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RESEARCH ARTICLE

"Brothers in arms": Activity-related skeletal changes observed on the humerus of individuals buried with and without weapons from the 10th-century CE Carpathian Basin

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Abstract

Investigation of warfare-related lifestyle based on the activity-induced skeletal changes is of great interest for bioarchaeologists. Numerous studies have described various skeletal traces connected to the regular practice of different types of weapons. However, methodological problems, such as the multifactorial aetiology of these presumed activity-related skeletal changes, make it difficult to evaluate which changes are reliable in the identification and characterisation of a given class of individuals in a population. This paper aims to find significant morphological and metric differences on the humerus between individuals buried with and without weapons. We focused on the Hungarian Conquest period (10th-century CE) collection of Sárrétudvari-Hízóföld, characterised by a high number of burials associated with weapons and, especially, archery-related equipment. Only adult males were selected for this study to decrease the influence of nonmechanical factors, such as age and sex. We analysed the bones for the presence of entheseal changes, joint changes, morphological variants, and traumas. The selection of these markers relied on anatomical and sport traumatological data. We also calculated indices of robusticity and shape based on the external measurements of the humerus. The values were compared according to the presence (armed group) or absence (unarmed group) of weapon deposits in the graves. An independent group of nonwarriors from the documented Luís Lopes Skeletal Collection (Lisbon) was also used for comparison.

In general, the armed group exhibited higher rates of changes, and statistical tests revealed significant intergroup differences concerning certain entheseal changes and indices of robusticity and shape.

Although the multifactorial aetiology of skeletal changes highly limits the possible interpretations, our results suggest that a set of morphological and metric features on the humerus is indicative of the practice of activities including archery and other fighting techniques. We assess that the further analysis of activity-related changes of the upper limb bones will contribute to the recognition of the presence of warriors at a populational level.

KEYWORDS
activity-related skeletal changes, anthropometrics, archery, burials with weapons, entheseal changes, Hungarian Conquest period, joint changes

1 | INTRODUCTION

Reconstruction of past lifestyle from skeletal markers supposed to be activity-related is a long-standing issue in bioanthropology. It became a topic of increased interest for bioarchaeologists since the 1980s (e.g., Dutour, 1986; Kennedy, 1989; Stirland, 1984). The general paradigm is based on the fact that bones can adapt their structure and form depending on the mechanical loading according to Wolff (1892), which has been confirmed at the architectural level by computational model (Huiskes, Ruimerman, van Lenthe, & Jansen, 2000).

Activity-related skeletal changes include qualitative and quantitative features, such as entheseal changes (at the insertion sites of tendons and ligaments), joint changes, and bone geometry (e.g., cross-sectional geometry), which are the most frequently studied parameters (Alves Cardoso & Henderson, 2010; Niinimäki, 2012; Nikita, 2017; Myszka, Krenz-Niedbała, et al., 2019). In the last few decades, numerous studies focused on the analysis of changes related to general or specific activities (e.g., Alves Cardoso & Henderson, 2013; Berthon et al., 2019; Djukic, Miladinovic-Radmilovic, Draskovic, & Djuric, 2018; Dutour, 1986; Hawkey & Merbs, 1995; Henderson, Mariotti, Pany-Kucera, Villotte, & Wilczak, 2016; Kennedy, 1989; Mariotti, Facchini, & Belcastro, 2004; Mariotti, Facchini, & Belcastro, 2007; Pálfi & Dutour, 1996; Rhodes & Knüsel, 2005; Robb, 1998; Ryan, Desideri, & Besse, 2018; Stirland, 1998; Thomas, 2014; Villotte, 2006; Villotte et al., 2010; Wilczak, 1998). The link between the actual activity and the skeletal changes is, however, not yet clear because other nonmechanical factors (e.g., genetics, sex, age, metabolic disorders) can influence their development (e.g., Dutour, 1992; Jurmain, Alves Cardoso, Henderson, & Villotte, 2012; Nikita, Xanthopoulou, Bertsatos, Chovalopoulou, & Hafez, 2019; Thomas, 2014; Waldron, 2009; Weiss, 2003). Scholars even questioned the validity of these changes (particularly the entheseal changes) as markers for reconstructing past activities, because of their multifactorial aetiology (e.g., Nikita et al., 2019). Although it seems that physical stress remains among the main factors influencing the development and characteristics of these changes (Henderson, Mariotti, Santos, Villotte, & Wilczak, 2017; Karakostis, Jeffery, & Harvati, 2019), the possible influence of nonmechanical factors must be controlled (Thomas, 2014), for instance, by taking great care when selecting pertinent materials and methods to avoid possible overinterpretations (Pálfi & Dutour, 1996).

