



## OPEN New insights of cultural cannibalism amongst Magdalenian groups at Maszycka Cave, Poland

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The manipulation of human corpses started to become commonplace during the Upper Paleolithic. This well-documented behavior among Magdalenian peoples consists of perimortem manipulation and the removal of soft tissues and has been understood as forming part of the cultural repertoire of mortuary actions. The study of these practices has given rise to several interpretations with the consumption of human flesh (cannibalism) occupying a central position. The human assemblage of Maszycka Cave (18,000 cal. BP) is part of this ongoing debate. Although initial research in the 1990s suggested cannibalism, more recent studies challenge this interpretation arguing that the low incidence of human activity rule out the likelihood of processing for the purpose of consumption and proposing skull selection as a funerary practice. This study reviews the assemblage and presents previously unpublished postcranial skeletal specimens along with evidence of whole-body manipulation for consumption. This behavior is also observed in other chronologically and culturally similar assemblages throughout continental Europe, suggesting that cannibalism was integral practice within the cultural systems of these Magdalenian groups.

European Upper Paleolithic hunter-gatherers navigated the death of others through a wide variety of mortuary practices. These behaviors were particularly diverse during the Magdalenian, a period from which preserved human remains are scarce and fragmentary and occasionally represented only by isolated specimens<sup>1</sup>. This fragmentation has been associated with human behavior, as a result of either the postmortem selection of certain anatomical portions or the perimortem manipulation of the cadavers<sup>1–10</sup>.

Primary burials during the Magdalenian period are distinctly rare among the human assemblages from the same period (e.g., France = 9%)<sup>4</sup>, although some particularly well-preserved examples have yielded valuable information of the Magdalenian funerary world<sup>11</sup>. Elements of the cranial and postcranial skeleton have been widely recovered, and sometimes the position of the body can also be discerned<sup>3</sup>. Burial sites have occasionally been documented covered in ochre and containing grave goods<sup>5,12</sup>. In these scenarios, the absence of some bones has been related to carnivore activity and/or the intentional selection of elements for secondary deposition elsewhere<sup>5</sup>. Meanwhile, the absence of other body parts has been linked to the presence of isolated elements commonly found in the Magdalenian record<sup>1</sup>, perhaps because they were treated as relics. These assemblages tend to present interpretative problems regarding the context in which the bodies were deposited. However, it is commonly believed that the scarcity of materials and their dispersion cannot be related to natural processes<sup>1</sup>. The appearance of disarticulated and unconnected elements, mostly from the skull, suggests their intentional selection<sup>3</sup>. In fact, the deliberate selection of certain body parts may be reflected in some examples of parietal art which depicts isolated body parts like heads and trunks without extremities<sup>13</sup>.

Magdalenian groups also used human bone as a raw material by for the manufacture of skull cups and jewelry<sup>2</sup>. Some of these specimens bear decorative motifs or engravings added some time after the removal of the skin and flesh<sup>14,15</sup>. In fact, the percentage of human remains with signs of soft tissue removal is significantly

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high. In France alone, cut marks generated during the defleshing of the bodies have been documented on 93 Magdalenian individuals, approximately 40% of those calculated for this period in this region<sup>4</sup>. Human-induced modifications (HIMs) have been linked to mortuary practices in which bodies were defleshed and disarticulated. Although evidence of this type has been recovered in central, northern, and western Europe regions (Table S1)<sup>2,6,10,12,16,17</sup>, the scarcity of materials has impeded further interpretations for these assemblages. This is despite the fact that the presence of these modifications is most pronounced during the Middle and Late Magdalenian, when the archaeological record points to a general population increase<sup>4</sup>.

Opposing explanations have been proposed to explain how perimortem handling of corpses occurred in assemblages with a greater abundance of skeletal remains. On the one hand, cut marks have been related to the perimortem cleaning of bones as part of mortuary practices in which the aim is a secondary deposition<sup>16,17</sup>. On the other hand, the location and frequency of the cut marks suggests that the cadavers were intensively processed for consumption<sup>2,6,10</sup>.

The human bone assemblage from Maszycka Cave (Poland) is one of the Magdalenian sites where both interpretations about the manipulation of carcasses have been proposed. While early anthropological studies from the 1990s suggested the selection of skulls for the consumption of the brain<sup>18</sup>, later studies disproved the cannibalism hypothesis pointing to the lack of human tooth marks and the scarcity of cultural modifications. Proponents of this argument attribute the modifications present on the assemblage to the funerary processing of the skulls<sup>17</sup>.

This research aims to examine the Maszycka Cave assemblage to determine the origin of the cultural modifications and to consider the significance of these remains within the Magdalenian cultural system in central Europe.

## Results

The identified human assemblage from Maszycka Cave is made up of 69.8% (NISP = 37) cranial and mandibular fragments and 30.2% (NISP = 16) pieces of postcranial skeleton (Table 1). A minimum number of 10 individuals was recorded: six adults and four juveniles (Fig. 1). The dental eruption and the state of epiphyseal fusion suggest that one mandible (NR7-1) and one scapula belonged to a juvenile of six years of age. Another mandible (NR1-1) contained the mandibular third molar (M3) in crypt, near eruption, pointing to an individual under 21 years of age. Two left clavicles have unfused ends and belonged to two individuals of between 16 and 23 years of age. Finally, two humeri exhibited unfused distal epiphyses, and were therefore attributed to an individual of between 10 and 16 years of age.

The analysis of the bone surface reveals 36 specimens (67.9% NISP) with cultural modifications (Table 1). Among them, 31 specimens exhibit linear marks with key features characteristic of cut marks, such as straight, parallel, and deep incisions (Fig. 2; Fig. 3) with V-shaped cross-sections (Fig. S1; Fig. S2). Quantitative analysis of these marks, along with comparisons to experimentally produced marks from known agents (cut marks, trampling marks and carnivore tooth scores), indicate that both univariate and multivariate statistical analyses support these findings, confirming that these modifications align with cut mark morphology. Results from normality tests indicate a non-normal distribution across all measurements (Tables S3, S4).

Additionally, univariate statistics reveal significant variability in measurements among the different groups of surface modifications (Table S5). Width and depth dimensions (WIS, WIM, WIB, and D) in Maszycka Cave display a wide range between maximum and minimum values, unlike the experimental cut marks and trampling marks, which exhibit a more consistent distribution. In contrast, carnivore tooth marks show extreme values associated with larger dimensions. Similarly, the lengths of the lateral walls (LDC and RDC) indicate that trampling marks are generally the shallowest, whereas tooth marks show the greatest average depths and Maszycka Cave reach the highest depths. Finally, the cross-sectional angle ( $OA_{\text{linear}}$ ) demonstrates a stronger similarity between the experimental cut marks and those from Maszycka Cave, setting them apart from the carnivore tooth and trampling marks (Table S5). The PCA results show that the proximity between Maszycka Cave (blue) and the experimental cut marks (green) suggests that these groups share similar metric characteristics, indicating a possible correspondence in their patterns (Fig. 4). In contrast, trampling (orange) and carnivore scores (black) are more dispersed and positioned farther apart in principal component space. Notably, however, one of the 20 modifications (MAK77-2-1) is located near the carnivore scores group (Fig. S4). The variance shows that components 1 and 2 account for 99.1% of the data variance (Table S6). The MANOVA results corroborate the PCA interpretation, confirming significant differences between the modification groups, with archaeological and experimental cut marks distinctly separated from trampling and carnivore tooth marks (Table S4) (Fig. 5).

