



Case study

Activity-related skeletal changes at the olecranon tip in three individuals from the Iron Age cemetery in Hallstatt, Austria

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ABSTRACT

Objective: This study aims to describe and interpret specific pathological alterations at the elbow as observed in the special context of the Iron Age cemetery at Hallstatt, Austria.**Materials:** The study examined skeletal remains from 64 adult individuals from the Iron Age cemetery at Hallstatt Hochtal.**Methods:** A macroscopic analysis was conducted to identify bony changes in the elbow region. Measurements of asymmetry and 3D surface scans were used to provide an additional visualisation of the changes.**Results:** Approximately 14 % (n = 3) of the individuals with preserved right olecranon (n = 22) exhibit distinct lesions at the olecranon tip. These changes are likely biomechanical in origin.**Conclusions:** The lesions observed at the tip of the olecranon potentially result from posterior elbow impingement, a condition caused by repetitive and abnormal contact of the olecranon with the olecranon fossa. Movements requiring hyperextension and supination of the forearm, like in overhead throwing, can explain their location. They may relate to combat or hunting activities.**Significance:** This study presents a rare type of elbow lesion, providing important insights into the Hallstatt culture. Similar lesions may also occur in other bioarchaeological populations and cultural contexts. We aim to stimulate further research on their distribution.**Limitations:** The fragmentary preservation of skeletal remains from the Hallstatt Hochtal cemetery may obscure the actual frequency in the group.**Suggestions for Further Research:** The diagnostic and interpretive approach can be applied to other bioarchaeological populations to enhance our understanding of paleopathology, behavior, biomechanics, and sociocultural practices in ancient groups.

1. Introduction

In this paper, distinctive lesions on the olecranon of Iron Age individuals will be discussed in the specific context of the Hallstatt cemetery (800–400 BCE) in the Hallstatt “Hochtal” (high valley). Located in the rugged inner Alps of Austria, the Hallstatt region became famous for its extensive salt deposits, which have been exploited for over 7000 years (Brandner et al., 2022; Kern et al., 2008). Two key periods of

prehistoric salt mining in the Hochtal (c. 900 m above sea level) were identified: the Middle and Late Bronze Age (15th–11th centuries BCE) and the Early Iron Age (8th–6th centuries BCE). The exceptional preservation of organic materials due to salt exposure has resulted in unparalleled archaeological discoveries (Kern, 2011; Kern et al., 2008; Kromer, 1959; Reschreiter and Kowarik, 2019; Tiefengraber, 2024).

Around 800 BCE, a cemetery was established in the Hochtal, near the Hallstatt salt mines, and was actively used until the mid-4th century BCE

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(Hallstatt until Early La Tène period). First excavations of the cemetery began in the mid-19th century and revealed a rich assemblage of grave goods, reflecting Hallstatt's importance as a center of wealth, trade and cultural interaction. Artefacts of both local and imported origins illustrate the affluence and broad connections of the region's inhabitants. The cemetery—estimated to contain between 4000 and 5000 graves, including both inhumations and cremations—highlights the central role of salt mining and its surrounding activities in the social and economic structure of the community (Kern et al., 2008).

Morphological analyses suggest that at least a part of the people buried in the Hochtal were actively involved in the salt mining processes (Pany, 2003; Pany-Kucera et al., 2019; Goritschnig, 2025). Since most skeletal remains were not recovered during the 19th-century excavations, a larger number of representative skeletal remains has only become available through systematic excavations conducted in the 20th and 21st centuries. The gravelly soil contributes to the fragmentary condition of many skeletons (Pany, 2003), and the densely packed, sometimes intercutting grave layout—combined with the cemetery's location on a mountain slope at the valley's end—poses significant challenges for the bioarchaeological interpretation (Kern et al., 2008).

