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Projectile weapon injuries in the Riparo Tagliente burial (Veneto, Italy) provide early evidence of Late Upper Paleolithic intergroup conflict

Vitale Stefano Sparacello[1], Ursula Thun Hohenstein[2]✉, Francesco Boschin[3], Jacopo Crezzini[3], Antonio Guerreschi[2] & Federica Fontana[2]

Evidence of interpersonal violence in the Paleolithic is rare but can shed light on the presence of ancient conflict in prehistoric hunter-gatherer societies. Projectile injuries suggest confrontations between groups and have primarily been identified through lithic elements embedded in bones. Recently, the study of projectile impact marks (PIMs) has allowed for the recognition of projectile injuries in the absence of embedded elements. We report here the discovery and study of one of the earliest evidence of PIMs in human paleobiological record, found in the burial from Riparo Tagliente (individual Tagliente 1, Veneto, Italy), directly dated to ca. 17,000–15,500 cal BP. Analyses through SEM and 3D microscopy demonstrate that the femur and the tibia show clear evidence of PIMs impacting the bone from different directions. This could be due to the presence of multiple attackers, or to the victim turning between impacts. No trace of healing is present; one PIM is close to the femoral artery, which can cause a rapid death if pierced. Evidence at Riparo Tagliente could be attributed to conflict between different groups of hunter-gatherers expanding in newly opened Alpine territories during climatic amelioration after the Last Glacial Maximum.

Keywords Taphonomy, Bone modifications, Projectile impact marks, Upper Paleolithic burial, Prehistoric violence, Northeastern Italy

Prehistoric skeletal signs of interpersonal violence constitute the most direct evidence for our understanding of the nature of conflict in the past[1–4]. Some scholars suggest that in certain prehistoric periods, such as the Mesolithic (in southern Europe around 11.7–8. cal ka BP)[2,5–8], or the Neolithic (in southern Europe around 8.-6. ka cal BP)[3,9–11], it is possible to detect an increase in the frequency or scale of conflict in the human bioarchaeological record, while others point out similar trauma prevalence since the Upper Paleolithic[12,13]. In general, diachronic evaluations are likely to be biased by the skeletal record becoming increasingly fragmentary with greater temporal depth. Furthermore, the study of bony lesions is challenging due to technical and interpretative problems: evidence of trauma, when recognized, does not necessarily imply interpersonal violence, and even more difficult is demonstrating conflict between different groups[14].

Despite these challenges, certain occurrences allow evidence of violence to be more confidently attributed to external attacks, such as multiple contemporary burials resulting from massacres (e.g.,[15–17]. In addition, wounds caused by projectile weapons – especially when multiple – are strongly suggestive of intergroup conflict[2,6,18–27]. In fact, in small-scale, traditional societies, projectile weapons are most often used in raiding and formal warfare, with melee weapons usually employed to dispatch a wounded enemy[27,28].

Traditionally, lesions found in the bioarchaeological record were unequivocally attributed to killing at a distance when the projectile remained embedded in the bone. Examples of injuries of this kind in the Paleolithic human skeletal record are extremely rare, with the oldest cases dating to the end of the period, such as Grotte des Enfants 2 (ca. 13,200–12,800 cal BP) [29] and San Teodoro 4 (15,300–14,200 cal. BP)[30,31], both from the Late

[1]Department of Life and Environmental Sciences, Neuroscience and Anthropology Section, University of Cagliari, 09124 Cagliari, Italy. [2]Department of Humanities, Prehistoric and Anthropological Sciences Section, University of Ferrara, 44121 Ferrara, Italy. [3]Department of Physical Sciences, Earth and Environment, University of Siena, 53100 Siena, Italy. ✉email: ursula.thun@unife.it

Epigravettian of Italy, Vasilyevka and Voloshskoye from the Epipaleolithic of Ukraine (ca. 12,000 cal BP, although radiocarbon dates for these sites are strongly affected by freshwater reservoir effects and might in fact date considerably younger[32,33]), and several individuals from the Epipaleolithic cemetery of Jebel Sahaba in Sudan (13,727–7981 cal BP)[34,35]. Earlier weapon injuries tentatively attributed to projectiles lack embedded elements, as seen in the wound on the first thoracic vertebra of Sunghir 1 from the Gravettian (Russia; 27,700–26,500 cal BP)[36,37], and in a rib of the Neanderthal Shanidar 3 (Iraq, 47,000–40,000 BP)[38].

Recent advancements in the study of projectile impact marks (PIMs[39]) have allowed researchers to identify wounds originated by projectile weapons in the absence of embedded lithic elements[40–42]. Smith et al.[43] highlighted the challenges in the identification, suggesting that, when flint-tipped projectiles strike bone tangentially, they may produce incised linear defects that resemble butchery marks. Furthermore, they noted that the problematic recognition of those incised linear defects as weapon injuries may explain why projectile wounds in limbs seem to be under-represented in the archaeological literature[43–45]. More recently, experimental research highlighted a series of qualitative and morphometric characteristics of PIMs that discriminate them from cut marks caused by other activities and may have the potential to provide insights into projectile technologies and point typologies[39,42,46]. In this study, we report the discovery of incised linear defects and other perimortem bony lesions in the lower limb (femur and tibia) of an Upper Paleolithic individual (Tagliente 1) from the Late Epigravettian of Riparo Tagliente (Verona, Italy).

The site of Riparo Tagliente is situated on the left slope of the Pantena Valley in the Lessini Mountains (southeastern Alps, Verona, Italy; Fig. 1A). Excavations beginning in 1962, and still ongoing, unearthed a thick