The detailed descriptions of cultural modifications are presented below by anatomical segments: Skull and mandible. Anthropogenic activity was identified on 24 cranial specimens including parietals, occipitals, one zygomatic and one mandible (64.8%). These modifications were recorded as cut marks (56.7%) and anthropogenic breakage (32.4%) (Table 1). A total of three refits from green breakage cranial fragments were documented.

The parietals exhibited groups of cuts in parallel to the sagittal suture on the central part of the bone and the inferior temporal line. These cuts are associated with scalping. Other groups of cuts located on the origin of the temporalis muscle, the superior temporal line, the parietal protuberance, and on the squamosal suture are related to defleshing and the removal of the ears. The occipital bones bore groups of slice marks on the occipital protuberance and cuts on the origin of the occipitalis and on the lambdaoid suture, both related to defleshing (Fig. 5c, d, f). We documented slice marks on one mandible at the lower edge of the chin, at the beginning of the right gonium to cut the masseter muscle, on a left ramus, a coronoid process, and the labial view of the retromolar area (Fig. 5g, h). The cut marks are associated with the defleshing of the mandible and its disarticulation from the skull (due to the cuts on the ramus).

Number	Element	Side	Age	Agent-Breakage	Anthropogenic Breakage	Cut mark	Practice	Total (HIM)
NR2-3	Scapula	L	Y	Hominin/Diagenetic	N, P	Sl	Skin	
NR2-1	Parietal	L	Y	Hominin		Sl, Sc	Skin	
NR2-2	Parietal	L	Y	Hominin	PN, PP, N	Sl	Skin	
NR1-1	Mandible		P	Green	N	Sl	Flesh/Dis	
NR1-2	Parietal	R		Hominin	N	Sl	Flesh	
NR1-3	Parietal	R	P			Sl	Flesh	
NR1-4	Parietal	R		Hominin	N	Sl	Skin	
NR1-5	Parietal	R	P	Hominin	N	Sl	Skin	
NR3-1	Occipital			Hominin	PP	Sl	Flesh	
NR3-2	Occipital							
NR4-1	Parietal	R	Y	Green/Diagenetic		Sl	Flesh	
NR4-2	Occipital		Y	Hominin	N			
NR4-3	Temporal	L	Y					
NR4-4	Parietal	L	Y					
NR4-5	Occipital		Y			Sl	Flesh	
NR5-1	Parietal + Wormian	R	P	Hominin	N	Sl	Flesh	
NR5-2	Parietal	R	P			Sl	Flesh	
NR5-3	Parietal	L	P			Sl	Flesh	
NR6-1	Parietal	R	Y	Green	N	Sl	Flesh	
NR6-2	Parietal	L	Y			Sl	Skin	
NR6-3	Parietal	L	Y					
NR6-4	Parietal	L	P			Sl	Skin/flesh	
NR6-5	Parietal	L	Y			Sl	Flesh	
NR7-1	Mandible							
NR7-2	Parietal	R	Y					
NR7-3	Occipital		Y	Green	N			
NR7-4	Skull							
NR8-1	Parietal	R		Hominin	N, PP	Sl	Skin	
NR8-3	Parietal	R	Y	Hominin	N, PP			
NR8-4	Occipital	R	Y	Hominin	N, PP	Sl	Flesh	
NR8-5	Occipital	L						
NR8-6	Parietal	R	Y	Green	PN	Sl	Skin	
NR8-7	Skull		Y					
NR8-8	Skull		Y	Green	N			
NR9-1	Clavicle	L	P	Hominin	P	Sl, Ch, Sc	Flesh/Dis	
NR9-2	Clavicle	L	Y	Hominin	P	Sl	Flesh	
NR9-3	Clavicle	L	Y			Sl	Flesh	
NR39	Parietal	R		Green	N	Sl	Flesh	
NR39-9	Skull							
NR39-9	Parietal	R						
Mak76-1	Metatarsal I	R	P					
Mak77-1	Rib I	R	P					
Mak77-2	Humerus	L	P	Green		Sl	Dis	
Mak77-3	Humerus	R	Y	Green				
Mak77-4	Humerus	L	Y	Hominin	PP	Sl	Dis	
Mak77-6	Radius	R	Y			Sl	Flesh	
Mak77-8	Clavicle	R		Hominin	P			
Mak87-1	Femur	R		Green		Sc	Flesh	
Mak87-2	Femur	R		Diagenetic/Hominin	ON, IN			
Mak87-3	Femur	R		Hominin	PN, PP, AF, CE	Sl	Flesh	
Mak87-5	Fibula	R		Hominin	N	Sl	Flesh	
Mak87-6	Humerus	L		Green/Diagenetic				
Continued								

Number	Element	Side	Age	Agent-Breakage	Anthropogenic Breakage	Cut mark	Practice	Total (HIM)
NR8-82	Parietal	R		Hominin	N			
<b>Crania</b>	<b>37 (NISP)</b>				<b>12 (32.4%)</b>	<b>21 (56.7%)</b>		<b>24 (64.8%)</b>
<b>P-Crania</b>	<b>16 (NISP)</b>				<b>8 (50%)</b>	<b>10 (62.5%)</b>		<b>12 (75%)</b>
<b>Total</b>	<b>55 (NISP)</b>				<b>20</b>	<b>31</b>		<b>36</b>
<b>Total %</b>	<b>100</b>				<b>37.7%</b>	<b>58.5%</b>		<b>67.9%</b>

**Table 1.** Maszycka Cave human assemblage, age, and human induced modifications. Table 1 (Y) young, (P) prime, (N) notch, (IN) incomplete notch, (PN) pseudo notch, (PP) percussion pit, (AF) adhered flake, (CE) cortical extraction, (ON) on lapped notch, (P) peeling, (SL) slice mark, (Sc) scrape mark, (Ch) chop mark. (HIM = Human-induced modifications).

Notches were identified on the lambdoid, coronal, and sagittal sutures on the parietal protuberance, the central area of the parietal and the upper border above the sagittal suture (Fig. 1). Percussion pits and abrasions are mainly associated with notches and documented on the transverse sulcus, the coronal, the sagittal and the lambdoid sutures (Fig. 5a, b). All these modifications are linked to the breakage of the skull for the removal of the brain.

**Shoulder girdle.** Evidence of butchery on the shoulder bones was identified on all specimens: one scapula and four clavicles. The scapula had one slice mark associated with defleshing. Slice and chop marks were observed on the inferior facet of the clavicular body, the posterior facet of the acromial extreme, the contact surface of the first rib and the different facets of the diaphysis (Fig. 5l, n). All these modifications occurred during defleshing. Two slice marks on the inferior facet of the scapular extreme were caused during the process of defleshing and disarticulation from the scapula. We observed a general peeling on the scapula and classic peeling on three of the clavicles, also caused during the disarticulation of the elements (Fig. 5m).

**Trunk.** The only trunk element is a first rib, and no human activity was identified on this specimen.

**Arms and legs.** Cut marks and anthropogenic breakage were identified on the surfaces of six of the long bones (Table 1). Signs of defleshing were documented on two femurs as one scrape and two slice marks on the anterior and medial facet of the shaft. One radius exhibited six slice marks on the insertion of the supinator muscle (lateral facet). Disarticulation was identified on two humeri as groups from one to five slice marks on the supracondylar crest and around the coronoid fossa (Fig. 5k). One fibula displayed cut marks on the shaft related to defleshing (Fig. 5s).