Among the various topics of interest, the anthropological approach of hunting- and warfare-related activities gave promising results because regular practice with given types of weapons (e.g., atlatl and bow) can lead to the development of various skeletal traces (e.g., Angel, 1966; Dutour, 1986; Ortner, 1968; Rhodes & Knüsel, 2005; Stirland, 1984; Weiss, 2007), and, in some conditions, differences can be detected at a populational level (e.g., Thomas, 2014). Moreover, these bioarchaeological investigations allowed to extend knowledge on social and symbolical aspects of burial rituals and grave goods related to weapons (Härke, 1997). Because the evaluation of the social status and probable occupation of an individual are mostly based on archaeological data, bioarchaeological studies can greatly enrich the knowledge of populations of the 10th-century CE, corresponding to the so-called Hungarian Conquest period of the Carpathian Basin. The possible meanings of the grave goods, whether they reflect the past life, are, however, a controversial issue (Härke, 1997). In particular, the definition of the "warrior class" is still based on the presence of weapons in the burials, although an individual with no weapon in the grave may have been an active warrior during his life (Tihanyi et al., 2015). The most obvious bioarchaeological signs of interpersonal violence are the specific traumas, such as parry fracture and cut wounds. Unfortunately, these markers are a modest occurrence even in the cemeteries of the Conquest period. Thus, more frequently observed indicators are needed for detecting and distinguishing a given class of individuals among a population. According to written and archaeological sources, the 10th-century Hungarian armies consisted of highly skilled soldiers, especially in light cavalry and mounted archery (e.g., Veszprémy, 2017). During the Conquest period, they lead more than 40 successful campaigns throughout the whole of Europe, which required excellent tactics and constant training in archery and close combat. This repetitive practice suggests differences between the lifestyle of the "archers" and the civilian people. However, at this point, we have to note that the investigation of violence, warfare, and warriors is an extensive problem (e.g., Allen & Jones, 2014; Martin & Harrod, 2015). The use of multifunctional weapons such as the atlatl or bow might not refer to one single occupation like warrior or hunter, and these activities are frequently overlapping with each other (e.g., Martin & Harrod, 2015). To avoid this problem, we focus only on the activities themselves, and in our definition, the archers are individuals who were practicing archery and other combat styles in a regular way.

Extending a preliminary investigation and re-evaluating its results focusing on the entheseal changes (Tihanyi et al., 2015), we introduce in this paper the results of our research concerning the extensive bioarchaeological analysis of graves with weapons from the 10th-century CE cemetery of Sárrétudvari-Hízóföld (Hungary). We analysed the main entheses, joints, metric properties, morphological variants, and traumatic lesions through the comparison between two subgroups of individuals from Sárrétudvari-Hízóföld, according to the presence or absence of weapons in their graves, as well as an extra control group. We aimed to find differences that can lead to the reliable bioarchaeological identification of the potential archers in the population.

2 | MATERIALS AND METHODS

2.1 | The cemetery of Sárrétudvari-Hízóföld and the composition of the sample

The 10th-century cemetery of Sárrétudvari-Hízóföld was excavated by Ibolya Nepper between 1983 and 1985 (Nepper, 2002). A total of 262 graves, containing the skeletal remains of 265 individuals, were uncovered. The anthropological material is housed in the skeletal collection of the Department of Biological Anthropology of the University of Szeged (Hungary). The archaeological findings consist of different types of jewels, clothing ornaments, tools, horse riding-related equipment (stirrups, bits, saddle parts), horse bones, and weapons. The number of weapons and horse riding-related grave goods is superior to the ones of other cemeteries from this period in the Carpathian Basin. Weapons were found in 58 graves. They consisted of archery equipment (antler bow plates, quiver elements, arrowheads), and in three cases, an additional sabre or axe (Nepper, 2002; Figure 1).

Anthropological and paleopathological analyses were previously conducted on this collection of Sárrétudvari-Hízóföld. Besides, some horse riding- and archery-related markers were discussed (Berthon, 2019; Berthon et al., 2019; Pálfi, 1997; Pálfi & Dutour, 1996; Tihanyi et al., 2015). In these previous studies,