In 2009 and 2010, a particularly noteworthy grave complex was excavated by A. Kern and his team in the far northwestern area of the cemetery, designated as graves KE 97–100 (Kern, 2010:418–420; Kern, 2011). Initial analysis suggests a central cremation grave (KE 98) richly furnished with grave goods and surrounded by three spatially associated burials (graves KE 97, 99, inhumations, and KE 100, another cremation). All four graves were aligned parallel to the slope in the typical Hallstatt northwest-southeast orientation. Based on the typological analysis of grave goods, the burials date to the first half of the 6th century BCE.

While performing contracted work to establish basic biological profiles for newly excavated individuals from burials KE 97 and KE 99, one of the authors (DPK) observed previously undocumented alterations at the proximal ulna of the two individuals from this distinctive burial complex. These findings prompted a systematic re-examination of this anatomical region across the entire skeletal collection, where a similar lesion was found in another individual from the Hochtal in a grave excavated by F. Morton in 1939, MO 7. The latter burial is dated to the 6th and 5th centuries BCE by grave goods.

2. Material and methods

2.1. Sample selection and size

All adult individuals from the Hallstatt cemetery with preserved right and/or left elbow parts ($n = 64/165$ inhumations excavated until 2018) were included in the study. The individuals were analyzed for bony alterations in the olecranon fossa of the distal humerus and the trochlear notch at the proximal ulna. Individuals with good preservation and no postmortem damage at this location served as a comparative sample. The skeletal remains are curated at the Department of Anthropology, Natural History Museum in Vienna, Austria.

2.2. Age-at-death and sex estimations

Age-at-death estimation of the adult individuals was conducted using tooth abrasion (Miles, 1963), pubic symphysis morphology (Brooks and Suchey, 1990), changes at the sternal joint surface of the clavicle (Szilvássy, 1978) and cranial suture closure (Ferembach et al., 1980). These methods were recently supplemented (Goritschnig, 2025) with transition analysis using the TA3 tool (Getz, 2020; Milner et al., 2020). Sex estimation was based on a combination of morphological traits of the cranium, mandible, and pelvis (Acsádi and Nemeskéri, 1970; Ferembach et al., 1980).

2.3. Examination and measurement procedures

Lesions were assessed through macroscopic inspection, high-resolution surface scanning, and close-up photography. Three-dimensional surface models were generated using an Artec Space Spider scanner. They can be best viewed using the MeshLab freeware. Post-processing of 3D meshes and texture mapping was performed with Artec Studio software (version 16) (Bastir et al., 2019).

In terms of differential diagnosis, our analysis incorporated etiological interpretations informed by relevant clinical literature. We primarily aimed to distinguish post-mortem damage that might be mistaken for fractures, with particular attention to colour differences and the morphology of the fracture edges (Grube et al. 2015).

To evaluate preferential upper limb use in individuals with elbow lesions, asymmetry was calculated for the available measurements of the distal humerus, proximal ulna, and radial shaft in the Hallstatt sample. Asymmetry was computed as:

$$\frac{(\text{maximum} - \text{minimum})}{(\text{average of maximum and minimum})}$$
 expressed as a percentage (e.g. Auerbach and Ruff, 2006), and hence it represents an absolute (non-directional) asymmetry.

3. Results

The Hallstatt sample considered in this study includes 25 males, 13 females, and 26 adults of indeterminate sex.

3.1. Elbow lesions: identification, description and frequency

Distinctive elbow lesions were identified in three individuals (Fig. 1–4): two males (individuals from graves KE 97 and KE 99), and one adult of undetermined sex (grave MO 7).

The skeleton of individual KE 97 is poorly preserved and fragmented



Fig. 1. Individual grave KE 97. 1a) Overview of available upper arm and forearm bones from right and left side. Black circle indicates region with observed change; 1b) Close-up of right and left proximal ulnae (ventral view) showing the crescent-shaped lacuna at the medio-anterior aspect of the right olecranon tip (arrow); 1c) Superior view of right and left ulna showing the lacuna at the medio-anterior aspect of the right ulna (arrow). © W. Reichmann, NHM Vienna.