We also observed percussion pits on one humerus and notches, pseudonotches, an adhered flake and cortical extraction on the lateral and posterior facets of the midshaft on two femurs attributed to marrow removal. The aforementioned fibula also had one notch and percussion pits. Green breakage was observed on three humeri and one femur.

**Hands and feet** were also scarce, represented only by one first metacarpal. This specimen had a carbonized surface associated with direct exposure to fire. Based on the categories established by Stiner et al.<sup>19</sup>, this specimen exhibits stage one characteristics as it is slightly burned, localized and carbonized on less than half of the surface.

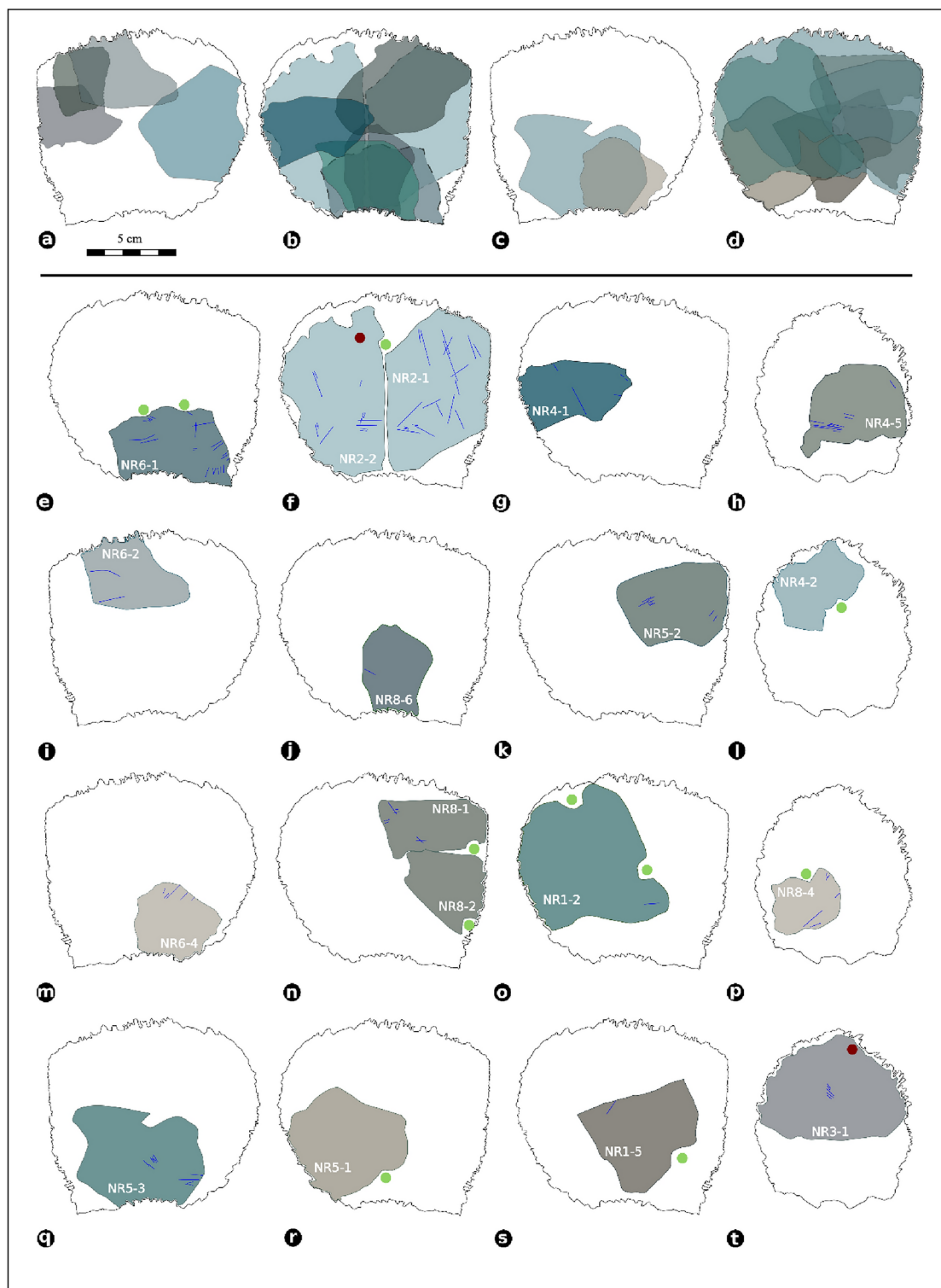
## Discussion

Post Last Glacial Maximum human remains are scarce and fragmentary in Europe<sup>1,12</sup>. In southwestern Europe, the percentage of human remains with cultural modifications dating to the Magdalenian is high, while primary burials are scarce<sup>4</sup>. Inferences regarding funerary practices during the Late Upper Paleolithic are diverse and include primary and secondary burials, funerary cannibalism, colorant staining, and the manufacture of skull cups and ornaments<sup>2–4,6,10,12,14,20,21</sup>.

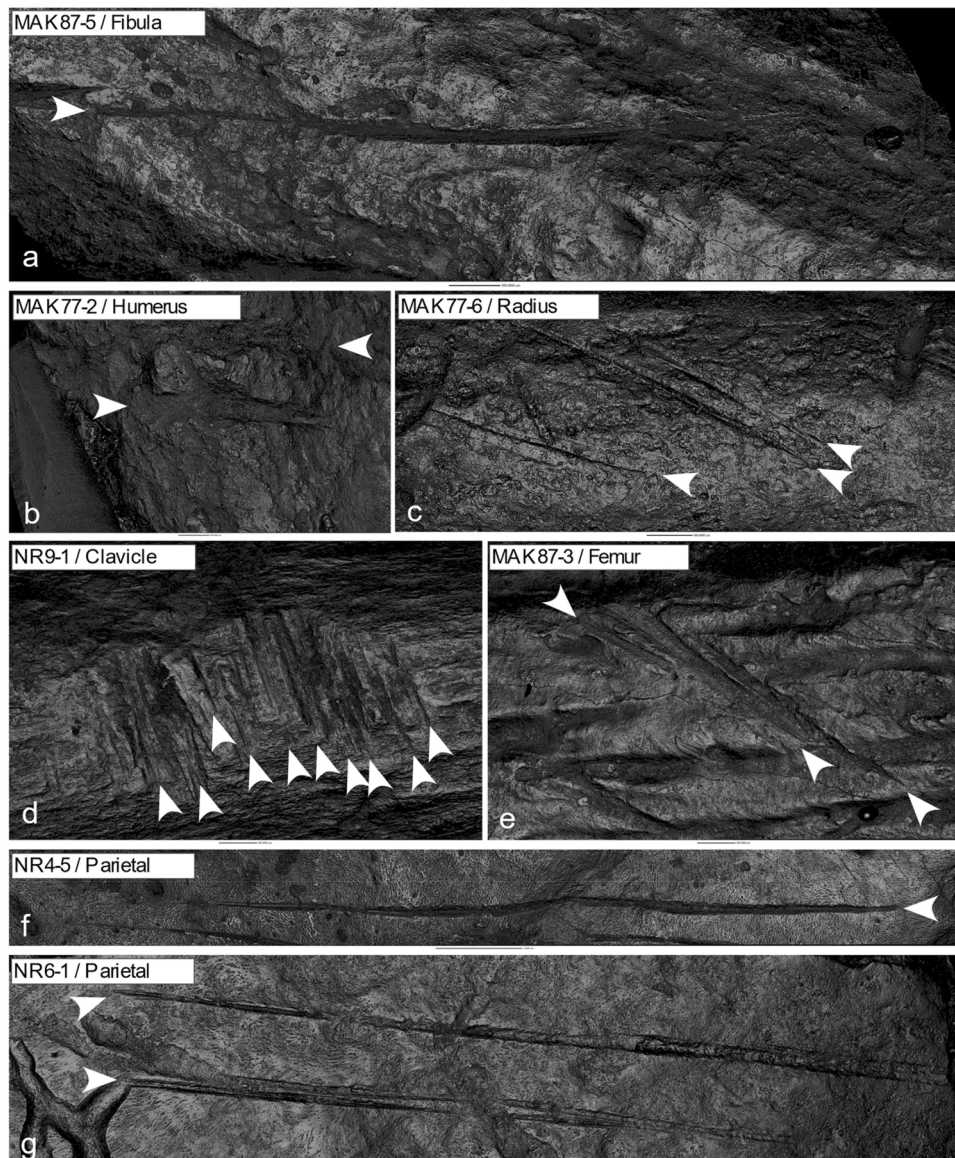
When butchering marks are documented on human bones, their causality is often the focus of much debate. Among the proposals, two main hypotheses come to the forefront. First, the presence of cut marks, anthropogenic breakage and/or human tooth marks suggests that the bodies were butchered and consumed in acts of human cannibalism<sup>6,10</sup>. Second, the manipulation of the bodies points to an extended mortuary tradition among Magdalenian hunter-gatherers, which included systematic defleshing and disarticulation but not consumption<sup>16,17</sup>. The main problem in differentiating consumption from non-consumption is that the same taphonomic signs can be produced in both behavioral contexts. Nevertheless, taphonomic studies suggest that there are significant differences in the frequency and distribution of these types of modifications depending on the ultimate intention<sup>22–25</sup>.

