 26 BP	5024–4845 BCE	0.85 g	0.18	-25.8	This study
Lugo di Romagna	US 1171, pit US 1170	Calcined bone	LTL-13471 A	6335 ± 45 BP	5468–5213 BCE	-	-	-	Steffé 2019

understanding the ritual use of fire in the past, it is meaningful to remind that its use as a transformative element in funerary rituals reflects human beliefs about the relationships between body, spirit, and the afterlife across different cultures (Tartari 1996; Wright 2021). Burnt remains represent the final discernible event in a series of treatments given to the corpse, which often leave few traces archaeologically. In both ancient and many contemporary societies, there is a need to preserve the essence of the deceased in an indestructible form, such as bones, which are not subject to visible decomposition. According to Van Gennep, the purpose of destroying the body is to separate the immaterial from the material (Van Gennep 1909). Fire rituals often aim to separate the soul and return the bones to the community. Bones are seen as enduring symbols of life, preserving the identity of the deceased, and the dead are not merely biological remains but retain cultural and emotional significance (Favole 2003). Cremation transforms rather than eliminates remains, ensuring the generative potential of bones and maintaining the connection with ancestors and future generations (Lévi-Bruhl 1927; Tartari 1996).

In particular, regarding Lugo di Grezzana, it is essential to note the presence of both human and non-human bones within the same pit, a feature rare in Neolithic contexts of the Italian Peninsula. The *Serra d'Alto* site of Le Macchie (Bari, Apulia), in southeastern Italy, is one of the few available comparisons: among the numerous human remains with evidence of burning, belonging to multiple individuals, several fragments of caprine bones were identified (Fiorentino et al. 2000). However, what stands out at Lugo di Grezzana is the absence of human cranial elements—typically the anatomical components central to ritual attention—and the exclusive presence of postcranial bones.

Interpretation in this regard can take two main perspectives. On one hand, emphasising fire as the principal element of ritual activity, the context acquires a ritual significance centred on the combustion of human bones. On the other hand, highlighting the absence of the cranium—possibly removed due to its symbolic value—could suggest that the pit served as a location for disposing of biological remains no longer imbued with symbolic significance. Our interpretation leans toward emphasising the transformative role of fire as a key element in the treatment of human remains. The ritual linked to fire is, therefore, a multifaceted and complex practice that assumes various forms and variations over time and space. New archaeological and bioarchaeological data suggest that the use, albeit sporadic, of this rite in the Italian Peninsula can be traced back to the Neolithic (Fig. 7; Table 5). Thus, the cultural context behind this rite must also be reconsidered, including human perception of corpse treatment and the use of ritual practices involving multiple stages of handling and manipulation of human remains.

In northern Italy at Lugo di Romagna (Ravenna, Emilia-Romagna) (Fig. 7), the role of fire as a transformative element of human remains is also attested within the Early Neolithic Fiorano culture. The cremation deposit from pit US 1170 of the hut (phase 0) belongs to a non-adult of 3–5 years (Mazzucchi and Fontana 2019), whose radiocarbon date (LTL13471A) on a calcined bone fragment yielded the date 6335 ± 45 BP, corresponding to the calibrated interval 5468–5213 BCE at 2σ (Steffé 2019) (Table 5). The oval pit was dug outside the eastern side of the hut, later covered by the hut floor, suggesting a ritual linked to the building's construction rather than a consolidated funerary practice (Steffé and Degasperis 2019).

The Early Neolithic funerary findings at Portonovo (Ancona, Marche), associated with the *Ceramica Impressa* culture, are also noteworthy (Fig. 7), as they are linked to the discovery of 16 ovens used between 5800 and 5600 cal BCE (Conati Barbaro 2019). Two of these ovens contain the remains of three inhumed individuals, while to the southwest, in a nearby open area, the cremation deposit of a 20-year-old woman was found in a pit, likely originally placed in a perishable container. The only available ^{14}C date on bone comes from the inhumed individual 3 from oven 5 (LTL5191A, 6418 ± 50 BP), dated between 5479 and 5235 cal BCE (2σ) (Conati Barbaro 2013), confirming the use of the ovens as burial spaces once their primary function was lost.

The presence of burnt human remains is also known within the site of Nave (Brescia, Lombardy) (Fig. 7), where a ^{14}C date (GX-24945; 6440 ± 90 BP) on charcoal places the cremation deposit Grave 1 between 5611 and 5217 cal BCE (Baioni et al. 2021). However, this date seems older than expected and requires further verification, considering that the settlement context uncovered during the excavations at Nave appears to be related to the Middle Neolithic archaic VBQ 1 (*Cultura dei Vasi a Bocca Quadrata* - Square-Mouthed Vases Culture) (Pedrotti et al. 2022). From this site, apparently at the same level, comes the inhumation burial of a 17–20-year-old woman of the VBQ 1 phase, indirectly radiocarbon dated based on a fragment of charcoal from a posthole (GX-21306, 5975 ± 70 BP) between 5044 and 4706 cal BCE (Pedrotti et al. 2022; Poggiani Keller 1999), and a second grave containing the burnt remains of a human skull currently under study by our research group, which plans to directly date the calcined bone. The two graves with burnt remains suggest a complex ritual: Grave 1 contained flintworking debris mixed with the bones, while in Grave 2, the skull fragments were kept inside a *figulina* pottery vase; the remains are completely calcined, making it impossible to determine if the selection of the skull occurred before or after the burning events. Of particular interest is the discovery of a menhir with anthropomorphic decoration, likely serving as a marker for the graves (Baioni et al. 2021).