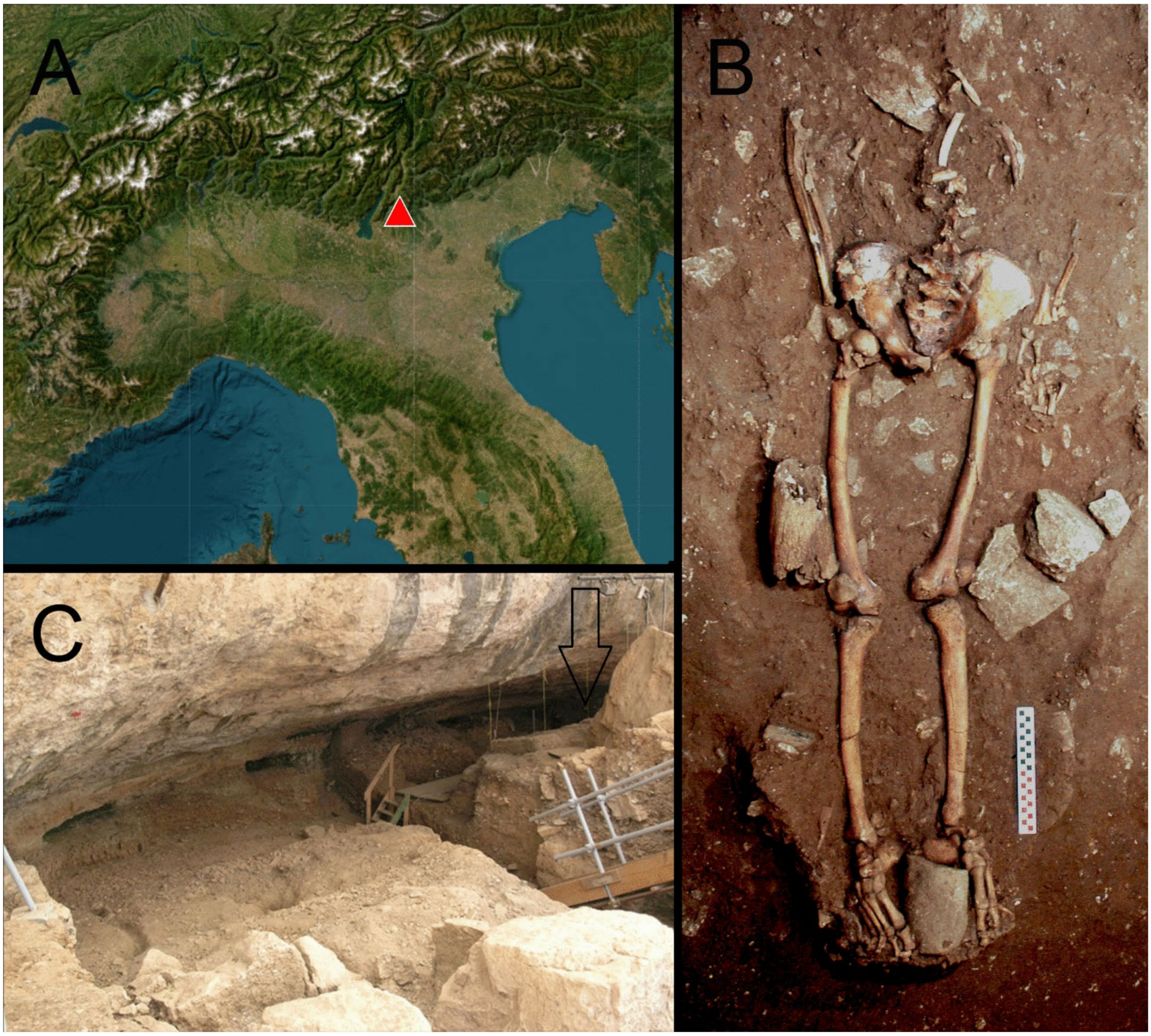

Fig. 1. (**A**) The geographic position of the site of Riparo Tagliente in northeastern Italy (map from https://srvcarto.regione.liguria.it/; copyright 2025 Maxar technologies). (**B**): Zenithal picture of the burial at the time of discovery. (**C**): The Riparo Tagliente rock shelter; the arrow indicates the position of the burial of the individual Tagliente 1.

stratigraphic series which includes layers dated to the Mousterian, the Aurignacian and the Late Epigravettian. The latter include one of the most complete Late Paleolithic sequences in northern Italy. The burial Riparo Tagliente 1 was found during excavations in 1973[47,48] in the southern sector of the site. It was contained in a pit dug into the Mousterian deposits in an area protected by the overhang of the shelter. The stratigraphic analysis allowed the burial to be referred to the first phase of the Late Epigravettian occupation of the site, spanning ca. 17,000–15,000 cal BP[49–51]. Two direct dates carried on the skeleton do not overlap, but are consistent with this time frame (for Tagliente 1: OxA-10672, 13,190 ± 90 14C BP, i.e. 16,126–15,571 cal BP; MAMS 62,622.1.1, 13,491 ± 40, i.e. 16,416–16,096; for Tagliente 2, a mandible found in reworked layers[52] attributed to the same individual via genetic analysis[53]: MAMS-27188, 13790 ± 60, 16,975–16,509 cal BP. All dates report 95.4% probability calibrated using Oxcal v4.4.4)[54].

Unfortunately, the excavation of a pit in historical times had disturbed the upper portion of the burial; only the lower limbs, some fragments of lumbar vertebrae and ribs, and part of the right and left forearm were preserved in situ[47] (Fig. 1B). However, the disposition of the non-disturbed skeletal elements suggest that the individual was lying supine in a shallow pit, with arms distended on the sides, as typical for Epigravettian burials[55–57]. The skeleton was accompanied by a limestone pebble stained with ochre, and a fragment of a large bovid horn. More uncertain is whether a pierced *Tritia* shell belongs to the backfill of the pit. Most remarkably, the lower limbs were covered with stone slabs, one of which is engraved with the depiction of a lion and the horn of an aurochs[47]. The analysis of the pelvic remains indicates that the individual was a young adult male[47,48]. The circumstances of death were hitherto unknown.

Late Epigravettian hunter-gatherers (approximately 17,000–11,700 cal BP) recolonized the southern Alps during the Late Glacial (19.-11,7 ka cal BP). The first and sparse evidence of this recolonization refers to the late phase of Greenland Stadial 2.1 (GS2.1 – 17.-15. ka cal BP) while in the Late Glacial temperate interstadial (GI1e-c – 14.7–12.8 ka cal BP)[58] the number of sites increases spanning from Alpine valley-bottoms to highland prairies up to 1,700 mt a.s.l. Although highland sites are mostly attested on the pre-Alpine plateaus (i.e. Lessini, Asiago, Cansiglio, Pradis) some of them reach the inner Dolomites region[59,60]. Late Epigravettian bands seasonally ascended to high altitudes to hunt medium to large sized game, particularly ibex and red deer, while exploiting valley-bottoms to supply a wider range of resources, including freshwater ones[51,61]. Projectile technology was widely used, as suggested by lithic and osseous productions[42,62–64]), the presence of PIMs in faunal assemblages[42,63] and skeletal adaptations, such as high levels of asymmetry in humeral biomechanical rigidity (e.g.[65]).

The Late Epigravettian occupation at Riparo Tagliente (from ca. 17,100–16,300 cal BP to 14,572–13,430 cal BP) represents the first evidence in the southern Alps following the end of the Last Glacial Maximum (LGM)[49,50]. This occupation occurred in a context of probable demographic expansion, as indicated by the increase in the number of sites in the following millennia[59,60,66,67]. While this evidence suggests increasing interactions between groups, the nature of these relationships remains poorly understood.

This study presents evidence that may contribute to shedding light on the nature of intergroup dynamics during this period, focusing on newly identified incised linear defects in Riparo Tagliente 1. Macroscopic, microscopic, and morphometric analyses confirm that these lesions correspond to PIMs. These findings contribute to the limited corpus of early evidence for interpersonal violence associated with projectile weaponry. We will discuss how this evidence is mostly compatible with intergroup conflict, as opposed to within-group or domestic violence.

Results

The skeleton of Riparo Tagliente 1, as previously noted, is incomplete and fragmented, and exhibits numerous "dry bone" fractures[68–70]. Several fractures observed in the upper body appear to result from disturbances to the burial during historical times, whereas those in the lower limbs are likely attributable to the pressure exerted by stones placed over the individual as part of the funerary ritual. Notably, near some of these lesions we identified linear marks which cannot be explained by edaphic processes. The linear marks found in the left femur are incised on the medial surface of the diaphysis, around the midshaft level. They consist of a set of parallel incisions running from superiorly and anteriorly to inferiorly and posteriorly. Two incisions are deeper (A and B in Fig. 2) and run along the surface 2.5 mm from each other for 12 and 15 mm respectively. A third, less deep set of linear marks runs parallel 1.2 mm superiorly to A, and a fourth, very faint, set of parallel incisions is visible about 2 mm above the third. In concomitance with the superior-anterior onset of the two deeper incisions, the bone surface is chipped with the detachment of a c. 2 cm^2 bone flake.