In contexts in which cannibalistic behavior has been suggested, the rates of human activity on the bodies exceed 30%<sup>23</sup>. In these cases, human-induced modifications are thought to be related to the preparation and extraction of the edible parts of the bones, often combined with other modifications associated with cooking and consumption<sup>23,26,27</sup>. Conversely, anthropogenic manipulation not associated with consumption takes place in funerary ritual contexts in which the bodies are defleshed and disarticulated for reburial in secondary depositions<sup>22</sup>. In these situations, the bodies are manipulated after a period of decomposition<sup>2,28</sup>. In contrast to cannibalized accumulations, in these, the frequency of anthropogenic modifications ranges between 1 and 5%, and human bone breakage and tooth marks are absent<sup>22,25,29</sup>.

The human remains from Maszycka Cave are part of the debate surrounding interpretations related to cannibalism versus non-consumptive funerary treatment. The research conducted to date has given rise to opposing interpretations. The first anthropological studies suggested that the observable traces on the bone



**Fig. 1.** Superposition of lateralized parietals resulting in the minimum number of individuals count. Each color represents an individual on a complete parietal background (a-d). Representation of anthropogenic activity on juvenile and adult parietals and occipitals displaying cut marks (blue line), percussion pits (red dot) and notches (green dot).

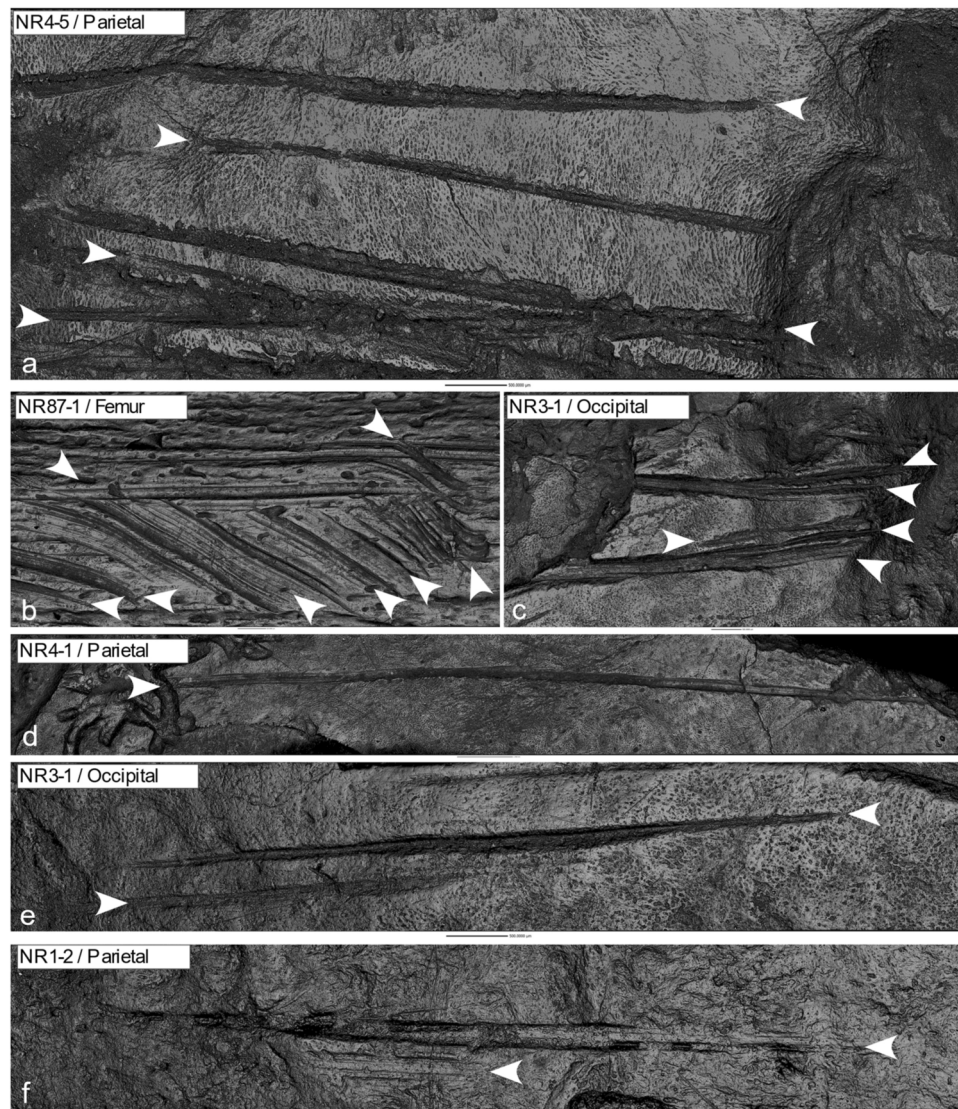


**Fig. 2.** Confocal microscope images of anthropogenic modifications from Maszycka Cave. Example of cut marks (white arrow) on long bones: fibula (a), humerus (b), radius (c), clavicle (d) and femur (e), and two parietal bones (f, g). Each image includes the specimen ID alongside the bone element identification and scale at the bottom.

surfaces were caused by butchering the skulls to consume the brain<sup>18</sup>. A more recent examination agreed with the inference regarding the intentional selection of skulls, but linked this human behavior to funerary practices, rejecting the possibility of consumption based on the low number of modified specimens (NISP = 5) and the absence of the postcranial skeleton and human tooth marks<sup>17</sup>.