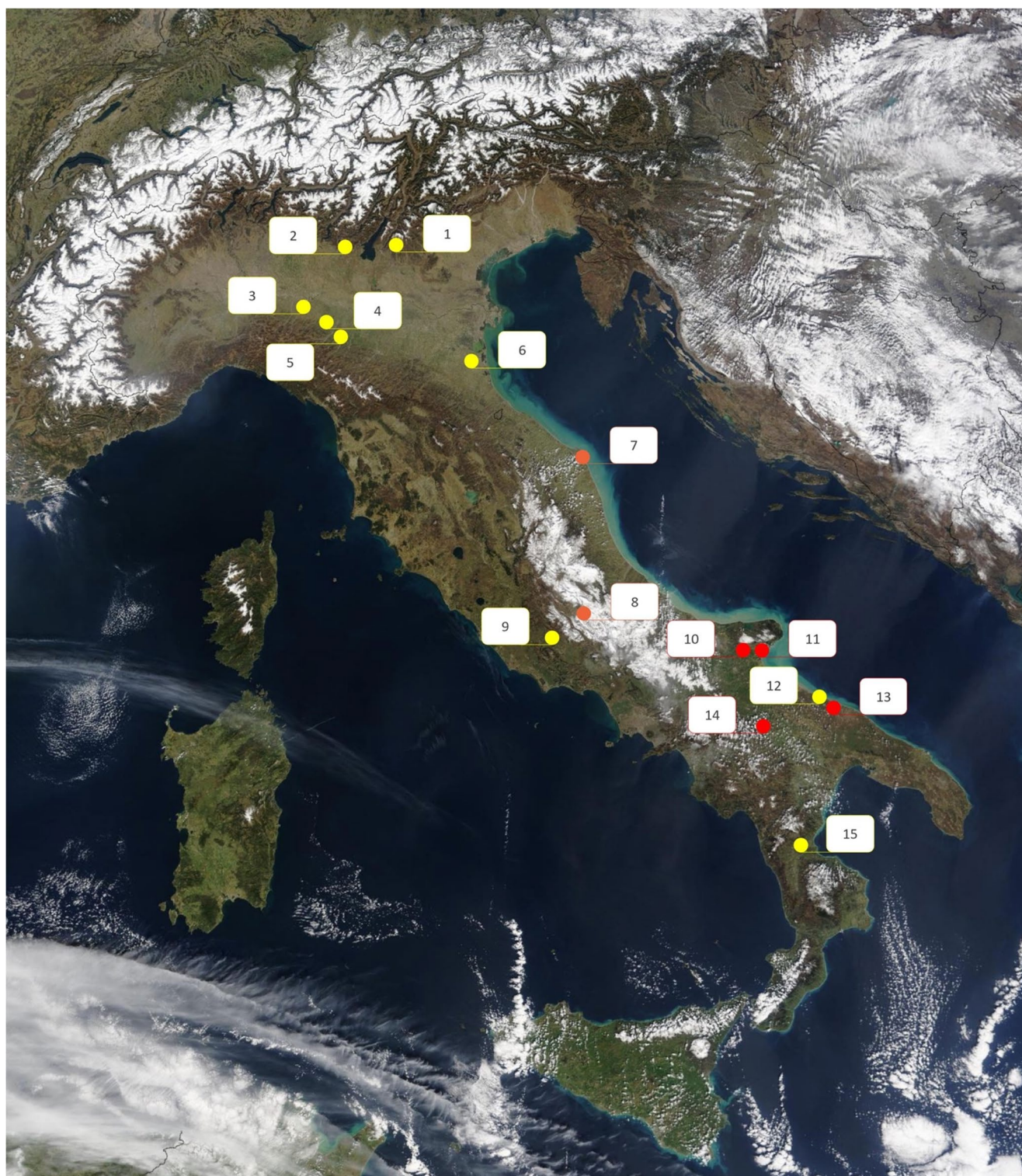


Fig. 7 Distribution map of Italian Neolithic sites where human bone remains with traces of fire-induced transformation have been found. 1 - Lugo di Grezzana (VR); 2 - Nave (BS); 3 - Le Mose (PC); 4 - Ponte Ghiara (PR); 5 - Gaione-Catena (PR); 6 - Lugo di Romagna (RA); 7 - Portonovo (AN); 8 - Grotta Continenza (AQ); 9 - Casale del Dolce (FR); 10 - Passo di Corvo (FG); 11 - Masseria Candelaro (FG); 12 - Le

Macchie (BA); 13 - Balsignano (BA); 14 - Rendina (PZ); 15 Grotta Pavovella (CS). The contexts dating before 5400 BCE are highlighted in red, those around 5400 BCE in orange, and those after 5400 BCE in yellow. The dates refer to the context, and only in the cases of Lugo di Romagna and Lugo di Grezzana the dates were obtained from calcined human bone (see also Table 5)

The cremated remains of a woman intermingled with the similarly burnt remains of a dog and a calcite bead were discovered in Structure 23, Grave 2, at the site of Ponte Ghiara (Parma, Emilia Romagna) (Fig. 7), above an archaic VBQ 1 inhumation burial ^{14}C dated to 4797–4554 cal BCE (Dal Santo and Mazziere 2010). The treatment of the osteological remains, the deliberate use of fire, and the location of the burial pit—positioned at the top of a silo—strongly suggest a ritual significance for this deposition (Bernabò Brea et al. 2010, 2014, 2016). Other VBQ sites, in Emilia Romagna, that yielded cremated human remains are Le Mose (Piacenza), with two cremation deposits, and Gaione-Catena (Parma) (Fig. 7), where four cases were recorded (Bernabò Brea et al. 2010).