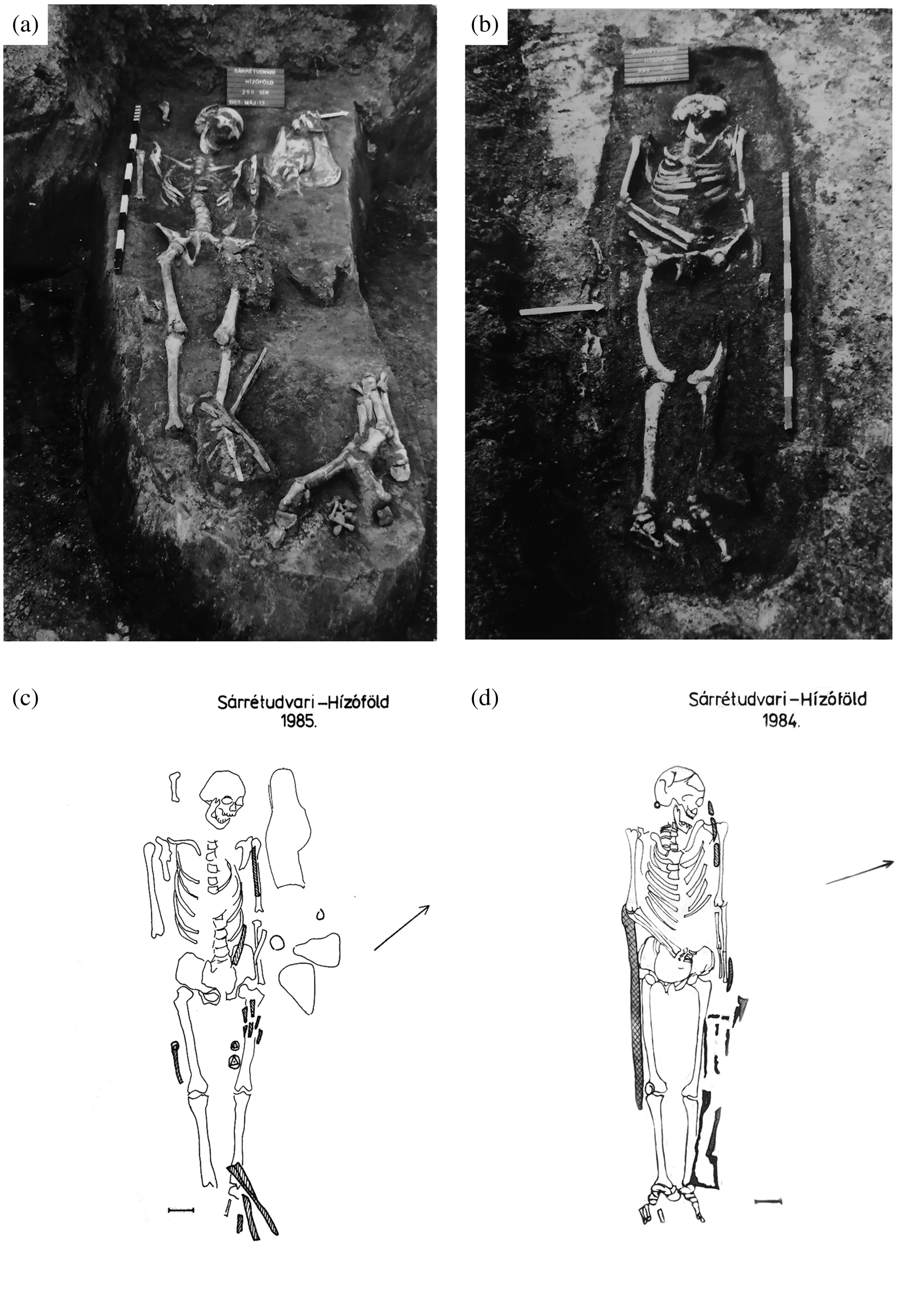

FIGURE 1 Excavation photographs and archaeological drawings of the burial Nos. (a and c) 258 and (b and d) 264, equipped with archery equipment, horse riding-related deposits, and sabre (Nepper, 2002)

101 subadults and 162 adults (with two indeterminate individuals) in total were analysed in the population (Oláh, 1990; Pálfi, 1997). Because activity reconstructions have many limitations, we had to consider certain prerequisites when selecting the sample. To limit the influence of sexual dimorphism and growth changes, we selected only the adult (>20 years) males into this investigation. The adults over 50 years of age were excluded from the investigation in the case of the analysis of entheseal and joint changes because age-related degenerative processes are among the main nonmechanical factors of influence (Villotte et al., 2010). Concerning the other types of analyses (morphological variants, traumatic lesions, and metrics), we did not exclude the elderly adults (>50 years) because those aspects are not or less considered to be influenced by ageing process than the entheseal and joint changes. In addition, previous paleopathological studies on this series (e.g., Pálfi, 1997) did not allow identifying conditions that may have affected those analyses (e.g., osteoporosis in the elderly individuals). Additionally, we excluded all cases showing pathological changes (not only on the humerus) that may have influenced the development and, thus, the evaluation of the activity-induced changes (e.g., diffuse idiopathic skeletal hyperostosis or spondyloarthropathies). After the reassessment of the age-at-death and sex (see Berthon et al., 2019), we divided the individuals into two subgroups according to the presence ("armed") or absence ("unarmed") of the weapon-related grave goods. Depending on the type of analysis, we could include up to 38 individuals (entheses and joints: 19; metrics and morphological variants: 35; traumas: 38) from the armed group and up to 29 individuals (entheses and joints: 18; metrics, morphological variants and traumas: 29) from the unarmed group to the evaluation.