The linear marks in the left tibia are incised on the posterior-lateral surface of the mid-proximal diaphysis, above the nutrient foramen and lateral to a marked groove for the insertion of the soleus muscle. Dry-bone fractures are also evident in this case, characterized by stepped and jagged fracture lines. Their appearance rules out a traumatic origin and instead suggests creeping fractures caused by sediment weight (Fig. 3). The most apparent linear marks in this region consist of three parallel incisions running almost vertically. The main incision is the most medial and shows unilateral flaking on its lateral side. In concomitance with the superior terminus of these linear marks, the bone is chipped with the detachment of a c. 1 cm^2 bone flake. Several faint, sub-parallel and intersecting linear marks are present in the area between the chipped bone and the nutrient foramen.

High resolution and magnification images of the main grooves obtained through SEM allow for a better appreciation of the morphological difference between the two sides of the incisions, one being steeper, and the other rising more gradually (cf.[71,72]). In the latter side, multiple ancillary parallel microstriations are visible, which are typical marks left by the irregular (and often retouched) edge of a flint tool (Fig. 4)[71,72], but the irregular morphology of the bottom of the grooves is incompatible with the slicing action produced by the sliding of a cutting edge.

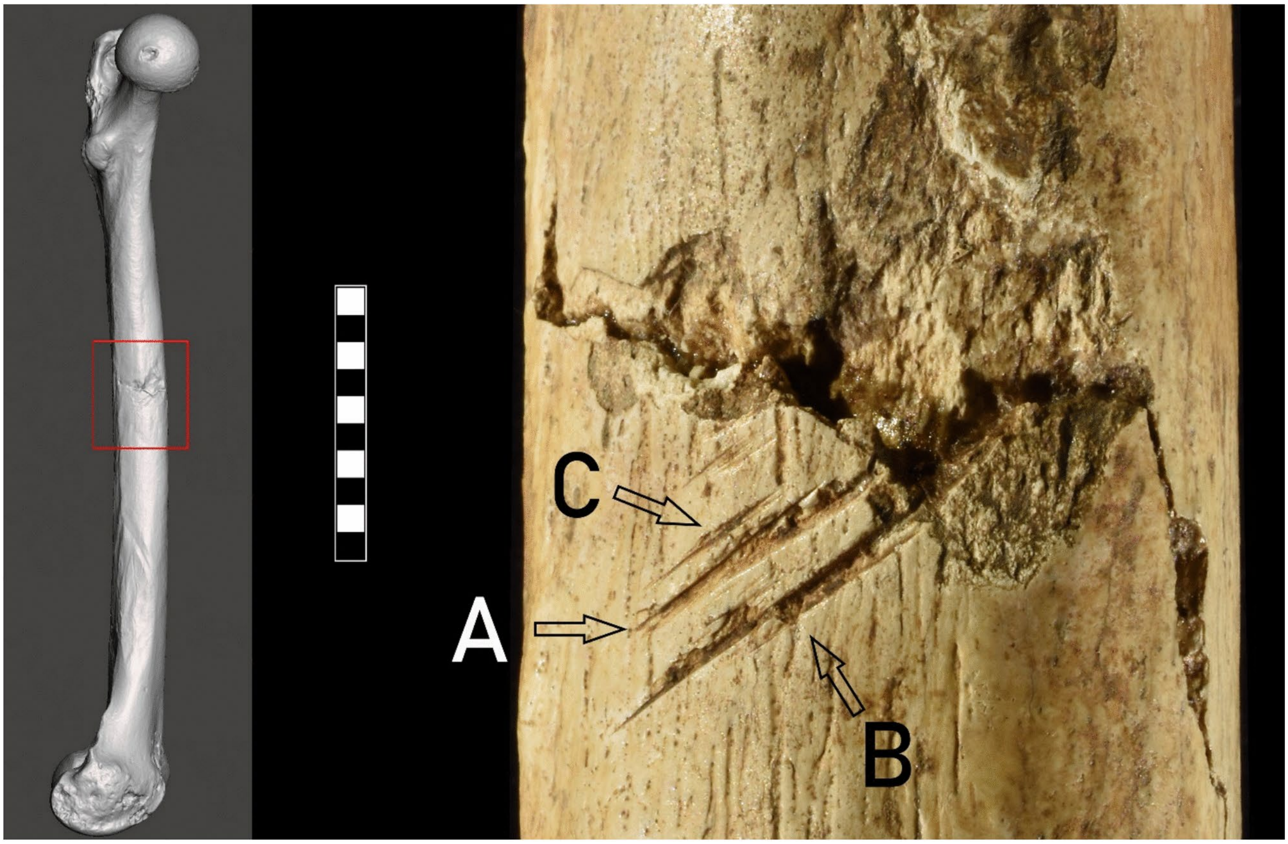

Fig. 2. (**A**) surface 3D model (left) and a macro picture (right) showing the location and the appearance of the incisions discovered in the medial aspect of midshaft left femur. The three lesions that were analyzed via microscopic 3D and SEM analysis are labeled (**A**, **B**, and **C**). Scale is 10 mm.

In this respect, microscopic 3D analysis allowed for a more in-depth morphological and quantitative assessment of the characteristics of the incised linear marks in Tagliente 1, and for a comparison with experimental and bioarchaeological data from drags (i.e. cut-like marks) due to projectile impacts and slicing cut marks (i.e. a slice on the bone created by the drawing of the cutting edge of a lithic tool across the surface of the bone) [71] generated by butchery of animal carcasses, cannibalism, and funerary defleshing[46,73–76]. Linear marks suitable for a 3D analysis are grooves A, B and C on the femur (henceforth referred to as FA, FB, and FC; Fig. 2) and grooves A and B on the tibia (TA and TB; Fig. 3). These are generally U-shaped with a wide floor (Fig. 5a), and, similarly to PIM drags, show a low RTF index (ratio between breadth at the top and breadth at the floor of the cut), in contrast with the high values of experimental cut marks (butchery) produced with retouched and unretouched tools (Fig. 5b, c)[42,46,63]. One exception is represented by the groove TB, that shows a more "V-shaped" cross-section. In addition, the sample from Tagliente 1 is characterized by cross-sections that are deeper than those of most butchering marks and are comparable with those of PIMs (Fig. 5b), with the exception, again, of groove TB. The marks FA, FB and TA are also deeper than the ones observed by Bello et al. [76] on human remains from four European sites (Fig. 5d). They observed that cut marks on human remains – related to defleshing human bodies after a period of decay – were deeper than those produced for feeding purposes. This might be due to the greater force needed to clean human bones by removing remnant and probably partially desiccated tissues. All these characteristics are compatible with a projectile thrown at high speed[39,46], as opposed to a hand-held, stone-tipped spear [77]. The fact that striations found on the Riparo Tagliente specimens are deeper can represent another clue that they are not butchering marks, but alterations produced by a more violent event.

Linear and angular measurements collected on the cross-sections of grooves from Tagliente 1, as well as on a large sample of PIMs and butchering marks (see SI), were processed through a PCA (Fig. 6). PC1 describes 72.8% of the sample's variability, whilst PC2 and PC3 describe 17.0% and 6.4% respectively. PIMs are generally scattered on the right side of the plot, whilst butchering marks are grouped on the left one. PC1 seems to be the best component to separate PIMs and butchering marks and is mostly influenced by the general size of marks. All grooves from Tagliente 1, except for TB, are compatible with PIMs and fall out of the distribution of butchering marks.