(Fig. 1, and Supplementary Information 5). This adult male, estimated to have died in his fourth or fifth decade of life (30–50 years), displays evidence of joint changes to most major synovial joints. Individual KE 97 displays a bone lacuna located medio-anteriorly at the right olecranon tip measuring approximately 15 mm in width and at least 5 mm in anteroposterior depth. The lesion is characterized by a crescent-shaped, concave fracture line. The slight postmortem damage in the marginal part of the tip, indicated by lighter colour and more angular edges, as compared to the darker coloured in vivo changes with rounded and thickened edges, has made it more difficult to assess the extent of the lesion (Fig. 4a, b, and Supplementary Information 1).

Individual KE 99 is partially preserved (Fig. 2 and Supplementary Information 6). This adult male died after 35 years of age. The skeleton is characterized by pronounced bone robusticity, poor oral health, and a potentially well-healed fracture of the left femur. The spine exhibits signs of severe degenerative changes, particularly affecting the lumbar vertebrae. Individual KE 99 shows a more extensive bone lacuna than individual KE 97, but in the same medio-anterior region of the right olecranon tip. This lacuna measures approximately 2 cm in width and 1 cm in anteroposterior depth. The lesion margin is deeply concave with irregular, rounded and thickened edges of dark colour. The marginal part of the tip shows postmortem damage indicated by lighter colour and more angular edges. Although partially damaged post-mortem, a cavity is visible along the fracture line, resembling a cystic formation (Fig. 4c, d, and Supplementary Information 2, 3). However, the postmortem

damage has made it more difficult to assess the extent of the lesion and assess the cystic formation. Notably, the isolated fragment of the olecranon tip appears to have become fused to the distal humerus within the olecranon fossa.

The individual from grave MO 7 is represented by a highly fragmentary skeleton (Fig. 3 and Supplementary Information 7). This adult individual, whose sex is undetermined due to missing skull and pelvic parts, died after 30 years of age. The skeleton exhibits significant degenerative changes of the vertebral articular surfaces and hand bones, along with unilateral spondylolysis and a wedge-shaped deformity of the third lumbar vertebra. Individual MO 7 exhibits similar anterior changes to the right olecranon as KE 97 and KE 99, though precise measurements are difficult to obtain. The lesion appears irregular, concave, and flattened, contributing to the overall deformity of the region. A small marginal fragment appears to have been partially broken off or detached and subsequently re-fused. Additionally, a polished, shiny area (approx. 8 × 5 mm) is present on the proximal portion of the superior surface of the olecranon, resembling eburnation typically seen in synovial joints (Fig. 4e, f, and Supplementary Information 4). Notably, the attachment area of the *M. triceps brachii* just dorsal to the lesion is unaffected. The margin of the tip shows slight postmortem damage indicated by more angular edges, which did not impair the assessment of the lesion.

The three cases represent 4.7 % (3/64) of the adult sample under study. These cases account for 13.6 % of all individuals with a preserved right olecranon (n = 22). No comparable lesions were observed on the left side or in female individuals.

3.2. Upper limb dominance

Asymmetry values for the distal humerus, proximal ulna, and radial



Fig. 2. Individual grave KE 99. 2a) Overview of available upper arm and forearm bones from right and left side. Black circle indicates region with observed change; 2b) Close-up of right and left proximal ulnae (ventral view) showing the crescent-shaped lacuna at the medio-anterior aspect of the right olecranon tip (arrow); 2c) Superior view of right and left ulna showing the lacuna at the medio-anterior aspect of the right ulna (arrow); 2d) Close-up of lacuna (arrow), medial view; 2e) Dorsal view of distal right humerus, showing the isolated fragment of the olecranon tip fused to the distal humerus within the olecranon fossa (arrow). © W. Reichmann, NHM Vienna.