2.2 | The comparative unarmed sample

In our preliminary study on the entheseal changes, we had suspected similarities between the armed and unarmed groups of the Sárrétudvari sample (Tihanyi et al., 2015), therefore we decided, for this investigation, to involve an independent, documented collection of individuals for which the repetitive practice of archery and other combat-related activities was excluded. Although such identified skeletal collections have their own limits and problems (Alves Cardoso & Henderson, 2013), they still can provide more reliable comparative data for our current investigation than any other historical series. We used the Luís Lopes Skeletal Collection, housed in the National Museum of Natural History and Science of Lisbon (Portugal). The collection consists of 1,692 skeletons with data on sex, age-at-death and occupation (Alves Cardoso & Henderson, 2013; Cardoso, 2006). We selected adult (>20 years) males who mainly lived and died during the first half of the 20th century, in the urbanised area of Lisbon. Concerning the entheseal and joint changes, we included in this study only the individuals under 50 years of age. After restricting the selection of the individuals according to the limiting factors (sex, age-at-death, disorders), our sample was composed of 47 individuals (entheses and joints: 31; metrics, morphological variations and traumas: 47).

2.3 | Recording of the macromorphological and metric data

For this study, we decided to focus on the arm bone, the humerus. This bone is, indeed, more robust than the forearm bones and therefore more frequently well-preserved. Furthermore, the humerus is related to both shoulder and elbow movements which are heavily involved in the activities of interest in our study, and especially archery (Axford, 1995).

In the last decades, studies revealed the problems and limits of the different categories of activity-related skeletal changes. We followed a combined methodology (e.g., Thomas, 2014), composed of five categories: entheseal changes, joint changes, metric data, morphological variants, and traumas (Figure 2, Table 1). When a single trait could not be recorded, it was considered as "nonobservable." Entheseal changes have been the most frequently used for reconstructing past populations' activities (Alves Cardoso & Henderson, 2010); however, the question of their scoring and evaluation remains debated (e.g., Nikita et al., 2019; Thomas, 2014). Although changes at fibrocartilaginous entheses are seemingly better activity-related indicators (e.g., Benjamin et al., 2002; Benjamin et al., 2006), we decided to analyse both fibrous and fibrocartilaginous entheses because we are interested in activities with complex muscle work. The selection of the analysed entheses relied on anatomical and sport traumatological data (e.g., Axford, 1994; Niestroj, Schöffl, & Küpper, 2018). Keeping in mind the limits and problems (e.g., Michopoulou, Nikita, & Henderson, 2017; Michopoulou, Nikita, & Valakos, 2015; Nikita et al., 2019) of the existing scoring methods (e.g., Hawkey & Merbs, 1995; Henderson et al., 2016; Mariotti et al., 2004, 2007; Villotte, 2006; Villotte et al., 2010), we used binary (presence/absence) scores.

Joint changes, and especially osteoarthrosis, represent also a frequent subject of studies on activities, usually scored on a multigrade scale (e.g., Buikstra & Ubelaker, 1994). Nevertheless, our aim was not to diagnose osteoarthrosis but to test whether the weapon-related activities can influence the development of joint changes. Regarding this and the limited sample size, we used a binary scoring based on the five groups of symptoms (Waldron, 2009). We did not take porosity into account because of its methodological and interpretational problems (Rothschild, 1997).

Morphological variants are expressions of the variation in bones and teeth in different sizes and formations (see White, Black, & Folkens, 2012). Some nonpathological morphological variants, such as *os acromiale*, have been considered as possible activity-related changes (Stirland, 1984). In most of the cases, multifactorial aetiology and methodological problems (e.g., lack of definitions and standards) make, however, the scoring and the evaluation difficult (White et al., 2012); We selected two commonly used variants of the humerus, namely, the supracondylar spur and septal aperture that are assumed to be—among others—activity-related (e.g., White et al., 2012; Myszka, Kubicka, & Tomczyk, 2019). Our aim was to test whether these variants are specific to the armed group.

The binary recording of traumas allowed us to see if differences possibly related to the lifestyle (e.g., Jurmain, 1999) can be evidenced.