Other morphometric and morphological similarities between the marks from Tagliente 1 and PIM drags include the large absolute dimensions of the cross-sections and an abrupt angle between the flat floor and the lateral slopes, as seen in 3D models in[42,46]). Additionally, they exhibit extensive flaking along the ridges and abrupt partial interruptions in the grooves, followed by changes in their depth (Fig. 7), as also observed in the

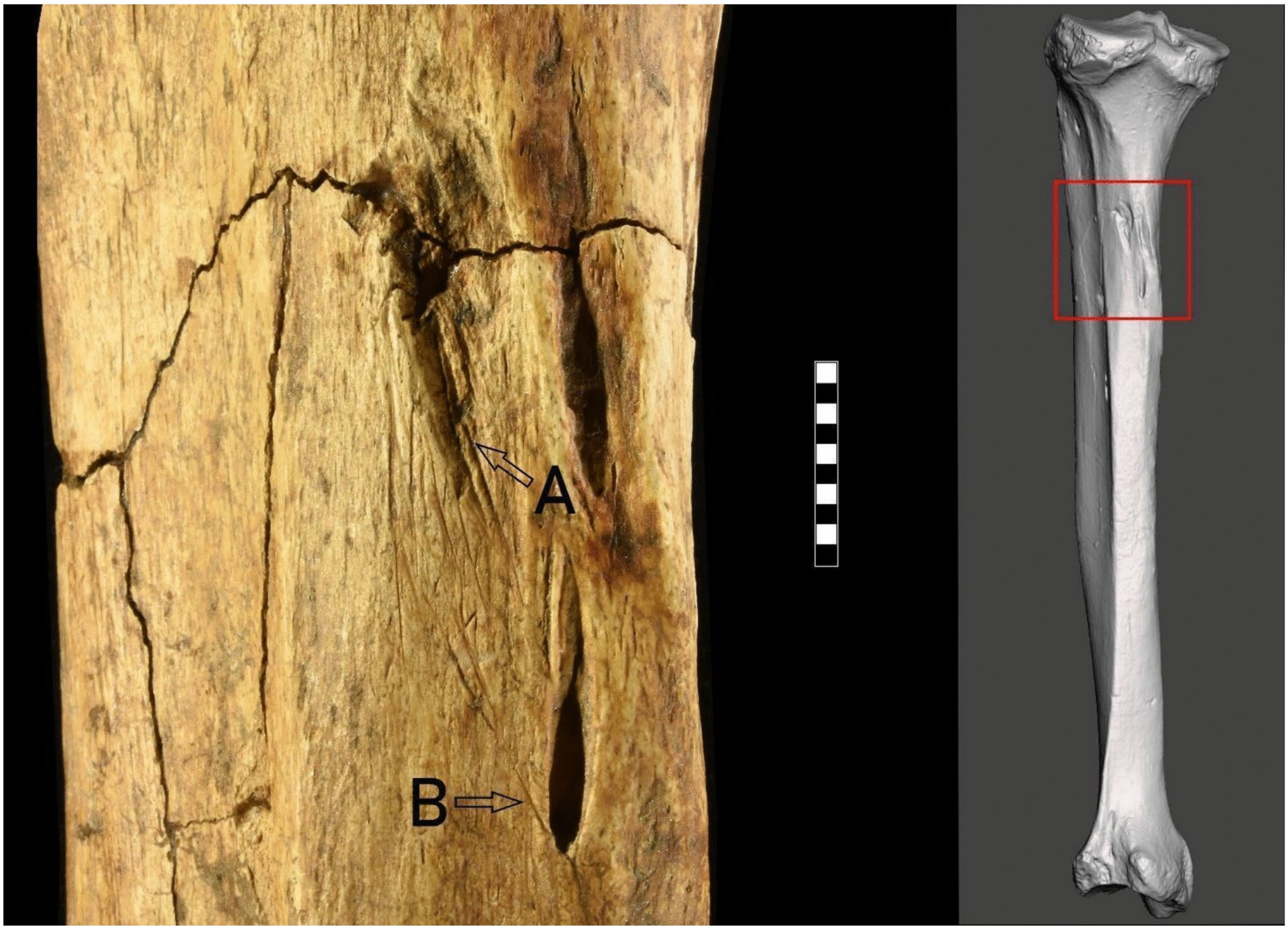

Fig. 3. A surface 3D model (right) and a macro picture (left) showing the location and the appearance of the incisions discovered in the mid-proximal posterior aspect of the left tibia. The two lesions that were analyzed via microscopic 3D and SEM analysis are labeled (**A** and **B**). Scale is 10 mm.

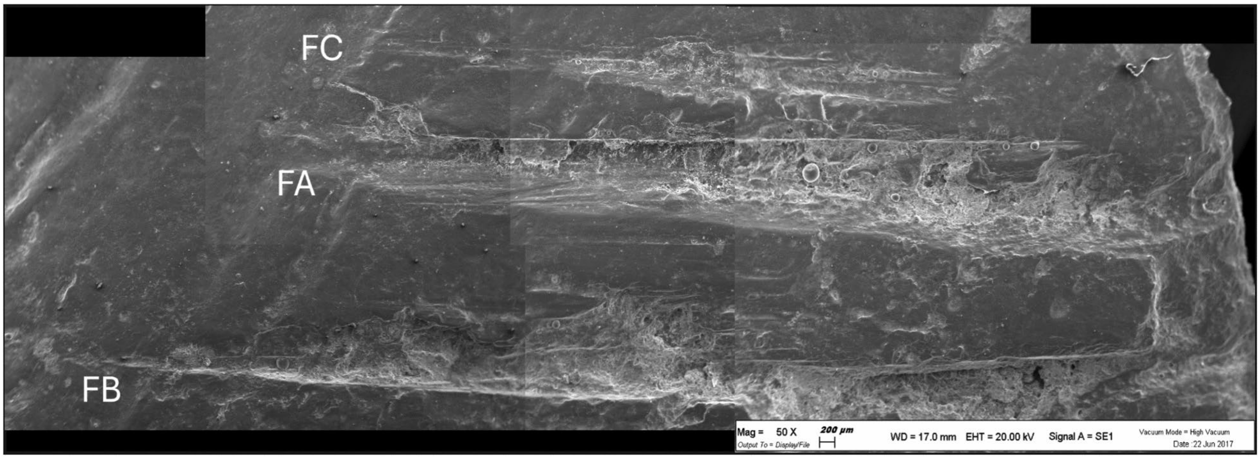

Fig. 4. SEM images of the three parallel main marks on the femur. The steep sides and deep sulcus of the grooves are evident on the right side of FA and FB. In the terminal part of the marks, these grooves abruptly narrow showing the microstriations produced by the sliding edge of a flint tool.