Evidence suggesting the use of fire on human bones also comes from central and southern Italy. In the Early Neolithic Middle-Adriatic Impressed Ware facies (*Cultura della Ceramica Impressa*, 5600–5100 cal BCE), Grotta Continenza (L'Aquila, Abruzzo) (Fig. 7) is known for numerous inhumation burials, representing the predominant ritual, and some cremation deposits. These come from an area below the rock wall of the cave where vessels with burnt human remains were recovered. The calcined bone fragments from Grotta Continenza pertain to three individuals: two children aged four and eight years, contained in two vases, and an adult woman, whose remains were scattered over the vases (Grifoni Cremonesi and Mallegni 1978; Seradimigni et al. 2016). Evidence of bone treatment by fire is also present in Lazio in the pottery with incised lines (*Ceramica a linee incise*, 5300–4700 BCE, Pessina and Tinè 2022) site of Casale del Dolce (Fig. 7). In the area E, pit T11 yielded burnt bone remains likely belonging to a unique individual along with charcoal fragments and grains of wheat and barley, within a productive area characterised by numerous pyrotechnological structures (Bistolfi and Muntoni 1997; Conati Barbaro and Muntoni 2007). In the village of Rendina (Potenza, Basilicata), evidence has been found of human skeletal remains with traces of fire. Dated to the Early Neolithic, specifically the Rendina I phase, burial 3 was a double grave containing the remains of an adult woman and an 8–9-year-old child. A tibia and the temporal bone show clear signs of burning (Conati Barbaro 2008; Borgognini Tarli 1981).

Numerous burnt individuals were found in Grotta Pavolella at Cassano allo Ionio (Cosenza, Calabria) (Fig. 7). During the occupation of the site, which occurred during the trichrome pottery facies between 5300 and 5000 cal BCE (Pessina and Tinè 2022), above a layer containing Neolithic inhumation burials, the burnt remains of 20 individuals were found in a 10–15 cm thick layer, mixed with fineware pottery, lithic tools, burnt faunal remains, and charcoal, suggesting at least one in situ cremation event. This led some

researchers to interpret this layer not as a cultural variation of the funeral rite but as the result of a health contingency that saw fire as a useful element to quickly dispose of numerous individuals who died under unknown circumstances in a short time frame (Carancini and Guerzoni 1987; Colelli and Larocca 2018).

In southeastern Italy, the Apulia region is rich in evidence of human bone funerary treatments using fire. In the Early Neolithic *Ceramica Impressa* (Impressed Ware facies) settlement of Balsignano (Bari, Apulia) (Fig. 7), a parietal bone, a maxilla, and a mandible belonging to a 21–40-year-old male were found in a pit outside the perimeter of the settlement but located a short distance northwest of hut 1. This is not a traditional cremation deposit but probably a complex ritual involving at least the skeletonization of the subject, manipulation of the skeleton, selection of the skull, and exposure of the pieces to a heat source (Conati Barbaro 2008; Radina 1996). In the site of Passo di Corvo (Foggia, Apulia) (Fig. 7), three fragments of the neurocranium exhibiting traces of fire were discovered (Mariotti et al. 2020). These fragments were found among the scattered bones. The remains originate from Area β , specifically from square I9 of the excavation. The spatial distribution of the scattered bones suggests a possible association with the findings in the γ and β ditches, which are characterised by pottery painted in white (archaic Passo di Corvo) and thus can be dated to 5600–5400 BCE (Whitehouse 2014). The interpretation of these fragments remains uncertain due to their context of deposition, making it difficult to determine whether they are linked to ritual practices or simply the result of incidental processes. Nevertheless, it is intriguing to note yet another instance of skeletal element selection, in this case favouring cranial remains.

The site of Le Macchie (Bari, Apulia) (Fig. 7), in which numerous cremations were found, was dated to the Middle Neolithic *Serra d'Alto* facies between 4845 and 4556 cal BCE (Radina and Torre 2022). Around a central rectangular area delimited by five postholes, several stone circles, one to one and a half meters in diameter, were found, with four symmetrically arranged around the structure (Radina 2002). The stone circles contained the remains of a complete adult and numerous non-adults, including both skull and postcranial elements; in two cases, human remains were mixed with those of sheep and goats (Fiorentino et al. 2000). Several portions of the cranium bearing traces of fire damage were recovered from Structure Q at Masseria Candelaro (Foggia, Apulia) (Fig. 7). This structure encompasses a vast area of more than 200 m², where, between 5500 and 5400 BCE, over 400 bone fragments were found, all belonging to the cranium and mandible. Some of these fragments exhibited traces of fire exposure, while others did not. In this context, the prominence of the cranial region as a significant

element in ritual practices is evident, as is the use of fire as a transformative agent in certain cases (Marconi et al. 2004; Thompson et al. 2024).