The results of our analysis of the Maszycka Cave assemblage indicate intensive cultural manipulation of human remains with no observable carnivore modifications. The good state of preservation of the remains has allowed us to accurately document human activity, which was identified in over half of the studied specimens (Table 1). The cranial and mandibular fragments exhibited modifications related to scalping, defleshing and disarticulation<sup>27,30</sup>. Meanwhile, the skulls bore notches and percussion pits on different areas, generated during the removal of the brain (Fig. 2). The location of the cut marks shares some similarity to where they would be on skulls cleaned prior to the manufacturing of skull cups<sup>21</sup>. However, the distribution of the cut and percussion marks do not follow a specific pattern, and there are fewer cuts than in cases like those at Gough's Cave (Magdalenian) or El Mirador cave (Bronze Age)<sup>2,21,31</sup> (Fig. S3). Therefore, although the human bone breakage documented on these remains was performed to access the brain, it cannot be related to the purpose of preserving the calotte as in other Magdalenian assemblages<sup>2,6</sup>.

The upper and lower limb bones were similarly treated. Signs of defleshing were identified on the shaft of the clavicles and long bones, while disarticulation was documented by means of slice marks on the epiphysis and

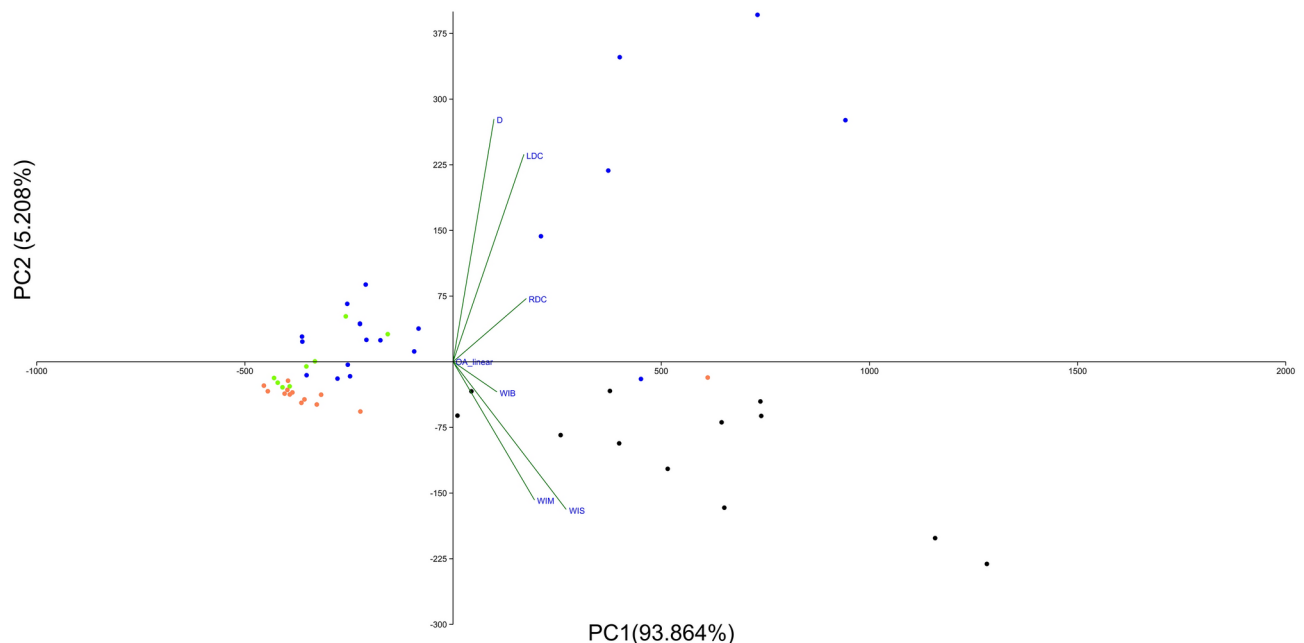


**Fig. 3.** Confocal microscope images of anthropogenic modifications from Maszycka Cave. Example of cut marks (white arrow) on three parietals (**a**, **d**, **f**), an occipital bone (**c**, **e**) and a femur (**b**). Each image includes the specimen's ID alongside the bone element identification and scale at the bottom.

shaft portions near the epiphysis (Fig. 5k, r). The long bones, even the fibulae, were intensively broken to remove the marrow (Fig. 6i). Contrary to that suggested by Kapica and Wiercinski<sup>18</sup> and Orschiedt et al.,<sup>17</sup> no specific anatomical selection was identified in this case. The bodies of adults and juveniles were butchered for the same purposes. In fact, the anatomical representation of the Maszycka Cave assemblage may reflect the criteria of the earliest excavations, in which probably only the specimens with strong human anatomic characteristics were considered for study.

This treatment of the cadavers shows that the butchering process took place shortly after death with no period reserved for the bodies to decompose or dry as is the case of secondary treatments<sup>22,28,29</sup>. In this case, the main difficulty is in differentiating between butchering processes related to the preparation of the corpses for consumption and other types of perimortem manipulation that may have taken place as part of mortuary practices and in which ingestion did not play a part<sup>10</sup>. Nonetheless, the purpose of the butchering process was the extraction of nutritional resources – meat, viscera, and marrow – a procedure in which clear patterns related to exploiting carcasses are evident.

Long bone breakage plays an important role in understanding the Maszycka Cave assemblage. The systematic breakage of these elements has been extensively studied in taphonomic research due to the value of these bones as a nutritional resource<sup>32</sup>. In fact, marrow from humans and other animals is a high-calorie food source<sup>33</sup>, that has been exploited in the same ways by foragers and farmer societies from the Lower Paleolithic to the Bronze Age<sup>30</sup>. Thus, the bodies at Maszycka Cave were intensively manipulated to remove all tissues and make use of their caloric contribution. These same patterns and same rates have been documented at other Magdalenian assemblages like Gough's Cave<sup>2,10</sup> and Brillenhöhle<sup>6</sup> where human-induced modifications have



**Fig. 4.** PCA of experimental cut marks (green), trampling (orange), carnivore scores (black) and cut marks from Maszycka Cave (blue).