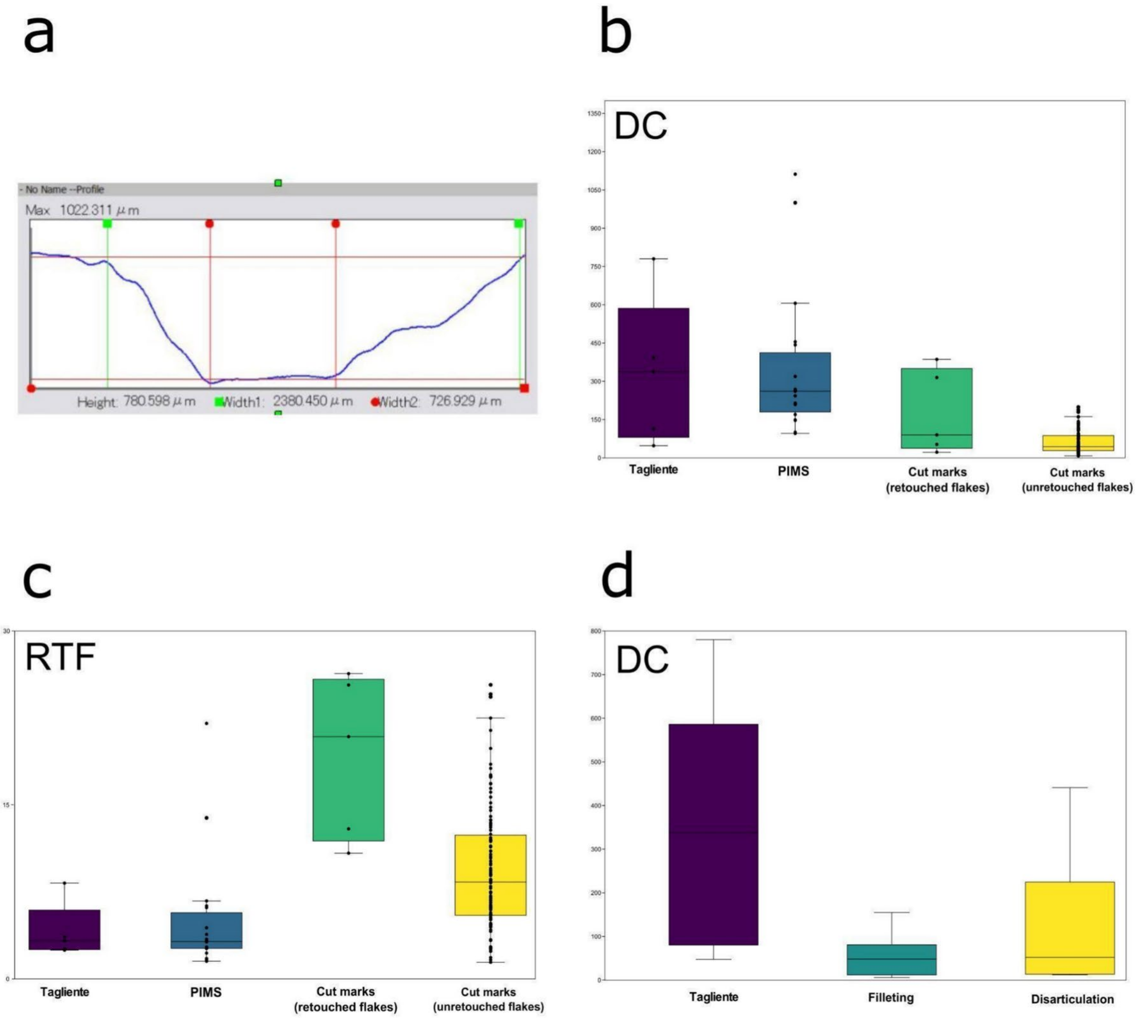

Fig. 5. (**a**): median cross section of mark TA; (**b**): Depth of Cut (DC) of marks from Tagliente in comparison with experimental PIMs and cutmarks; (**c**): RTF index of marks from Tagliente in comparison with experimental PIMs and cutmarks; (**d**): DC of marks from Tagliente in comparison with archaeological butchering marks on human bodies.

archaeological drag from the Cornafessa rock shelter[63]. Among the marks analyzed by means of 3D microscopy, TB has a shallow V-shaped profile and does not show large flaking phenomena. It seems to be produced by much weaker energy than TA, but its orientation is the same as the latter. Mark TB belongs to a group of shallow striations between mark TA and the nutritive foramen. Some of these striations show different orientations. The presence of chaotic striations near a drag has been observed in experimental studies, for example the one by O'Driscoll and Thompson[39]. Thus, it is difficult to state if mark TB and the other shallow striations are related to the impact or to a separate event.

Discussion

Several characteristics of the linear marks found in the femur and tibia of the Epigravettian individual buried at Riparo Tagliente allow for making inferences on the mode and circumstances of his death. SEM analysis revealed microscopic longitudinal striations in the main sulcus of the marks, confirming they were made by chipped flint tools rather than bone/antler/tooth tools[72]. Linear marks can be left on bones by cut marks (butchery or defleshing)[76,78–80], trampling[81,82] and projectiles striking tangentially[43]. Although scholars agree that linear marks can be left by projectiles, these incisions are often considered to resemble the ones left by butchery processes (cut marks) (e.g.[39]). Until recently, experimental research with replicas of Paleolithic tools focused on their performance as projectiles, the damage occurred to the point, and emphasized the presence of perforations and notches left on bones[83–85]. Hence, the recognition of projectile injuries on bones was mainly based on the presence of embedded lithic elements both in human[38,43] and fauna remains[40,41,46,63,86–99]. More recently, experimental work has begun to highlight features that can discriminate between cutmarks and drags left by projectiles, drags being one of the characteristics of projectile impact marks (PIMs)[39,46]. Except for mark TA on the tibia, all the linear marks of Tagliente 1 show the hallmarks of PIM drags according to these studies: they are deeper than cutmarks, with a wide flat floor, and a low RTF ratio. In addition, large flaking phenomena

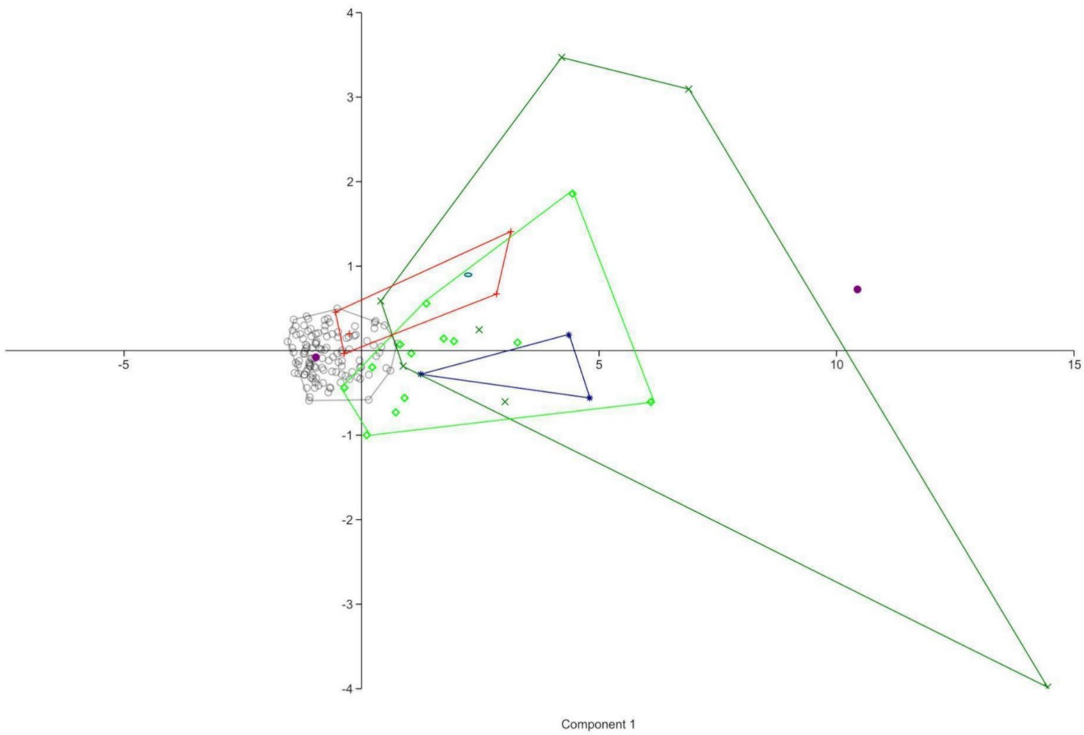

Fig. 6. Principal Component Analysis performed on the dataset of measurement of median cross-sections. Grey circles: cutmarks (unretouched flakes); red crosses: cutmarks (retouched flakes); green diamonds: experimental PIMs on coypus; green crosses: experimental PIMs (ungulates); teal oval: PIM from Cornafessa rock shelter; blue stars: Tagliente 1 femur; filled purple dots: Tagliente 1 tibia.

are observed, as well as possible evidence suggesting the partial shattering and bouncing of the lithic element, such as the abrupt change in depth of mark FB. All these characteristics are compatible with a projectile thrown at high speed[39,46,100]. Therefore, morphometric evidence strongly suggests that Tagliente 1 was hit by at least two projectiles. As for the shallower mark on the tibia, their interpretation remains speculative in absence of proper experimentation programs that could be the focus of further research. Indeed, their presence could be either part of the impact or related to another event, such as an attempt to remove the projectile.