Fig. 3. Individual grave MO 7. 3a) Overview of available forearm bones from right and left side (no upper arm bones present). Black circle indicates region with observed change; 3b) Close-up of right and left proximal ulnae (ventral view) showing the detachment of the right olecranon tip (arrow); 3c) Superior view of right ulna indicating the detached area and the polished, shiny surface (arrow); 3d) Close-up of olecranon margin (ventral view), indicating the potentially partly broken or detached and reattached fragment (arrow). © W. Reichmann, NHM Vienna.

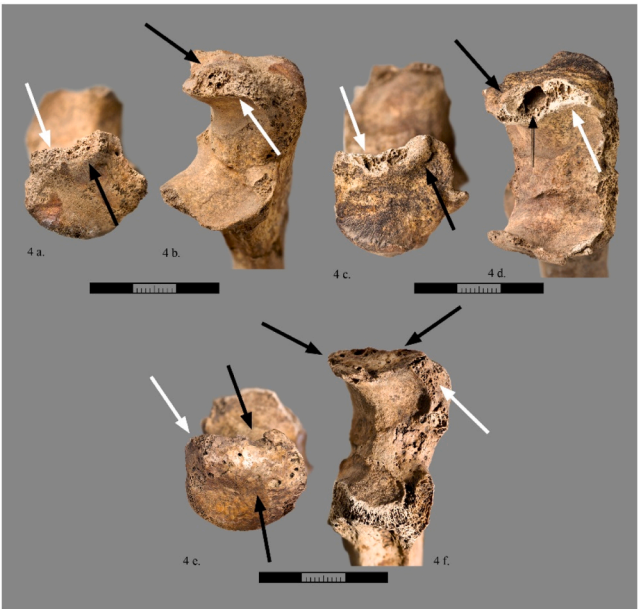


Fig. 4. Details of the affected right olecranon tips of the three individuals. Colour differences and the morphology of the fracture edges allow identification between in vivo changes (black arrows) and postmortem damage (lighter and more angular edges, white arrows); 4a; Superior view, individual KE 97; 4b) Medial view, individual KE 97; 4c) Superior view, individual KE 99; 4d) Medial view, individual KE 99, with the smaller, striped arrow in Fig. 4d pointing to the cystic lesion; 4e) Superior view, individual MO 7; 4 f) Medial view, individual MO 7. © W. Reichmann, NHM Vienna.

shaft of individuals KE 97, KE 99, and MO 7 are presented in Table 1. In all three cases, measurements were higher on the right side, indicating preferential right upper limb use. Asymmetry percentages for the ulna and radius approached or exceeded 10 %, placing them at or above the highest values observed when compared to other individuals in the Hallstatt sample.

4. Discussion

4.1. Differential diagnosis

All three individuals exhibit distinctive changes at the right olecranon. Some of these changes are characterized by light colour and angular edges, which indicate postmortem damage. Others are clearly related to in vivo events, recognizable by darker colour and partly thickened, irregular, rounded, and smooth edges. In two individuals—those from graves KE 97 and KE 99—well-defined bony lacunae are located on the medial aspect of the right olecranon tip. In both cases, the lesion margins are markedly concave and thickened, suggesting a fracture line. This is particularly evident in individual KE 99, where the

loose fragment appears to have become fused within the olecranon fossa, rendering a diagnosis of a healed, but non-united fracture reasonable.

In contrast, the margins of the lesion in individual MO 7 are thinner, sharp-edged and involve the entire anterior margin of the olecranon tip. This pattern likely represents a complete detachment of the triangular tip of the olecranon (Waris, 1946), perhaps followed by healing. The presence of a polished, shiny surface on the superior aspect of the olecranon, resembling eburnation in a synovial joint, further suggests abnormal, repetitive contact between the superior surface of the olecranon and the olecranon fossa. The mechanical origin of the lesions in the three individuals is supported by their unilateral occurrence and consistent location on the right side.