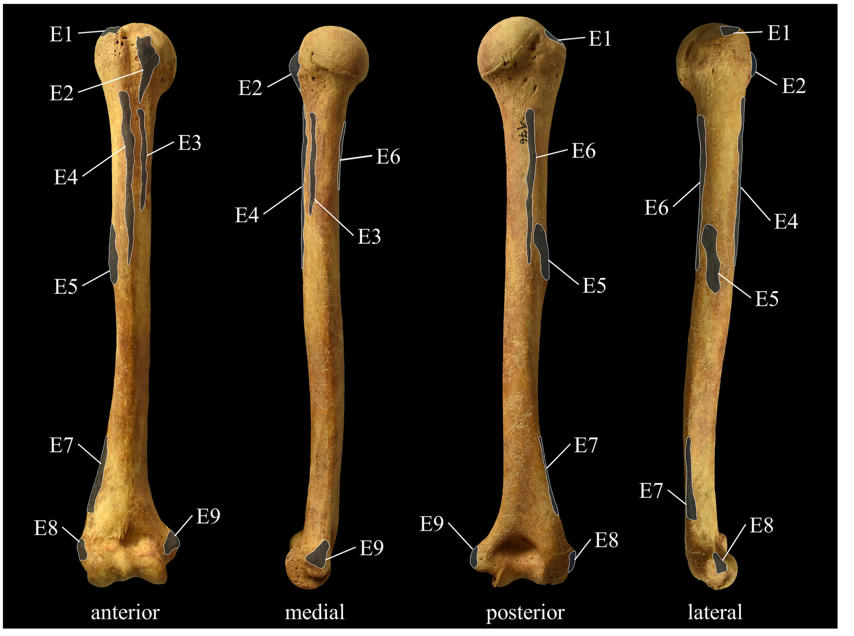

FIGURE 2 Localisation of the entheses observed on the humerus in the Sárrétudvari groups with (ARM) and without (UARM) weapons and in the Lisbon (LIS) group. For the codes of the entheses, see Table 1 [Colour figure can be viewed at wileyonlinelibrary.com]

Also, to avoid the methodological problems, we excluded cases (i.e., the affected side) with macroscopic signs of trauma (on any upper limb bones) from the analyses of entheseal changes, joint changes, morphological variants, and metric indices because the presence of traumatic lesions could bias the results of those analyses.

External bone measurements have been used for recording populational differences and reconstructing lifestyle. In particular, measurements on upper limb bones are used to investigate habitual behaviour and asymmetry (Ponce, 2010). We used direct measurements to calculate indices of shape and robusticity, following Martin's system (Bräuer, 1988). Only the analysis of the indices was included for this study to avoid bias related to stature. Both the left and right sides were measured, and directional asymmetry (difference between right and left side values) was calculated (see Steele & Mays, 1995).

2.4 | Statistical analyses

The aim of our study was to detect possible activity-induced differences between the Sárrétudvari groups with (armed = ARM) and without (unarmed = UARM) weapon-related grave goods and the comparison group from Lisbon (= LIS). Regarding the low sample size, we used only nonparametric tests to ensure the homogeneity of the results (following recommendations by Nikita, 2017). Fisher's exact test was used for the intergroup analysis of the entheseal changes, joint changes, morphological variants, and traumas for both sides, combined and independently. In addition, if a significant difference was noted, a pairwise analysis was performed and the Holm-Bonferroni method was used to correct the *p* values. Bilateral asymmetry was also calculated for each group using paired data and, compared between groups, using Fisher's exact test.

Kruskal–Wallis H test was used for the intergroup test concerning the indices for both sides, combined and independently. If a significant difference was found between groups, the Mann–Whitney U test was performed for the pairwise comparison and the *p* values were corrected with the Holm-Bonferroni method. Wilcoxon signed-rank test was applied to test the bilateral asymmetry in each group. The difference between both sides' indices was also calculated, and the pattern of asymmetry was compared between groups using the Mann–Whitney U test. The set significance level for all tests was α = 0.05. The analyses were performed using SPSS Statistics 25.

3 | RESULTS

3.1 | Entheseal changes

We recorded entheseal changes the most frequently among the different qualitative categories (Figures 3 and 4, Table 2, Data S1, Figure S1, and Tables S1 and S2). The armed group (ARM) showed higher frequencies concerning the sites of *m. latissimus dorsi/teres major* (E3) on the right side, *pectoralis major* (E4) on both sides and the common extensors around the lateral condyle (E7; E8). On the other hand, we found almost no changes at the entheses of the rotator muscles (E1; E2) compared with the Lisbon, and, especially, the unarmed groups.

Although we did not find significant differences between the two Sárrétudvari groups, we observed significant differences between the Sárrétudvari groups (ARM and UARM) and Lisbon (E2; E3; E4; E7): for two entheseal sites (E2 R + L; E3 L), between UARM and LIS groups, and for three sites (E3 R, R + L; E4 R, R + L; E7), between both Sárrétudvari groups and Lisbon. The analysis of the *pectoralis major* enthesis on the left side (E4) did not allow to identify significant differences between pairs of groups. With the current methodology, we

TABLE 1 List and description of the qualitative and quantitative variables involved in the analysis