To sum up, Italian Neolithic funerary rituals involving cremation, or more generally, the treatment of a human body or skeleton using fire as a transformative element, are well documented. However, the situation is far from uniform, with each context having specific characteristics and ritual variations. This lack of uniformity is also evident in inhumation burials, which display considerable heterogeneity in grave types and burial practices in central and southern Italy. Meanwhile, Early Neolithic inhumation burials in northern Italy remain poorly documented (Pesina and Tinè 2022).

At Lugo di Grezzana, the absence of the skull is particularly notable, as it is one of the most recognisable parts among assemblages of burnt bones from various species. Regarding the other postcranial bones, it is possible that they are mixed with non-human remains. However, the lack of macroscopic morphological criteria has hindered their identification, and comprehensive histological analyses were not conducted to preserve the integrity of the bone assemblage. The reuse of domestic structures for funerary purposes might be connected to the communal value of the site, transforming the settlement of the living into a “house of the dead.” At Portonovo, the deceased were placed in the ovens while the vaults were still present, but their original function had already been lost. Usually, hearths and ovens symbolise a domestic context, but in this case, where these structures are standalone production centres and not immediately connected to a house or village, they might represent something else (Conati Barbaro 2019).

The connection between the community, the spiritual world, combustion structures, and fire is made even more evident by the choice to use fire as a transformative element of the corpse or bones. As shown, the connection between fire and ritual seems quite widespread in the Neolithic. The abandonment of a domestic or productive structure is sealed with a funerary ritual that, in the case of Portonovo or Lugo di Grezzana, likely symbolises the end of a cycle of the structure’s use as confirmed by radiocarbon data. Abandoned huts, silos, and trenches can also be used as resting places because they still hold a strong communal memory, making them significant landmarks in the territory. These practices likely reflect a complex relationship between the living and the dead, where domestic and productive structures, once abandoned, assume new significance as places of memory and funerary rituality. The choice to use ovens and other fire-related structures for burials can be seen as part of a broader symbolic system that connects daily life, production, and the sacred, emphasising the continuity between the world of the living and the dead.

Conclusions

This study presents new data on rituals using fire as a transformative element for human remains during the Early Neolithic period in Italy. The analysis also considered other Early and Middle Neolithic archaeological evidence where bone remains with traces of fire were found, discussing their ritual and cultural significance. It highlighted how fire was not part of a funerary practice but rather a component of complex rituals whose effect on human remains we still do not fully understand. If we define cremation as the transformation of a body through fire, resulting in fully cremated bones after the loss of soft tissues, Neolithic contexts in Italy suggest the presence of additional variables that may indicate alternative types of ritual activities. In the Neolithic, the archaeological record presents a heterogeneous situation, likely reflecting a wider range of ritual variables within complex mortuary practices.

The presence of cracks within the Haversian canals of the di Grezzana sample could suggest combustion of the entire body. However, it is also possible that such features form when skeletal elements, already skeletonised but still rich in collagen, are burned. Thus, at Lugo di Grezzana, only postcranial elements may have been burned. Considering the dimensions of the pit, it is possible that the burning – whether partial or complete – of the corpse or skeleton occurred elsewhere, and that selected remains were subsequently deposited in the oven, where they were found together with non-human remains. However, it is also possible that the oven was the place where the remains of the individuals were burned, if not properly cremated, and that the fragments recovered represent what was left behind after the bones were collected from the pyre.

Considering the present data, the presence of cremated human bones, radiocarbon dated to 5024–4845 cal BCE, within ES 541 US 540 sector XVI suggests the use of the oven as a burial site, analogous to findings in Portonovo (Ancona), Italy. This simultaneously confirms the practice of manipulating and transforming skeletonised or in flesh human remains through fire, recently evidenced in the Impressed Ware culture at Portonovo (Conati Barbaro 2019) and in the Fiorano culture at Lugo di Romagna (Steffè and Degasperi 2019). Finally, at the current state of research, the review work suggests the spread of fire as a transformative element for human bones and/or human bodies, following a diffusion model that originates in Apulia and then expands across the Italian peninsula, eventually reaching the Po Valley.

This study also confirms the utility of histological methods in the analysis of cremated human osteological remains, particularly for verifying and supplementing macroscopic analysis when it does not provide sufficient data

for satisfactory interpretation. Additionally, this study highlights the importance of checking for the presence of human skeletal material within bone assemblages that might otherwise be identified solely as faunal elements. This is particularly relevant for burnt remains, as the process of burning causes changes in colour, fragmentation, and size that make morphological species determination more difficult, if not impossible (Nicholson 1993).

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Data availability No datasets were generated or analysed during the current study.