Olecranon fractures are relatively common injuries in modern adults, typically resulting from falls and occurring at the mid-trochlear notch (Brüggemann et al., 2022; Sullivan and Desai, 2019). Although several fracture classifications exist (e.g. Colton, 1973; Furushima et al., 2014; Sullivan and Desai, 2019), none adequately describe the small, localized bony changes observed in the Hallstatt individuals. For instance, the proximal olecranon fracture, classified as type 1 or "avulsion fracture" in Colton's system, involves the entire proximal part of the olecranon (i.e. the insertion site of the *M. triceps brachii*) (Colton, 1973), whereas the lesions described here are far more limited in scope.

A more plausible explanation is posterior elbow impingement resulting from repetitive and abnormal contact between the olecranon and the olecranon fossa (e.g. Hulkko et al., 1986). In boxers, such impingement typically affects the lateral region of the olecranon (e.g. Robinson et al., 2017; Valkering et al., 2008), while in throwing athletes, such as baseball pitchers, it occurs medially due to valgus stress and is referred to as valgus extension overload syndrome (e.g. Eygendaal and Safran, 2006; King et al., 2024; Ko et al., 2016).

Although stress fractures in athletes usually involve larger bone segments than those observed in our cases (Furushima et al., 2014), the association between posterior impingement and intra-articular bone fragments is well documented (e.g. Bowers et al., 2022; Eygendaal and Safran, 2006; King et al., 2024; Ko et al., 2016; Murphy, 1992). These fragments are typically interpreted as fragmented osteophytes caused by repeated impingement (Murphy, 1992; O'Driscoll, 2018; Wilson et al., 1983), though some studies demonstrated they may also originate directly from the olecranon tip itself (see Fig. 7 in Murphy, 1992), and that complete detachment of the triangular tip can happen (see Fig. 2 in Waris, 1946). Furthermore, subchondral cystic formations, such as the one observed in individual grave KE 99, are common in cases of posteromedial impingement (Ko et al., 2016).

In contemporary clinical literature, posteromedial olecranon impingement is most commonly reported in overhead-throwing athletes, particularly baseball pitchers (Ko et al., 2016). The underlying mechanism involves repeated elbow hyperextension combined with forearm supination (Valkering et al., 2008). Common clinical symptoms include posteromedial elbow pain, restricted extension, and hypertrophy of the dominant (throwing) arm (King et al., 1969; Ko et al., 2016).

Table 1
Absolute asymmetry computed for humeral, ulnar and radial measurements for the three cases and the comparative Hallstatt sample*.

		Humerus distal epicondylar breadth (M12)	Ulna transverse shaft diameter (M12)	Ulna proximal transverse diameter (M13)	Ulna greatest breadth incisura trochlearis (M6b)	Radius maximum transverse shaft diameter (M4)
Individual	KE 97		7.2 %	15.2 %	14.3 %	9.9 %
	KE 99	0.4 %			11.1 %	
	MO 7			15.0 %	10.9 %	
Hallstatt comparative sample	Males	5.0 % (1)	1.1–5.1 % (2)	1.4 % [0.4–3.4 %] (3)	1.8–8.8 % (2)	3.5 % [1.4–11.4 %] (3)
	Females	0.7–2.4 % (2)	3.1 % [0.0–4.3 %] (4)	1.2 % [0.0–1.5 %] (3)	8.7 % [2.8–18.3 %] (3)	3.0 % [1.4–10.5] (4)
	Total	2.4 % [0.7–5.0 %] (3)	3.2 % [0.0–5.1 %] (7)	1.6 % [0.0–6.5 %] (10)	5.7 % [1.6–18.3 %] (6)	3.6 % [0.6–11.4 %] (10)

* Linear measurements (M #) provided by Bräuer based on Martin (Bräuer, 1988). For the Hallstatt comparative sample, the median, minimum and maximum values (in brackets), and number of individuals (in parentheses) are reported. The total Hallstatt comparative sample includes males, females and unsexed individuals.