Code	Description	Notes and formulas
E1	Superior and medium facets of the greater tubercle	Insertion site of *m. supraspinatus* and *infraspinatus*
E2	Distal and lateral part of the lesser tubercle	Insertion site of *m. subscapularis*
E3	Medial lip of the intertubercular groove; crest of the lesser tubercle	Insertion site of *m. latissimus dorsi*/*m. teres major*
E4	Lateral lip of the intertubercular groove; crest of the greater tubercle	Insertion site of *m. pectoralis major*
E5	Deltoid tuberosity	Insertion site of *m. deltoideus*
E6	Crest for *triceps brachii* on the posterior proximal part of the diaphysis	Insertion site of *m. triceps brachii caput medialis et lateralis*
E7	Lateral supracondylar crest	Insertion site of *m. brachioradialis*/*m. extensor carpi radialis longus*
E8	Lateral epicondyle	Insertion site of *m. extensor digitorum communis*
E9	Medial epicondyle	Insertion site of *m. flexor digitorum communis*
J1	Shoulder joint	Articular facet of the *caput humeri*
J2	Elbow joint	Articular facet of the *trochlea* and *capitulum humeri*
I1	Index of robusticity	100× (least circumference of the shaft (M7)/maximum length (M1))
I2	Diaphysis cross-sectional index	100× (minimum diameter of the shaft (M6)/maximum diameter of the shaft (M5))
I3	Head cross-sectional index	100× (transverse diameter of the head (M9a)/longitudinal diameter of the head (M10a))
I4	Trochlea-epicondyle index (b)	100× (medio-lateral breadth of the trochlea (M11)/breadth of the distal epiphysis (M4))
V1	Supracondylar spur	
V2	Septal aperture	
T	Traces of macrotraumas	

Note. Entheses (E) were scored as 0 = absence of changes; 1 = marginal osteophytes or osteolythic/osteophytic formation on the surface; *N* = less than half of the enthesis was observable. Joints (J) were scored as 0 = absence of changes; 1 = marginal osteophytes/new bone production on the surface/pitting/changes of the contour/eburnation; *N* = less than half of the articular facet was observable. Morphological variants (V) and traumas (T) were scored as 0 = absence; 1 = presence; *N* = nonobservable.

could not record any changes at the site of *m. triceps brachii* (E6). The changes appeared mainly bilaterally. In the ARM group, more asymmetrical cases were registered concerning the *pectoralis major* and the *latissimus dorsi*/*teres major* insertions (E4; E3); however, only a false significant result was obtained (E3).

3.2 | Joint changes

We observed joint changes in a low number of cases (Figure 5, Data S1, and Table S3). The armed group showed relatively the highest frequency of the changes, especially concerning the distal articular facet. According to the tests of asymmetry, the changes appeared mostly bilaterally. In the case of the armed group, there is a difference between asymmetry at the proximal and distal ends, as the left side is more dominant at the glenohumeral facet, and the right side, at the elbow. We did not find any statistically significant differences.

3.3 | Morphological variants

We could record the presence of the supracondylar process in only one case in our sample, on the right side of an individual from the armed group. Septal aperture appeared in a low number in both three groups. In particular, the Lisbon group showed the highest frequencies. Concerning the asymmetry, in the Lisbon and the unarmed groups, the variants appeared mostly unilaterally and on the left side, whereas in the armed group, bilaterally. There was no significant difference between or inside the groups (Data S1 and Table S3).