Declarations

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References

- Angelucci D (2002) Il Sito preistorico di Lugo di Grezzana (VR): prime osservazioni micromorfologiche. *Preist Alpina* 38:109–129
- Baioni M, Lo Vetro D, Poggiani Keller R (2021) Aggiornamenti su siti e materiali vbq della Lombardia settentrionale. In: Mottes E (ed) Vasi a bocca quadrata. Evoluzione delle conoscenze e nuovi approcci interpretativi. Provincia autonoma di Trento, Trento, pp 93–130
- Barfield LH (2007) Excavations in the Riparo Valtenesi. *Manerba* 1976–1994. Origines, Florence
- Barker G (1999) Hunting and farming in prehistoric Italy: changing perspectives on landscape and society. *Pap Br Sch Rome* 67:1–36. <https://doi.org/10.1017/S0068246200004517>
- Barone R (1976) Anatomia comparata dei mammiferi domestici. Edagricole, Bologna
- Bernabò Brea M, Maffi M, Mazziere P, Salvadei L (2010) Testimoni-anze funerarie della gente dei Vasi a Bocca Quadrata in Emilia occidentale. *Archeologia e antropologia. Rivista di Scienze Preistoriche* LX:63–126
- Bernabò Brea M, Maffi M, Mazziere P, Salvadei L (2016) Sepolture anomale nei contesti VBQ dell'emilia occidentale. In: Bernabò Brea M (ed) Preistoria e Protostoria dell'Emilia-Romagna – I. Atti Della XLV Riunione scientifica dell'Istituto Italiano di Preistoria e Protostoria. Studi di Preistoria e Protostoria, Florence, pp 211–218
- Bernabò Brea M, Maffi M, Mazziere P, Salvadei L, Tirabassi I (2014) Le necropoli VBQ in Emilia. *Rivista di Studi Liguri* LXXVII–LXXIX:303–313
- Bistolfi F, Muntoni I Lo scavo delle aree A, B, D E (1997) In: Zarattini A, Petrassi L (eds) Casale del Dolce. Ambiente, economia e cultura di una comunità preistorica della Valle del Sacco. Skira, Rome, pp 59–160
- Borgognini Tarli S (1981) Rendina: notizie antropologiche preliminari. In: Cipolloni Samppò I (ed) Origini: preistoria e protostoria delle Civiltà Antiche. Università La Sapienza di Roma, Rome, pp 333–335
- Boudin M, Van Strydonck M, van den Brande T, Synal HA, Wacker L (2015) Rich – a new AMS facility at the Royal Institute for Cultural Heritage, Brussels, Belgium. *Nucl Instrum Methods Phys Res B Beam Interact Mater At* 361:120–123. <https://doi.org/10.1016/j.nimb.2015.04.006>
- Bronk Ramsey C (2009) Bayesian analysis of radiocarbon dates. *Radiocarbon* 51(1):337–360. <https://doi.org/10.1017/S0033822200033865>
- Buikstra JE (2019) Ortner's identification of pathological conditions in human skeletal remains. Elsevier, United States
- Buikstra JE, Swegle M (1989) Bone modification due to burning: experimental evidence. In: Robson B, Sorg H (eds) Bone modification. Institute of Quaternary Studies, University of Maine Orono, pp 247–258
- Caccia G, Magli F, Tagi VM, Porta DG, Cummaudo M, Márquez-Grant N, Cattaneo C (2016) Histological determination of the human origin from dry bone: a cautionary note for subadults. *Int J Legal Med* 130:299–307. <https://doi.org/10.1007/s00414-015-1271-6>
- Capuzzo G, Barceló JA (2022) Cremation burials in central and south-western Europe: quantifying an adoption of innovation in the 2nd millennium BC. *Anthropol Prehist* 131:113–160. <https://doi.org/10.57937/ap.2022.006>
- Carancini GL, Guerzoni RP (1987) Gli scavi Nella Grotta Pavolella presso Cassano allo Jonio. Atti Della XXVI Riunione scientifica dell'Istituto Italiano di preistoria e Protostoria. Istituto italiano di Preistoria e Protostoria, Florence, pp 783–792