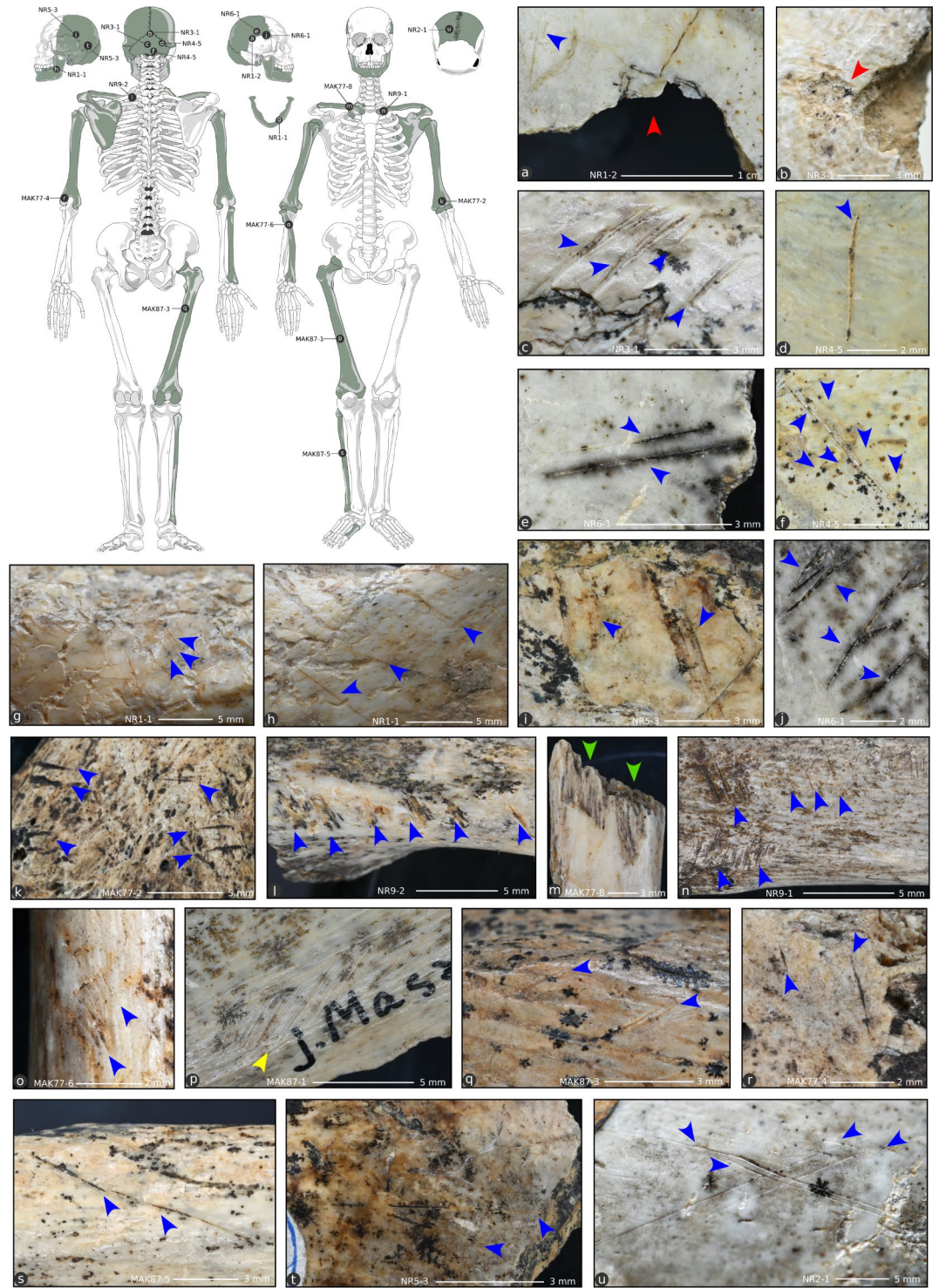
been documented on 65% and 64% of the remains, respectively. These proportions are common in cannibalized assemblages, regardless of the period, where cultural modifications range from 40% to more than 60%<sup>23,26,30</sup>.

Despite notable similarities with other European prehistoric assemblages displaying evidence of cannibalism from the Paleolithic, Neolithic, and Bronze Ages, human remains from Maszycka Cave differ in that no human tooth marks have been documented to date. Human tooth marks, however, are primarily observed on flat, fragile bones, such as those from the trunk, hands, and feet (Saladié et al., 2013), which are notably scarce in Maszycka Cave (NISP = 4, 6.6% of the assemblage). Prior studies (e.g., Saladié et al., 2013) document a range of possible modifications associated with human tooth marks, yet consistently highlight their prevalence on these specific skeletal elements. Similar anatomical patterns are observed in Magdalenian assemblages with cannibalistic evidence, such as Gough's Cave and Brillenhöhle (Bello et al., 2015; Sala and Conard, 2016), as well as in other Paleolithic contexts, including the TD6.2 level at Gran Dolina, Atapuerca (Saladié et al., 2012). This limited anatomical representation in the Maszycka Cave assemblage may be attributed to factors related to 19th-century excavation techniques.

Including Maszycka Cave, 17 Magdalenian assemblages currently contain pieces with signs of the anthropogenic manipulation of human bodies related to butchering processes (Table S1). Many of these assemblages lack sufficient data to interpret them unequivocally, and some merit review in light of new study methods and tools. The review of the materials, particularly of long bone shaft fragments mixed amongst faunal remains, revealed new specimens bearing both fractures and cut marks<sup>10,34</sup>. In fact, a recent review of five of these Magdalenian sets suggested that cannibalism was the most likely hypothesis<sup>6,10,35</sup>. Given the evidence indicating that the processing of corpses was a widespread behavior during this period<sup>4,12</sup>, the presence of cultural modifications may be related in more cases than expected to the consumption of the bodies, in other words, to human cannibalism.

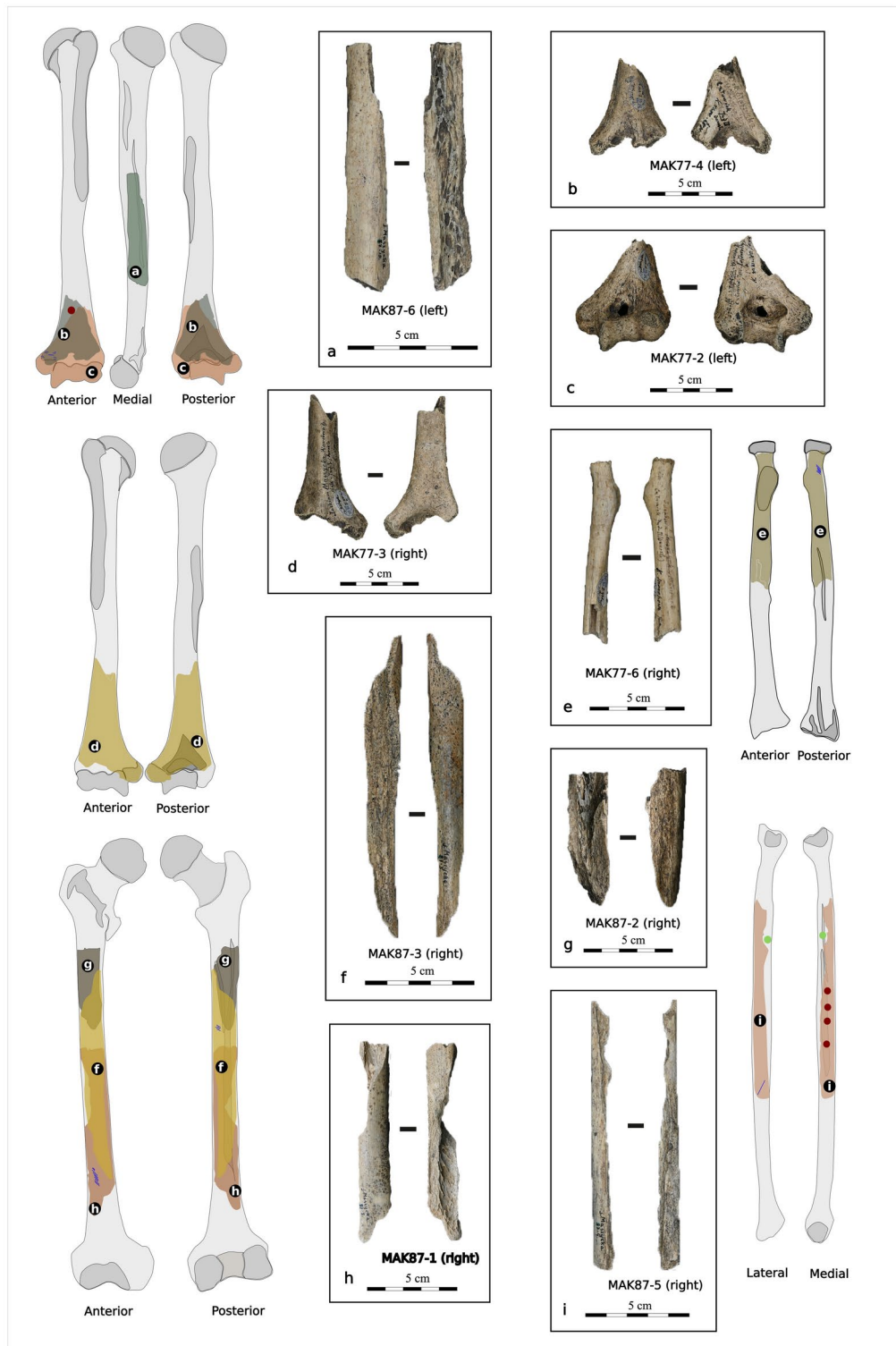
However, interpreting the context in which cannibalism occurred is both complex and challenging. One of the scenarios under consideration is the need to consume human flesh due to extreme survival conditions. Although this hypothesis is difficult to rule out, archaeological data suggests the opposite. Firstly, this chronological period was one of climatic improvement and population increase, which brings the occurrence of famines into question<sup>36</sup>, and secondly, direct dating of cannibalized fossils suggests that this behavior was continuous throughout the Magdalenian period, with a high incidence during the Middle Magdalenian<sup>35</sup>. However, distinguishing between endocannibalism (consumption within the same group) and exocannibalism (consumption of outsiders) constitutes a major challenge. Ethnographic research shows that funerary cannibalism involves the consumption of a member of the same group as an act of love<sup>37</sup>. Yet this type of treatment would likely leave the same archaeological record as its antonymous warfare cannibalism. The taphonomic evidence that would allow us to differentiate between the two contexts would be the respectful treatment of the bodies<sup>38</sup>. Still, the consumed Magdalenian remains apparently show no signs of what we understand today as respectful treatment. Recent DNA research conducted on individuals from eight Magdalenian assemblages linked cannibalism to GoyetQ2 genetic ancestry, while primary burial behavior corresponded to Villabruna ancestry<sup>35</sup>. This preliminary study proposes that cannibalism may have been a common funerary tradition for GoyetQ2 associated populations.