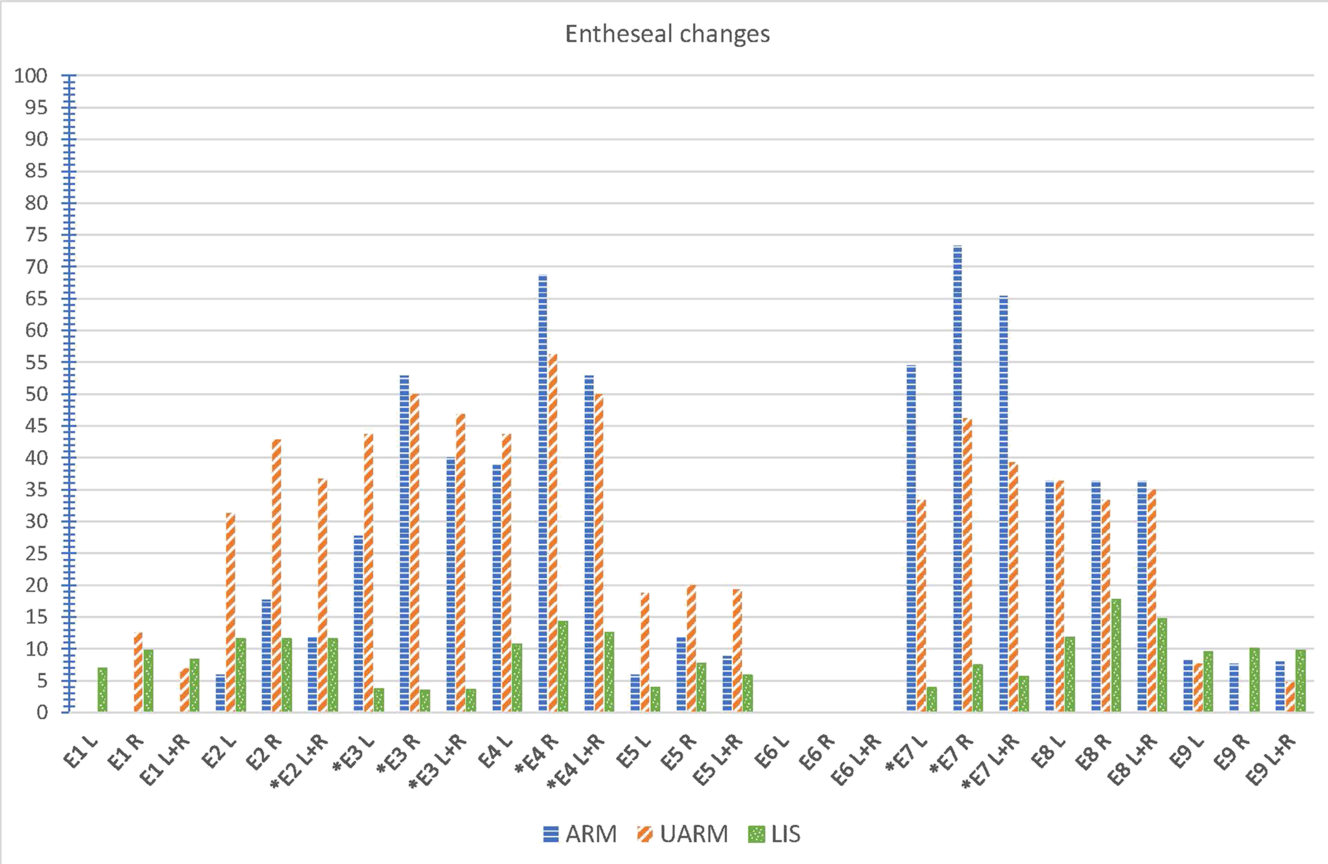

FIGURE 3 Frequency of entheseal changes in the Sárrétudvari groups with (ARM) and without (UARM) weapons and in the Lisbon (LIS) group. * indicates statistically significant differences between groups [Colour figure can be viewed at wileyonlinelibrary.com]

FIGURE 4 Examples of entheseal changes which show statistically significant differences between groups. E2: insertion site of *m. subscapularis*; E3: insertion site of *m. latissimus dorsi/m. teres major*; E4: insertion site of *m. pectoralis major*; E7: insertion site of *m. brachioradialis/m. extensor carpi radialis longus* [Colour figure can be viewed at wileyonlinelibrary.com]

3.4 | Traumas

Similar to the morphological variants, humeral traumas were also rare in the samples (Data S1 and Table S3). From the 38 (ARM), 29 (UARM) and 47 (LIS) individuals, only two traumatic cases were observed, in the armed group and in the Lisbon group, respectively.

3.5 | Metric indices

The analysis of the indices gave various results (Figure 6, Tables 3 and 4, Data S1, and Tables S4 and S5) even though we did not observe any statistically significant differences between the two Sárrétudvari groups. The indices of robusticity (I1) are rather similar in the two Sárrétudvari groups (ARM and UARM), and their mean values are higher than the ones in the LIS group; however, only a false significant result was found (L + R). Although there was no significant difference concerning the intergroup asymmetry test either, both the armed (p = .018) and unarmed (p = .006) groups showed significant right dominance in the robusticity. The shaft diameter indices (I2) are rather similar in the three groups, but the LIS group has slightly lower mean values. The left side in the armed group shows a wider range of values, but we did not find any significant intergroup difference. In the LIS group, the indices of the left side are significantly higher (p = .049) than for the right one, showing that the values of the minimum and maximum shaft diameters are close to each other. The mean value of the head diameter indices (I3) is lower in the armed group than in the

TABLE 2 Frequency and bilateral asymmetry of the most significant entheseal changes and results of the Fisher's exact tests (two-tailed) in the Sárrétudvari groups with (ARM) and without (UARM) weapons and in the Lisbon (LIS) group