- Cattaneo C, Porta D, Gibelli D, Gamba C (2009) Histological determination of the human origin of bone fragments. *J Forensic Sci* 54:531–533. <https://doi.org/10.1111/j.1556-4029.2009.01000.x>
- Cavazzuti C, Arena A, Cardarelli A, Fritz M, Gavranovic M, Hajdu T et al (2022) The first ‘urnfields’ in the plains of the Danube and the Po. *J World Prehist* 35:45–86. <https://doi.org/10.1007/s10963-022-09164-0>
- Cavulli F, Angelucci D, Pedrotti A (2002) La successione stratigrafica di Lugo di Grezzana (Verona). *Preist Alpina* 38:89–107
- Cavulli F, Costa A, Pedrotti A (2023) Pyrotechnological processes behind fire traces: experimental archaeology for the interpretation of the archaeological record of Lugo di Grezzana. *J Archaeol Sci Rep* 47:103829. <https://doi.org/10.1016/j.jasrep.2023.103829>
- Cavulli F, Pedrotti A (2002) L’insediamento del Neolitico Antico di Lugo di Grezzana: La Palizzata lignea. *Preist Alpina* 37:11–2
- Cohen A, Serjeantson D (1986) A manual for the identification of bird bones from archaeological sites. Jubilee Printers, London
- Colelli C, Larocca A (2018) Il pollino. Barriera naturale e Crocevia Di culture. Dipartimento di Archeologia e Storia delle Arti - Università della Calabria, Cosenza
- Conati Barbaro C (2008) Custodire La memoria: Le sepolture in abitato nel Neolitico Italiano. *Scienze dell’Antichità* 14(1):49–70
- Conati Barbaro C (2013) Cooking, working and burying in ancient neolithic: the ovens of Portonovo (Marche, Italy). *Origini* XXXV:31–51
- Conati Barbaro C (2019) Il fuoco e la memoria, i forni neolitici di Portonovo. Museo e Istituto Fiorentino di Preistoria Paolo Graziosi, Florence
- Conati Barbaro C, Muntoni IM (2007) Il Neolitico medio di Casale del Dolce: la cultura materiale (area E, scavo 1997). In: *Atti della XL Riunione Scientifica dell’Istituto Italiano di Preistoria e Protostoria*, pp 42–46
- Costa A, Cavulli F, Pedrotti A (2019) I focolari, forni e fosse di combustione di Lugo di Grezzana (VR). *IpoTESI Di Preistoria* 12:27–48. <https://doi.org/10.6092/issn.1974-7985/10256>
- Crescimanno A, Stout SD (2012) Differentiating fragmented human and nonhuman long bone using osteon circularity. *J Forensic Sci* 57:287–294. <https://doi.org/10.1111/j.1556-4029.2011.01973.x>
- Crivellaro F, Cavazzuti C, Candilio F, Coppa A, Tecchiati U (2022) Salerno—Dos de la forca (Adige valley, Northern Italy): a unique cremation site of the Late Bronze Age. *PLoS ONE* 17(5):e0267532. <https://doi.org/10.1371/journal.pone.0267532>
- Crowder C, Stout S (2021) Bone histology. An anthropological perspective. CRC, Boca Raton, Florida
- Dal Santo N, Mazzieri P (2010) Il Sito VBQ iniziale di Ponte Ghiara (Parma). Le industrie litiche e ceramiche. *Origini* 32:105–160
- De Boer HHH, Maat GJR (2012) The histology of human dry bone (a review). *Cuad Prehist Arqueol Univ Granada* 22:49–65
- Degasperi N, Steffè G (2019) Lo scavo: stratigrafia e strutture. In: Degasperi N, Steffè G (eds) *Il Villaggio neolitico di Lugo di Romagna Fornace Gattelli. Strutture ambiente culture*. Istituto italiano di Preistoria e Protostoria, Florence, pp 51–198
- Del Valle H, Rodríguez-Navarro AB, Moclán A, García-Medrano P, Cáceres I (2025) Bone diagenesis and stratigraphic implications from Pleistocene karst systems. *Sci Rep*. <https://doi.org/10.1038/s41598-025-88968-4>
- Depierre G (2014) Crémation et achéologie, nouvelles alternatives méthodologiques en ostéologie Humaine. EUD – Editions Universitaires de Dijon, Dijon
- Favole A (2003) Resti Di umanità. Vita sociale Del corpo Dopo La morte. Laterza, Rome-Bari
- Florentino G, Muntoni IM, Radina F (2000) La neolitizzazione delle Murge Baresi. In: Pessina A, Muscio G (eds) *La neolitizzazione tra oriente e occidente*. Museo friulano di Storia Naturale, Udine, pp 381–411