Little experimental work is available on methods to differentiate among point technologies and modes of projectile delivery, suggesting caution in the interpretation of these factors using PIMs[39]. Critically, most of the research in this direction has involved specifically Late Epigravettian lithic projectiles[42,46,63]. The PIMs found in Tagliente 1, particularly the femur one, most resemble the drag marks produced by composite projectiles with a single backed point as piercing element and multiple bi-truncated points hafted to the shaft as those recently experimented (Fig. 3e in[46]; Fig. 13 in[63]). Duches et al.[46] suggest that such morphologies are strictly related to narrow cross-sectional areas of the backed points and the sharp edges of both highly standardized tips and lateral cutting elements that are characteristic of Late Epigravettian projectile elements. However, the two main drags present in Tagliente 1's femur are more distinct than the ones obtained experimentally, which may suggest a different way of mounting the lateral elements; this detail could be explored in future experimental work. The use of composite projectile tips is documented in the Late Upper Paleolithic of Europe (Lower Magdalenian (20–18 ka cal BP)[84] and references therein) and Middle and Late Epipaleolithic of the Levant (16.5–11.5 ka cal BP[101] and references therein). Evidence of use of composite lithic projectiles has also been proposed for the Late Epigravettian based on use wear studies on lithic elements[102,103] and backed tools design[104–106]. The recent discovery of a complete composite projectile implement hafted on an osseous point from the Gravettian layers of the site of Prés de Laure dated to ca. 23.5 ka cal. BP confirms that barbed composite projectile points predate the Mesolithic and are anchored in the Upper Paleolithic[107]. The involvement of these kinds of projectiles in cases of interpersonal violence in the bioarchaeological record has been proposed for the embedded element of San Teodoro 4[31] (dated to 15,300–14,200 cal. BP)[30] and the multiple individuals with drag marks in the Late Pleistocene cemetery of Jebel Sahaba (13,727–7981 cal BP, see below)[35].

The linear nature of the wounds, and the location of the chipping damage to the cortical bone, allow for an approximate reconstruction of the trajectory of impact. The femoral injury saw the detachment of a large flake at the point of impact, followed by two major linear drags, as shown by some experimental studies (cf. Figure 13 in[63]). Based on this, Tagliente 1 appears to have been hit frontally, by a projectile following a descending ballistic trajectory (Fig. 8a,b). In contrast, the PIM in the tibia could have originated only from a projectile hitting from behind. In this case, the trajectory of impact appears ascending, with the detachment of the flake occurring at the end of the drags (Fig. 8c,d). The reconstructed trajectory is not compatible with an individual hit while standing;

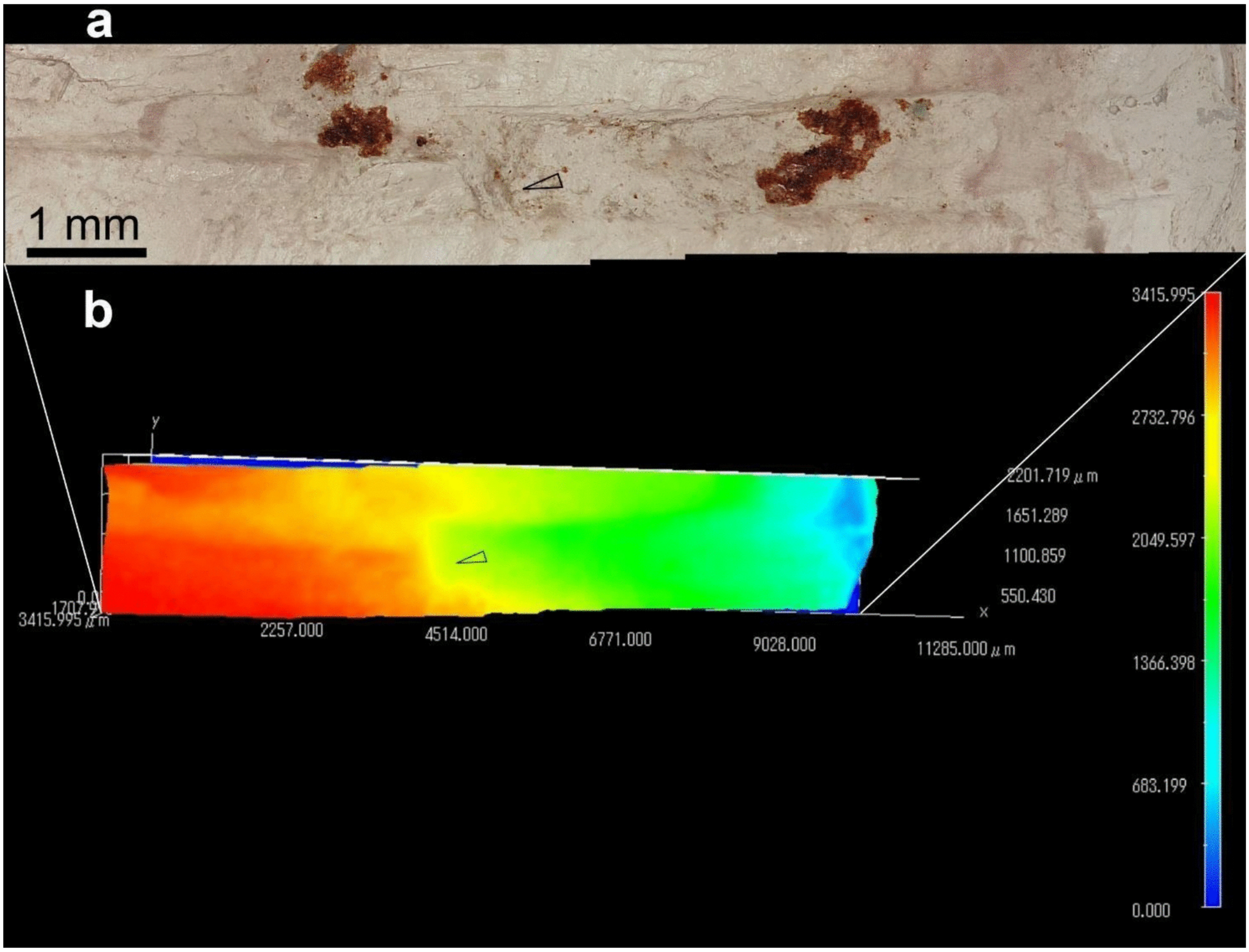

Fig. 7. Zenithal images of mark FB in real (**a**) and false (**b**) color. Arrows indicate a step-like feature representing a partial abrupt interruption of the main groove, followed by an abrupt change in depth.

in this case, the individual was either already lying prone, or the calf area was hit while the individual was flexing the leg – probably running – as proposed in other studies [35]. Other explanations for this pattern of lesions are certainly possible but appear less parsimonious.