It is also important to consider that many of the factors that might be referred to as emotional (respect, compassion, hatred) are invisible archaeologically, although they can occasionally be inferred through the



**Fig. 5.** Human induced modifications on cranial and postcranial remains. Cut marks (blue and yellow) due to scalping (e, u) and defleshing of the skull (c, d, f, i, j, t), percussion damage (red) on skull fragments (a, b). Defleshing marks on a mandible (g, h), on a clavicle (l, n), on a radius (o), on a femur (p, q) and on a fibula (s). Disarticulation marks on a humerus (k, r) and peeling (green) on a clavicle (m). The specimen ID is located next to the scale at the bottom of the images.

context. This is very common in the prehistoric cannibalism record, where although the existence of ceremonial or ritual patterns can be inferred, their link to warfare or funerary cannibalism cannot always be distinguished. In contrast, respect is often clearly discernible in primary burials, where the bodies may be accompanied by offerings or ochre staining<sup>1,5,12</sup>. Meanwhile, exocannibalism is, from an anthropological perspective, related to the dehumanization of the enemy<sup>39</sup>. In fact, these prehistoric assemblages with manipulated human remains



**Fig. 6.** Representation of the newly identified specimens from the upper and lower long limb bones of Maszycka Cave. Each color represents one specimen fitting on a complete element. The cultural modifications are cut marks (blue line), percussion pits (red dot) and notches (green dot).

may suggest this connotation as they were found mixed with the waste of other consumed animals. Among European hunter-gatherer societies, the treatment of the bodies and, above all, the indifference with which the remains were disposed of may be associated with the eaters' lack of respect and empathy for those that were eaten.

Several factors support the possibility of warfare cannibalism amongst Magdalenian groups, which may provide an explanation for the manipulation, high fragmentation and scattered remains found at these sites. After the Last Glacial Maximum, European populations experienced a demographic increase which began to repopulate and colonize previously inhabited areas of northern and central Europe<sup>36</sup>. The increase in the hunter-gatherer populations is directly linked to the constraints imposed by the carrying capacity of the environment, which leads to a state of resource strain and gives rise to intergroup tensions, occasionally escalating into acts of violence<sup>40</sup>. The combination of population growth and resource scarcity is considered a primary cause of war<sup>41</sup>. Conflicts of this type are commonplace amongst contemporary hunter-gatherers and have also been documented in prehistoric forager groups<sup>42</sup>. Assemblages such as that from the early Pleistocene level TD6 of the Gran Dolina site (Atapuerca, Spain) show that territorial conflicts between human groups can lead to cannibalism as a model of territorial tensions, resource control and power<sup>43</sup>. Indeed, warfare cannibalism has also been recognized in the Badegoulian sample from Le Placard site (France<sup>44</sup>), the Epipaleolithic of Les Perrats (France<sup>45</sup>), and in Neolithic peoples from Herxheim (Germany<sup>46</sup>) and Fontbrégoua (France<sup>47</sup>). Additionally, although the presence of scattered or manipulated human remains (e.g., pendants) may be related to Magdalenian family relics<sup>12</sup>, they may also be connected to the procurement of war trophies, as described elsewhere<sup>7–9,48</sup>.

Following the Last Glacial Maximum (LGM), foraging groups progressively, although not uniformly, expanded towards the territories of central Europe. This expansion was characterized by advances and retreats of varying speeds and magnitudes<sup>49</sup>. Maier and colleagues<sup>49</sup> argue that exploration expeditions may have been used to investigate regions far beyond familiar, regularly exploited areas, though there was no need to establish a permanent presence in these zones. This could have led to episodic encounters with unfamiliar groups.

The Magdalenian occupations at Maszycka Cave are isolated, and the presence of Magdalenian *à navettes* in central Europe is negligible<sup>50</sup>. The occupations documented here may therefore correspond to these more or less ephemeral occupations or expeditions. The age profile resembles that of a complete nuclear family unit, suggesting that they could have been attacked, subdued, and subsequently cannibalized. Increased human movement in the territories, coupled with climatic improvements and the colonization of new geographic regions, may have been key factors in the development of territorial tensions that could have led to acts of cannibalism. Given this context, the accumulation of human remains in Maszycka Cave might have been the result of one or more cannibalism events resulting from intergroup confrontations.

Cannibalism cannot be understood as a common or homogeneous occurrence during the Magdalenian period, at least not yet. Its widespread practice is even less likely considering that it is an extremely diverse behavior that can arise from a wide range of environmental conditions and previous circumstances. Additionally, the Magdalenian period *sensu stricto* is a chronological unit that encompasses a variety of heterogeneous phenomena that do not seem to adhere to a single identifying model. Nevertheless, the assemblages in which the consumption of human flesh by people have been found seem to suggest that it was not particularly extraordinary, even if it was not a habitual part of their daily or domestic life.