- France DL (2021) Human and nonhuman bone identification: A color atlas. CRC, Boca Raton, Florida
- García-Donas JG, Dalton A, Chaplin I, Kranioti EF (2017) A revised method for the preparation of dry bone samples used in histological examination: five simple steps. *Homo* 68:382–288. <https://doi.org/10.1016/j.jchb.2017.07.001>
- Gonçalves D, Thompson TJU, Cunha E (2011) Implications of heat-induced changes in bone on the interpretation of funerary behaviour and practice. *J Archaeol Sci* 38(6):1308–1313. <https://doi.org/10.1016/j.jas.2011.01.006>
- Grifoni Cremonesi R, Mallegni F (1978) Testimonianze di un culto ad incinerazione nel livello a ceramica impressa della grotta Riparo Continenza di Trasacco (L’Aquila) e studio dei resti Umani cremati. *Atti Della società. Toscana Di Scienze Naturali* 85:253–279
- Habermehl KH (1975) Die Altersbestimmung bei Haus- und Labortieren. Parey, Berlin
- Hillier ML, Bell LS (2007) Differentiating human bone from animal bone: a review of histological methods. *J Forensic Sci* 52:249–263. <https://doi.org/10.1111/j.1556-4029.2006.00368.x>
- Holck P (1986) Cremated bones. A medical-anthropological study of an archaeological material on cremation burials. Anatomisk institutt, University of Oslo, Oslo
- Hüls CM, Erlenkeuser H, Nadeau MJ, Grootes PM, Andersen N (2010) Experimental study on the origin of cremated bone apatite carbon. *Radiocarbon* 52(2–3):587–599. <https://doi.org/10.1017/S0033822200045628>
- Kerley ER, Ubelaker DH (1978) Revisions in the microscopic method of estimating age at death in human cortical bone. *Am J Phys Anthropol* 49:545–546. <https://doi.org/10.1002/ajpa.1330490414>
- Larentis O (2023a) Death rituals and funeral rites of the Celtic Golasceca civilization. Interpreting anthropological data from cremated human remains. BAR, British Archaeological Publishing, Oxford
- Larentis O (2023b) Human, all too human: differentiating non-human from human bones in protohistoric cremation contexts from Northern Italy. *Heritage* 6(1):647–661. <https://doi.org/10.3390/heritage6010034>
- Lévi-Bruhl L (1927) L’âme primitive. Félix Alcan, Paris
- Maccarinelli A, Marconi S, Pedrotti A (2015) I resti faunistici dell’insediamento del Neolitico antico di Lugo di Grezzana (Verona). *Stud Preistoria Protostoria* 2:605–609
- Mallorie A, Shine B (2022) Normal bone physiology, remodelling and its hormonal regulation. *Surg (Oxf)* 40(3):163–168. <https://doi.org/10.1016/j.mpsur.2021.12.001>
- Marconi N, Muntoni IM, Cassano SM (2004) Le strutture e le stratigrafie. In: Cassano SM, Manfredini A (eds) *Masseria Candelaro. Vita quotidiana e mondo ideologico in un villaggio neolitico sul Tavoliere*. Claudio Grenzi Editore, Foggia, pp 49–48
- Mariotti V, Muntoni IM, Belcastro MG (2020) New insights into the funerary rituals of the neolithic site of Passo di Corvo (Apulia, Italy): the study of the human remains. *J Archaeol Sci Rep* 34:102643. <https://doi.org/10.1016/j.jasrep.2020.102643>
- Masotti S, Mongillo J, Gualdi-Russo E (2020) Burned human remains: diachronic analysis of cremation rituals in necropolises of Northern Italy. *Archaeol Anthropol Sci* 12(3):74
- Mayne Correia P (1997) Fire modification of bone: A review of the literature. In: Haglund WD, Sorg MH (eds) *Forensic taphonomy the postmortem fate of human remains*. Routledge, London, pp 275–293
- Mazzucchi A, Fontana A (2019) I resti Umani. In: Degasperi N, Steffè G (eds) *Il villaggio neolitico di Lugo di Romagna Fornace Gattelli. Strutture ambiente culture*. Istituto italiano di Preistoria e Protostoria, Florence, pp 379–385
- McGrath K, Rowsell K, Gates St-Pierre C, Tedder A, Foody G, Roberts C et al (2019) Identifying archaeological bone via non-destructive zooms and the materiality of symbolic expression:

- examples from Iroquoian bone points. *Sci Rep* 9:11027. <https://doi.org/10.1038/s41598-019-47299-x>
- Minozzi S (2015) Italian Iron Age cremations. In: Schmidt W, Symes SA (eds) *The analysis of burned human remains*. Academic, Paris, San Diego, San Francisco, Singapore, Sydney, Tokyo, pp 307–322
- Mulhern D, Ubelaker D (2001) Differences in osteon banding between human and nonhuman bone. *J Forensic Sci* 46(2):220–222. <https://doi.org/10.1520/JFS14952J>
- Nicholson RA (1993) A morphological investigation of burnt animal bone and an evaluation of its utility in archaeology. *J Archaeol Sci* 20:411–428. <https://doi.org/10.1006/jasc.1993.1025>
- Olsen J, Heinemeier J, Hornstrup KM, Bennike P, Thrane H (2013) 'Old wood' effect in radiocarbon dating of prehistoric cremated bones? *J Archaeol Sci* 40(1):30–34. <https://doi.org/10.1016/j.jas.2012.05.034>
- Pedrotti A, Poggiani Keller R, Banchieri DG, Longhi C (2022) Il Neolitico in Lombardia. *Riv Sci Preist LXXII*(S2):123–165
- Pedrotti A, Salzani P, Cavulli F, Martina C, Angelucci D, Salzani L (2015) L'insediamento di Lugo di Grezzana (Verona) nel quadro del primo Neolitico padano alpino. *Studi di Preistoria e Protostoria*, vol 2, Preistoria e Protostoria del Veneto, pp. 95–107
- Pessina A, Tiné V (2022) *Archeologia del Neolitico. L'Italia tra il VI e il IV millennio a.C.* Carrocci editore, Milano
- Poggiani Keller R (1999) Il sito del Molino: l'insediamento e la sepoltura di età neolitica. In: Botturi C, Pareccini R (eds) *Archeologia Della Valle Del Garza Tra preistoria e Medioevo*. Edizioni ET, Milan, pp 41–50
- Quarta G, Tiberi I, Rossi M, Aprile G, Braione E, D'Elia M et al (2014) The copper age mound necropolis in Salve, Lecce, Italy: radiocarbon dating results on charcoals, bones, cremated bones, and pottery. *Radiocarbon* 56(03):949–957. <https://doi.org/10.2458/56.17887>
- Radina F (1996) Il villaggio neolitico di Modugno. Le ultime ricerche sollecitano alla ridefinizione del Neolitico antico nella Bassa Murgia. *Nuovi orientamenti XVIII*(78), pp 16–18
- Radina F (2002) La preistoria della Puglia. *Paesaggi, Uomini e tradizioni Di 8.000 anni fa. La preistoria della Puglia*. Adda Editore
- Radina F, Torre M (2022) Grotta della Tartaruga di Lama Giotta (Bari). Le deposizioni Serra d'alto della grotticella 5. In: Radi G, Sarti L, Martini F (eds) *In viaggio, sulla stessa strada. Scritti per Giuliano Cremonesi. Museo e istituto fiorentino di preistoria Paolo Graziosi*, Florence, pp 201–224
- Reimer PJ, Austin WEN, Bard E, Bayliss A, Blackwell PG, Bronk Ramsey C et al (2020) The IntCal20 Northern hemisphere radiocarbon age calibration curve (0–55 cal kBP). *Radiocarbon* 62:725–757. <https://doi.org/10.1017/RDC.2020.41>
- Rosa J, Marques MPM, Gonçalves D, Ferreira MT (2023) Half a century of systematic research on heat-induced colour changes in bone – a review. *Sci Justice* 63(5):573–580. <https://doi.org/10.1016/j.scijus.2023.07.002>
- Rottoli M, Cavulli F, Pedrotti A (2015) L'agricoltura di Lugo di Grezzana (Verona): considerazioni preliminari. *Studi di Preistoria e Protostoria*, vol 2, Preistoria e Protostoria del Veneto, pp. 109–116
- Salzani P, Dori I, Meloni F, Baldo M, Bisello M, Nicosia C, Talamo S, Fanti L, Caricola I, Dolfini A, Tecchiati U (2021) Una nuova necropoli Campaniforme-Bronzo Antico a Nogarole Rocca (VR). In: Aurino P, Bernabò Brea M, Cavazzuti C, Miari M, Salzani P (eds) *Sepulture tra Età Del Rame e Bronzo antico: Nuove scoperte*. Abstract book. 10 Incontro Annuale di Preistoria e Protostoria, pp 8–11
- Schmid E (1972) *Atlas of animal bones*. Elsevier, Amsterdam
- Serradimigni M, Colombo M, Grifoni R (2016) Grotta Continenza (Trasacco AQ): Uso funerario e uso abitativo della cavità dal paleolitico superiore all'età dei metalli. *Atti Del IV convegno Di archeologia Il Fucino e le aree limitrofe nell'antichità*. Archeoclub d'Italia, Avezzano, pp 49–57
- Snoeck C, Brock F, Schulting RJ (2014) Carbon exchanges between bone apatite and fuels during cremation: impact on radiocarbon dates. *Radiocarbon* 56(2):591–602. <https://doi.org/10.2458/56.17454>
- Steffè G (2019) Le datazioni assolute. In: Steffè G, Degasperì N (eds) *Il villaggio neolitico di Lugo di Romagna Fornace Gattelli. Struttura ambiente culture*. Istituto italiano di Preistoria e Protostoria, Florence, pp 279–288
- Steffè G, Degasperì N (2019) *Il villaggio neolitico di Lugo di Romagna Fornace Gattelli, strutture ambiente culture*. Origenes, Florence
- Tartari M (1996) *La Terra e Il fuoco. I riti funebri tra conservazione e distruzione*. Meltemi, Milan
- Tecchiati U (2014) Alle soglie dell'età del Rame. Il luogo di culto di Varna-Circonvallazione (Bz). In: De Marinis RC (ed) *Le manifestazioni del sacro e l'età del Rame nella regione alpina e nella pianura padana*, pp 85–110
- Thompson JE, Panella S, Soncin S, McLaughlin R, Muntoni IM, Alhaique F et al (2024) The Use-Life of ancestors: neolithic cranial retention, caching and disposal at Masseria Candelaro, Apulia, Italy. *Eur H Archaeol*:1–21. <https://doi.org/10.1017/eah.2024.43>
- Thompson TJU (2004) Recent advances in the study of burned bone and their implications for forensic anthropology. *Forensic Sci Int* 146:203–205. <https://doi.org/10.1016/j.forsciint.2004.09.063>
- Thompson TJU (2005) Heat-induced dimensional changes in bone and their consequences for forensic anthropology. *J Forensic Sci* 50(5):185–193. <https://doi.org/10.1520/JFS2004297>
- Van Gennep A (1909) *Le rites de passage*. Emille Nourry, Paris
- Van Strydonck M, Boudin M, De Mulder G (2010) The carbon origin of structural carbonate in bone apatite of cremated bones. *Radiocarbon* 52(2):578–586. <https://doi.org/10.1017/S003822200045616>
- White TD, Black MT, Folkens PA (2012) *Human osteology*. Academic, New York
- Whitehouse R (2014) The chronology of the neolithic ditched settlements of the Tavoliere and the Ofanto Valley. *Accordia Research Papers*
- Wojcieszak M, Van den Brande T, Ligovich G, Boudin M (2020) Pretreatment protocols performed at the Royal Institute for Cultural Heritage (RICH) prior to AMS 14C measurements. *Radiocarbon* 62(5):e14–e24. <https://doi.org/10.1017/RDC.2020.64>
- Wolf M, Streit B, Dokládál M, Schultz M (2017) Determining human age at death using cremated bone microstructure. *Biomed J Sci Tech Res* 1:785–791. <https://doi.org/10.26717/BJSTR.2017.01.00304>
- Wright E (2021) Beyond cremation: theorising fire in funerary contexts. *J Archaeol Sci Rep* 38:102953. <https://doi.org/10.1016/j.jasrep.2021.102953>
- Zazzo A, Saliège J-F, Lebon M, Lepetz S, Moreau C (2012) Radiocarbon dating of calcined bones: insights from combustion experiments under natural conditions. *Radiocarbon* 54(3–4):855–866. <https://doi.org/10.1017/S003822200047500>
- Zazzo A, Saliège JF, Person A, Boucher H (2009) Radiocarbon dating of calcined bones: where does the carbon come from? *Radiocarbon* 51(2):601–611. <https://doi.org/10.1017/S003822200055958>