More problematic is determining whether the wounds in the lower limb were the cause of death, given that the skeleton is partial, and other injuries may have been present in the thorax and cranium. However, the femoral injury may have been fatal, given the nearby presence of the femoral artery, which, if severed, may lead to rapid death (Fig. 8b)[108]. Regardless, the projectile wounds were clearly perimortem, given that no bone reaction is present in the affected area ([109] p.246). The periostosis visible in the femur in the form of surface bone deposition and remodeling (Fig. 2) is probably due to a mild form of bilateral diffused periostitis of the femoral and tibial diaphyses, a condition which is not related to the projectile injury and is a common consequence of overuse syndromes, especially in highly mobile athletes (e.g.[110]). Mild forms of this condition can be virtually asymptomatic but can lead to pain and impairment when the subject tries to run[111,112].

When attempting to reconstruct the circumstances of death, caution should be exercised since multiple scenarios could account for the evidence presented. However, the presence of two similar sets of projectile injuries makes a hunting accident[113], or self-inflicted wounds unlikely. It is therefore highly probable that the lesions resulted from intentional interpersonal violence. Distinguishing between intra- and inter-group aggression, however, remains a challenge[14]. Among hunter-gatherers, intra-group violence typically takes the form of domestic abuse, personal rivalries, altercations, or ritualized fighting[10,21,114–121]. Interpersonal aggression of this nature is typically frontal and close-quarter, resulting in blunt force trauma to the craniofacial region[2,14,122–124], or stab wounds to the left upper chest or mid-torso ([125] p.206; cf.[36]). In the case of Riparo Tagliente 1, the absence of the upper portion of the skeleton prevents verification of these kinds of traumatic lesions. However, the use of projectile weapons to inflict the visible wounds suggests that at least one phase of the attack – likely the initial stage—was carried out with medium- to long-range weapons. The individual was struck by projectiles both from the front and from behind; however, it remains unclear whether this indicates attacks from multiple directions (and assailants), as the individual may have turned between strikes. The attempt of killing at a distance is typical of the early phases of armed conflict between different groups, as it provides a tactical advantage in surprise

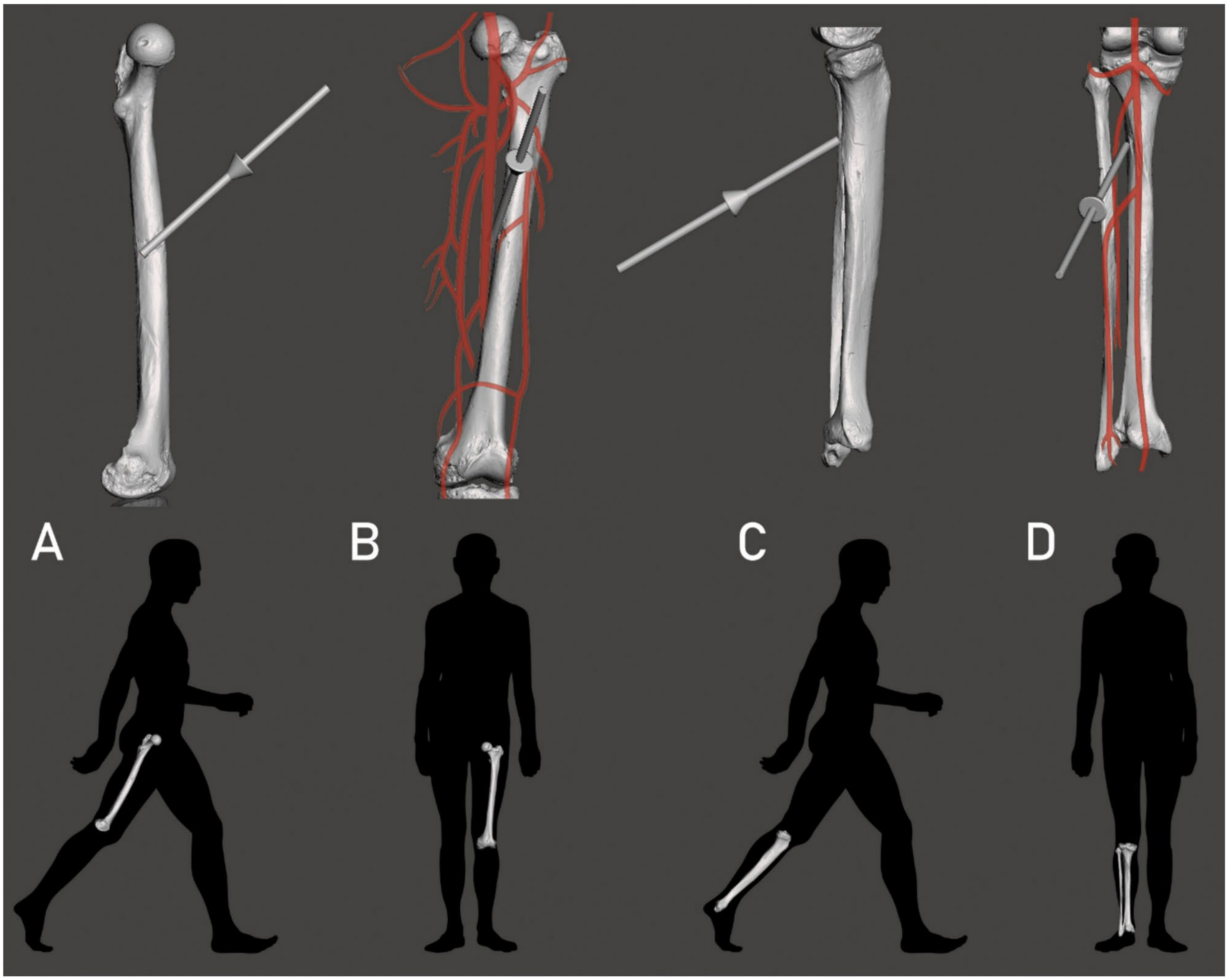

Fig. 8. Reconstruction of the probable ballistic trajectory of the projectiles that left the linear marks in Riparo Tagliente 1; In red, the course of the arteries of the lower limb is reconstructed. (**A**): Left femur, medial view; (**B**): Left femur, frontal view, showing the path of the femoral arteries; (**C**): Left tibia, medial view; (**D**): Left tibia, posterior view, showing the path of the tibial and fibular arteries. (Drawing of the path of arteries modified from: commons.wikimedia.org/wiki/File:2129ab_Lower_Limb_Arteries_Anterior_Posterior.jpg#file CC-BY-3.0; silhouettes from Wikimedia Commons CC-Zero).

ambushes or before close-quarter combat ensues[22,27,28,119,126–129]. Consequently, projectile wounds in human remains are widely recognized in the literature as strong evidence of intergroup conflict[2,7,19–21,23,24,34]. Overall, the circumstances surrounding the death of Riparo Tagliente 1 seem more consistent with intergroup conflict, though a personally motivated homicide remains a possibility[130].