## Methods

### Materials

The Maszycka Cave archaeological site is located about 20 km from the city of Krakow (Poland) on the left slope of the Prądnik valley. During the Paleolithic, the cave entrance was about 6 m wide, 13 m long and 2.5 m high<sup>51</sup>. The first excavations were conducted in 1883 by Gotfryd Ossowski, who excavated the interior and part of the terrace of the cave over a total area of 60 m<sup>2</sup>. Later, in 1960, Stefan Karol Kozłowski extended the excavation of the terrace. Finally, the last excavation campaign took place in 2013, when more than 200 small flakes were recovered from Ossowski's heaps, as well as more bone fragments and possible human remains. In total, the assemblage comprises 292 lithic artefacts, 98 bone items, one earring, 360 identified faunal remains<sup>50</sup>, and 61 human specimens. The Maszycka Cave human remains are currently stored in the Archaeological Museum in Krakow. In addition, the specimen ID present in this manuscript correspond to the museum's inventory system, organizing them by storage box (e.g., box MAK87, box NR1) and specimen number within the box (e.g., MAK87\_1, NR1\_1).

The accumulation of materials was interpreted as the remains of a campsite inhabited between autumn and winter<sup>52</sup>. Based on the technology documented at the site, it has been attributed to the Magdalenian *à navettes* phase, associated with the French Magdalenian<sup>52,53</sup>. Direct AMS dating on three human remains with cut marks and anthropogenic breakage provided chronologies of 18,586–18,184 cal BP (mandible, inv n° 1/1), 18,620–18,210 cal BP (frontal, inv n° 328) and 15,754–15,357 cal BP (right parietal, inv n° 1/5)<sup>51,54</sup>. Other AMS direct dating on an ulna (MAK77-5) provided dates consistent with the Neolithic (Ref. MAMS-50925; 5748 BC). This ulna presented a different taphonomic appearance with a more orange coloration than the other specimens and without any evidence of anthropic manipulation. This specimen, along with another fibula fragment with similar characteristics, was not included in this study.

The earliest studies on the human remains were conducted on 50 specimens, mostly cranial fragments<sup>18</sup>. These remains were associated with 16 individuals, eight adults and eight children, including three males and five females. The researchers responsible for these studies attributed the abundance of human-induced modifications on the bones to an exocannibalism event in which the brains of these individuals were consumed. A subsequent revision based on the same sample determined a lower number of individuals (MNI = 9), consisting of five adults and four subadults<sup>17</sup>. Orschiedt and colleagues reduced the number of substantiated cut marks to five specimens, and 3D digital models of the cut marks confirmed their cultural origin. The authors interpreted the assemblage as the result of funerary behavior in which skulls or skull fragments played a predominant role<sup>17</sup>.

## Taphonomy

For the study of the skeletal remains, the anatomical element, position, age, bone portion, lateralization (left/right) and landmarks were considered for each specimen. The whole set was observed macroscopically and microscopically with a Dino-Lite AD7013MT (20 – 200 x) microscope.

The Maszycka Cave human assemblage currently consists of 63 specimens, the descriptions of 50 of which were published by Kapica and Wiercinski<sup>18</sup> and Orschiedt et al.<sup>17</sup>. Of these 50, we studied 42 plus 11 specimens whose characteristics have never before been published, which were mixed in a box of faunal remains. The minimum number of individuals (MNI) was obtained by superimposing the most representative bones (parietal) through templates made with Inkscape 1.0.2 software<sup>55</sup>. In the same way, we also represented the location of the human induced modifications on the bone surface using templates. Age estimation was obtained using the criteria established by Ubelaker<sup>56</sup> for dental eruption and White and Folkens<sup>57</sup> for comparing the natural size of an infant scapula.

The presence of cut marks, anthropogenic breakage and direct exposure to fire are evidence of human activity on these pieces. The cut marks were classified according to their morphology as slices, scrapes or chop marks based on the position of the cutting tool during its use<sup>58–61</sup>. Slice marks occur when the cutting tool moves parallel to the long axis of the bone. Scrape marks are caused by the perpendicular position of the tool and are generally related to the extraction of the periosteum<sup>62</sup>. Finally, the dynamic application of force with the cutting edge produces chop marks<sup>59</sup>. The location and morphology of these modifications connect them to activities performed during the butchering process, such as skinning, evisceration, defleshing and disarticulation or dismemberment<sup>27,30</sup>. Anthropogenic bone breakage is related to the dynamic application of force with a hammer/anvil and is documented as notches, pseudo notches, percussion pits and abrasions<sup>63</sup>. This breakage is associated with the removal of the marrow in the long bones and the brain in skulls. Peeling was documented in bones with a certain degree of elasticity, such as the scapulae and clavicles, resulting from bending the specimens during disarticulation and consumption<sup>26,27</sup>. In addition, fracture lines related to percussion were documented on the skull<sup>64</sup>.

## Quantitative analysis of BSM

A preliminary quantitative analysis was conducted to confirm that the taphonomic modifications from Maszycka Cave are indeed cut marks. This analysis involved a morphometric study of the cross-sections of these traces. A total of 53 modifications were analyzed: 20 from Maszycka Cave, eight experimental cut marks, 12 experimental carnivore scores, and 13 experimental trampling marks from the taphonomic reference collection at the Catalan Institute of Human Paleocology and Social Evolution (IPHES).

For this purpose, we created high-resolution silicone molds of the Maszycka Cave modifications, using Provil<sup>®</sup> Novo Light (Kulzer Iberia S.A., Spain). Quantitative analysis was then performed using morphometric study of the cross-sections, which were compared with modifications from the reference collection. Cross-sections were obtained by scanning the surface with a confocal microscope (Sensofar S NeoX 3D optical profilometer) equipped with a Nikon EPI 10× objective at the IPHES. Section measurements were taken using the open-source software tpsDig232, placing seven landmarks following the protocol outlined by Bello and Soligo<sup>65</sup> and Maté-González et al.<sup>66</sup>. These seven landmarks provided quantitative data, including the maximum distance between points where each side of the landmark intersects the bone surface (WIS), the maximum distance between points located at the center of each face of the modification (WIM), the distance between points where the profiles of each face begin to converge (WIB), the perpendicular depth of the cut relative to the bone surface (D), the lengths of the left (LDC) and right (RDC) walls of the modification, and the angle between the midpoint and each side of the modification (OA). OA data were replaced by “OA<sub>linear</sub>” to enable multivariate analysis<sup>67</sup>. Measurements were extracted automatically using the open-source program Measurement Software<sup>68</sup>. Initially, Shapiro–Wilk tests were conducted to assess data normality and homogeneity<sup>69</sup>. Based on these results, parametric and non-parametric tests were applied to analyze normally and non-normally distributed data using R software (v.3.5.3; <https://www.r-project.org/>). For the univariate analysis, both robust and traditional descriptive statistics were calculated for each variable<sup>70–73</sup>. In the multivariate analysis, a principal component analysis (PCA) and a multivariate analysis of variance (MANOVA) were conducted to identify any significant differences among the variables.

## Data availability

Data is provided within the manuscript or supplementary information files.

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## Author contributions

F.M., P.S. and A. R-H. research design, analyzed the materials, wrote the main manuscript text and prepared figures. M. P-B, T. T. and D. B. contribute with the materials and wrote the manuscript. All authors reviewed the manuscript.

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## Declarations

The authors declare no competing interests.

## Additional information

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