The hypothesis of excessive use of the right upper limb leading to overuse-related impingement is indirectly supported by the asymmetry values observed in the three Hallstatt individuals. The ulna and radius show absolute asymmetry values approaching or exceeding 10 %, which are among the highest within the population and unusually elevated for long bone extremities or diameters (Auerbach and Ruff, 2006; Blackburn and Knüsel, 2006). These findings support a clear pattern of right-arm functional dominance, likely resulting from habitual activity involving forceful, repetitive movements.

4.2. Possible causes of lesions in the economic and socio-political context of Hallstatt

The lesions observed on the right olecranon tips of individuals KE 97, KE 99, and MO 7 are most likely of biomechanical origin, resulting from repetitive mechanical stress consistent with overuse of the elbow joint. The localized and specific nature of these changes suggests habitual engagement in movements that placed consistent strain on the posterior elbow. Within the broader framework of Hallstatt society and particularly considering the distinctive grave goods associated with these individuals, these injuries offer a unique opportunity to explore the interplay of occupational demands and social roles in this Iron Age community.

It must be emphasized, however, that the reconstruction of past behaviors based solely on osseous alterations has limitations (Villotte, 2024). While the lesions are consistent with microtrauma caused by repetitive (over-)use, their etiology may differ between individuals, and multiple activities could have contributed to their development. Moreover, factors beyond biomechanics, including individual health status, activity intensity, and cultural practices, may have played a role in lesion formation.

Nevertheless, several archaeological and contextual observations allow cautious interpretation. Two of the affected individuals are male; the third is of undetermined sex. All three were buried in graves containing weaponry, and their funerary contexts stand out significantly from the broader necropolis.

Graves KE 97 and KE 99 were positioned in proximity within a complex funerary arrangement centered around the prominent burial KE 98. In the latter, which likely contained cremated remains, a wide array of objects, including iron roasting spits, weapons, tools, ceramic vessels, and adornments were found. Among the exceptional items were a bronze bowl featuring a cow-and-calf handle (Kern et al., 2008) and a triangular bronze arrowhead of Scythian type.

Grave KE 99, located to the northeast and oriented parallel to grave KE 98, contained an inhumation accompanied by weaponry, including an iron axe, a folding knife, and a decorative dagger and a bronze snake brooch. Bear claws found in the burial suggest the deceased may have been interred on or within a bearskin. Grave KE 97, situated directly above KE 99 and following its outline, included a spearhead, a bronze belt plate, and a gold ring near the head—possibly an earring. Notably, it was oriented in the opposite direction to grave KE 99. Together with another small cremation, these graves maybe formed a contemporaneous burial complex and were in a large collective chamber measuring 3.5 × 3.7 m.

Grave MO 7 is located in the far western area of the cemetery and included grave goods such as two iron spearheads, an iron ring (possibly a belt ring), a whetstone, and an exceptional Scythian-style iron hammer-axe.

These shared characteristics – specific grave goods including weaponry, a special funerary context and very particular changes at the olecranon tip – suggest a degree of social differentiation which sets them apart from the rest of the necropolis in terms of a distinctive and shared status among them and potentially linked to specific activities.

Salt mining was central to Hallstatt's economy, requiring a physically demanding workforce. The repetitive mechanical stresses associated with mining, such as using heavy tools (e.g., picks, hammers (Barth,

1976; Pany, 2003)) or leveraging the arms during extraction and transport, could plausibly result in repetitive valgus stresses to the elbow joint. The interpretation associating the origin of these lesions with mining activities appears thus, at first glance, the most evident in the context of Hallstatt. However, the characteristics that group the affected individuals and the fact that these lesions are not more generalized within the necropolis allow us to propose another hypothesis.