Skeletal evidence of violent deaths in the Paleolithic has been previously reported (in addition to the references above, see also the thoraco-facial trauma in the Gravettian "Principe" from Arene Candide, dated to 27,880–27,290 cal BP)[131], but clear evidence of conflict as opposed to possible accidents or intragroup violence is extremely rare. Churchill and colleagues[38] suggest that the rib lesion in Shanidar 3 is most consistent with a light-weight projectile weapon, a technology that was not in use among Neanderthals, opening the possibility of interspecies conflict around 47,000–40,000 BP. The lesion in the first thoracic vertebra of Sunghir 1 from the Gravettian of Russia[36,37], directly dated to 27,700–26,500 cal BP[132], could have been caused by either a spear point or a hand-held blade, but the authors tend to consider intergroup conflict as the least likely explanation [36,37] (see below); still, more research on these possible PIMs is necessary. A convincing case of intergroup conflict is Jebel Sahaba in Sudan[34]. Direct radiocarbon dates on human remains at Jebel Sahaba span 13,727–7981 cal BP[35], but evidence for diagenesis suggests that the site may be older[133]. However, one older date made in 1988 shows a large error (Pta-116 13,740 ± 600) has been considered unreliable[133]. The skeleton of Tagliente 1, dated to approximately 17,000–15,500 cal BP, therefore represents one of the earliest directly dated evidence of PIMs in the human bioarchaeological record, suggesting the possibility of intergroup conflict among Late Pleistocene hunter-gatherers.

Although this finding suggests that conflict between groups was present in the Late Upper Paleolithic of the eastern Alps, the degree of its frequency and organization (feuding, raiding, or warfare)[134,135] remain difficult to determine based on the available evidence, apart from the possible indication of multiple attackers (see above). It is difficult to determine whether the iconographic evidence of individuals pierced by multiple projectiles from European cave art[136] (pp. 85–89) can be interpreted as a realistic representation of actual events[7], but the findings presented here certainly resonate those depictions. However, from a single instance, little can be added to the ongoing debate regarding the frequency and motivations behind conflict in these non-segmentary societies (e.g.[7,22,126,130,134,137–142]). Trinkaus and Buzhilova[36] argued that there is insufficient evidence to hypothesize intergroup aggression prior to the terminal Pleistocene, particularly considering the likely low population density of Interpleniglacial foragers. Indeed, it has been noted that nomadic hunter-gatherers tend to interact peacefully with neighbors, typically prioritizing cooperation, reciprocity, and conflict resolution mechanisms (e.g.[22,114,116,130,142,143]). However, conflict can arise, especially in situations of crowding and resource competition[130]. Climate degradation and resource competition have been proposed as contributing factors to the Paleolithic evidence of conflict discovered at Jebel Sahaba[35]. At Riparo Tagliente, competition for newly opened territories during deglaciation may have been driven by demographic increase. While further evidence is needed to better understand the social interactions of Late Pleistocene nomadic hunter-gatherers, Riparo Tagliente contributes to the contextual variability of the extremely rare instances of intergroup conflict.

Although the individual from Riparo Tagliente appears to have succumbed to interpersonal violence, he was formally buried and covered with engraved stones, likely by members of his own group. In the context of the diverse funerary and mortuary practices recognized across Late Upper Paleolithic Europe[144,145], it has been suggested that, for the Epigravettian culture, formal burial was reserved for a limited segment of the population, reflecting a substantial continuity with the previous Gravettian tradition[57,146]. Moreover, burials from these cultural contexts disproportionately include individuals with pathological anomalies, either due to congenital conditions or trauma[36,147–150]. These observations have led to the hypothesis that Upper Paleolithic burials may have functioned as a means of “containment” for "exceptional events," such as “bad deaths”, violent events, or disease[147,149,151]. The evidence presented here adds Tagliente 1 to the list of burials that are compatible with this theory.

In conclusion, the traces of projectile impact marks in Tagliente 1 provide a rare opportunity to reconstruct the circumstances around the death of a Late Paleolithic hunter-gatherer, and offer some of the oldest evidence compatible with conflict between human groups.

Methods

Taphonomic analyses were carried out in order to identify the state of preservation of the bone surface and the nature of the modifications, referring to the well-known literature in the field[78–80,82,152–160]. Fractures of the bones were analyzed too following Villa and Mahieu[68,161,162]. Recent papers regarding the identification often through experimental studies of projectile traumas on bones were consulted in order to compare the projectile impact marks described both on archaeological fauna[38,42,46,105] and hominin bones[39,40,76,100,163].

Bone surfaces were first analyzed using a stereomicroscope Optika with digital camera (Moticam 2500), at the Natural History Museum of Verona. All the bones of the burial (lower portion of the skeleton) were carefully examined, and pictures of the complete bones and detailed macro-images of the modifications were taken.

Further analyses to highlight the micro-characteristic of the modifications were conducted through Scanning Electron microscopy[81,164]. For this, casts with extremely high precision were done using silicone elastomer Provil® novo Light CD2, and Optosil Comfort® Putty/Xantopren ® (HERAEUS KULZER) and replicas were obtained with epoxy resin Araldite ® LY 554 (RENLAM® MS-1) and Hardener HY 956. This procedure does not damage the bone and guarantees a high recovery from deformation of the marks[165,166] and avoids the transportation of complete bones from the Museum. The marks were analyzed at the Centre of Electron Microscopy of Ferrara University, using a SEM Zeiss EVO 40 in variable pressure mode, enabling backscattered electron images to be acquired at magnifications between 50–500 × with the application of a conducting Au–Pd layer on the replicas. At Siena University, modifications on the femur and the tibia were analyzed using a Hirox KH-7700 digital microscope. It was equipped with both a MX-G5040Z body and with a MXG-10C body depending on the dimension of analyzed area. This microscope enables the creation of 3D models of the observed surfaces, allowing to work in good light conditions also at high magnifications[167]. Due to the presence of concretions within the incisions, 3D models were created only for grooves showing clean surfaces. When possible, linear and angular measurements of groove’s cross-sections were collected, according to[46] (Fig. S1) and compared with those of a set of 156 bone surface modifications. This sample is composed of experimental slicing cut marks produced using unretouched flint flakes (22 on cattle autopodials, 66 on cat and 35 on coypus’ carcasses) and retouched tools (5 on cattle autopodials)[42,73,74]. Experimental activities consisted in skinning, defleshing and disarticulation. The lithic implements used are fully compatible with those used at the time of the Tagliente burial. The experimentally produced projectile impact marks (PIMs) were inflicted on caprine carcasses (n = 7)[46,105] and on coypus’ carcasses (n = 13)[42]. Experiments were carried out using replicas of Epigravettian projectiles, thus with a technology compatible with that used by the hunter-gatherers from Riparo Tagliente. Finally, a BSM detected on a brown bear rib from the Epigravettian site of Riparo Cornafessa (northern Italy)[63] was added to the sample. This evidence is of great significance: as it is a drag associated with an embedded flint fragment, it is the only unquestionable archaeological PIM available to date, relating to the same chronological and cultural context as that of Riparo Tagliente. Raw data are available in SI.

Data availability
All data generated or analysed during this study are included in this published article (and its Supplementary Information files).

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Author contributions

V.S. and F.F. designed the project. V.S. wrote the original draft with substantial inputs of F.B., F.F., F.C. and U.T.H. U.T.H. conceived the taphonomic study. F.B., J.C., U.T.H. performed laboratory analyses. V.S. supplied the anthropological assessments; archaeological descriptions are due to F.F. and V.S. Funding was provided by F.F., V.S. and U.T.H. All the Authors discussed the results, reviewed and approved the paper.

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Declarations

Competing interests

The authors declare no competing interests

Additional information

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Correspondence and requests for materials should be addressed to U.T.H.