Weapons and military preparedness were also likely crucial to maintaining Hallstatt's socio-political structure. Control over valuable salt resources and trade likely required defense against external threats and internal disputes. It seems plausible, therefore, that these stress-induced lesions may instead be related to specific combat training or weapon use, possibly associated with a form of warrior elite. This hypothesis has the advantage of considering the funerary treatment, notably the regular presence of weapons in a high percentage of male's graves. First, we must mention the addition of lances and spears, whose metal tips have been preserved. As is known from contemporary depictions on bronze sheet objects decorated in the so-called *situla* style, such as buckets (*situlae*) or belt plates (e.g. Barth, 1963: belt plate of Vače, Slovenia p. 117), spears with throwing slings, which can increase target reliability and impact of the throw, were regularly used as throwing weapons by Early Iron Age warriors. Hundreds of lances and spearheads have been found in the graves of Hallstatt (Fig. 5), leaving no doubt as to their use. The same applies to axes and hatchets, which are also part of the standard equipment. Such a case is also presented by the long-stemmed so-called Scythian axe in Grave MO 7, which – like various depictions on Greek vase-paintings show – must originally have had a long shaft, also allowing this weapon to be used from horseback (e.g. amphore - Louvre site des collections; Amphora of Euphronios; Collection no. 676; Catalogue no. 106). This gave it great momentum and striking power, which could cause injuries to the elbow joint if a blow missed its target. However, this hypothesis remains highly speculative and requires the multiplication of similar observations in comparable contexts to be substantiated.

Regarding the skeletal remains, general signs of trauma or fractures, such as haematomas, healed long bone fractures and blunt force skull trauma, were observed in about half of the 47 adult individuals well-preserved enough for systematic recording (Goritschnig, 2025). In



Fig. 5. Watercolour by Isidor Engl: grave of a warrior with an iron spearhead (grave no. 290), excavated in 1855 in the Hallstatt graveyard. (NHM Vienna).

addition, preliminary analysis reveals an incidence of perimortem skull trauma in one adult from the Hallstatt group.

Another, often overlooked, possibility is that the lesions are related to hunting activities. While spearheads might have served military purposes, they could equally have been employed in the hunting of wild game. Although a systematic archaeozoological analysis of faunal remains from the Hallstatt cemetery is lacking, isolated finds of deer have been described for the archaeozoological record of the late Bronze Age (Pucher et al., 2013). The broader material culture of the Hochtal contains little direct evidence for hunting, despite the area's likely abundance of game (Kowarik et al., 2015). Nonetheless, the bear claws found in grave KE 99 constitute compelling evidence for the hunting of large animals. Such activity would have required regular practice and physical conditioning, potentially explaining the observed elbow changes.

5. Conclusion

The morphological changes observed on right proximal ulnae of three individuals from the Hallstatt cemetery are consistent with healed, but non-united fractures. The unilateral occurrence of these lesions, exclusively on the right side, strongly supports a biomechanical origin. This interpretation is further indirectly supported by pronounced asymmetry values, which suggest habitual overuse of the right upper limb.

The pattern and location of the lesions are consistent with posterior elbow impingement, particularly the posteromedial variant seen in throwing athletes, potentially resulting from a valgus extension overload syndrome. The posteromedial location of the lesions suggests a movement requiring repeated hyperextension and supination of the forearm, like in overhead throwing. The presence of grave goods such as spearheads, battle axes, lances but also finds like bear claws further suggests involvement in combat-related or hunting activities, which may have contributed to the observed skeletal changes.

This study offers new insights into the Hallstatt culture and possible habitual activities and living environments of the Hochtal people. Moreover, recognizing and interpreting the lesions described systematically herein for the first time provides a valuable contribution to the field. Describing these morphological changes in other cultural backgrounds and time periods is essential to expand the knowledge on biomechanical indicators of human behavior in the field of paleopathology.

CRedit authorship contribution statement

Doris Pany-Kucera: Writing – review & editing, Investigation, Formal analysis, Data curation, Conceptualization. **Sébastien Villotte:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Georg Tiefengraber:** Writing – review & editing. **Markus Bastir:** Writing – review & editing, Visualization.

Declaration of Competing Interest

The authors have no conflict of interest to declare.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ijpp.2026.02.002.

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