		ARM			UARM			LIS				p exact adjusted		
Enthesis		*N*	*n*	*n*/*N* (%)	*N*	*n*	*n*/*N* (%)	*N*	*n*	*n*/*N* (%)	*p* exact	ARM-UARM	ARM-LIS	UARM-LIS
E2	L	17	1	6	16	5	31	26	3	12	.165			
	R	17	3	18	14	6	43	26	3	12	.091			
	L + R	34	4	12	30	11	37	52	6	12	.016*	.073	1	.032*
E3	L	18	5	28	16	7	44	27	1	4	.003*	.475	.061	.007*
	R	17	9	53	16	8	50	29	1	3	<.001*	1	.001*	.001*
	L + R	35	14	40	32	15	47	56	2	4	<.001*	.627	<.001*	<.001*
E4	L	18	7	39	16	7	44	28	3	11	.022*	1	.067	.067
	R	16	11	69	16	9	56	28	4	14	.001*	.716	.002*	.012*
	L + R	34	18	53	32	16	50	56	7	13	<.001*	1	<.001*	.001*
E7	L	11	6	55	15	5	33	26	1	4	.001*	.426	.004*	.037*
	R	15	11	73	13	6	46	27	2	7	<.001*	.246	<.001*	.017*
	L + R	26	17	65	28	11	39	53	3	6	<.001*	.064	<.001*	.001*

		ARM		UARM		LIS			p exact adjusted		
Enthesis	Asymmetry	*n*	*n*/*N* (%)	*n*	*n*/*N* (%)	*n*	*n*/*N* (%)	*p* exact	ARM-UARM	ARM-LIS	UARM-LIS
E3	L > R	0	0	0	0	0	0	.045*	.700	.146	.700
	L = R	13	81	13	93	26	100				
	R > L	3	19	1	7	0	0				
	N pairs	16		14		26					

Note. The Holm-Bonferroni correction was used for the pairwise comparisons; *n* = number of observed changes; *N* = total number of observable cases; L = left side; R = right side. Asymmetry was calculated as left minus right side on paired bones; For the full data on the frequency and bilateral asymmetry of entheseal changes and results of the statistical tests, see Tables S1 and S2

*Statistically significant difference.

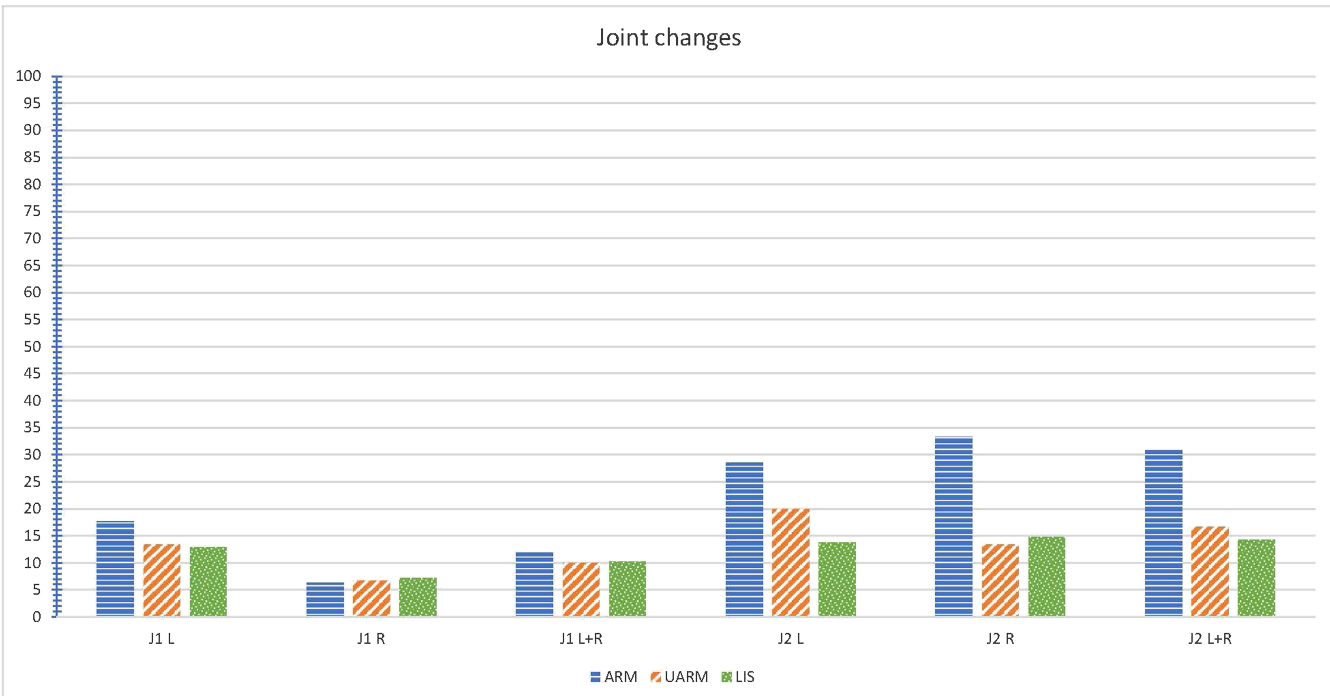

FIGURE 5 Frequency of joint changes in the Sárrétudvari groups with (ARM) and without (UARM) weapons and in the Lisbon (LIS) group. We did not find any statistically significant differences [Colour figure can be viewed at wileyonlinelibrary.com]

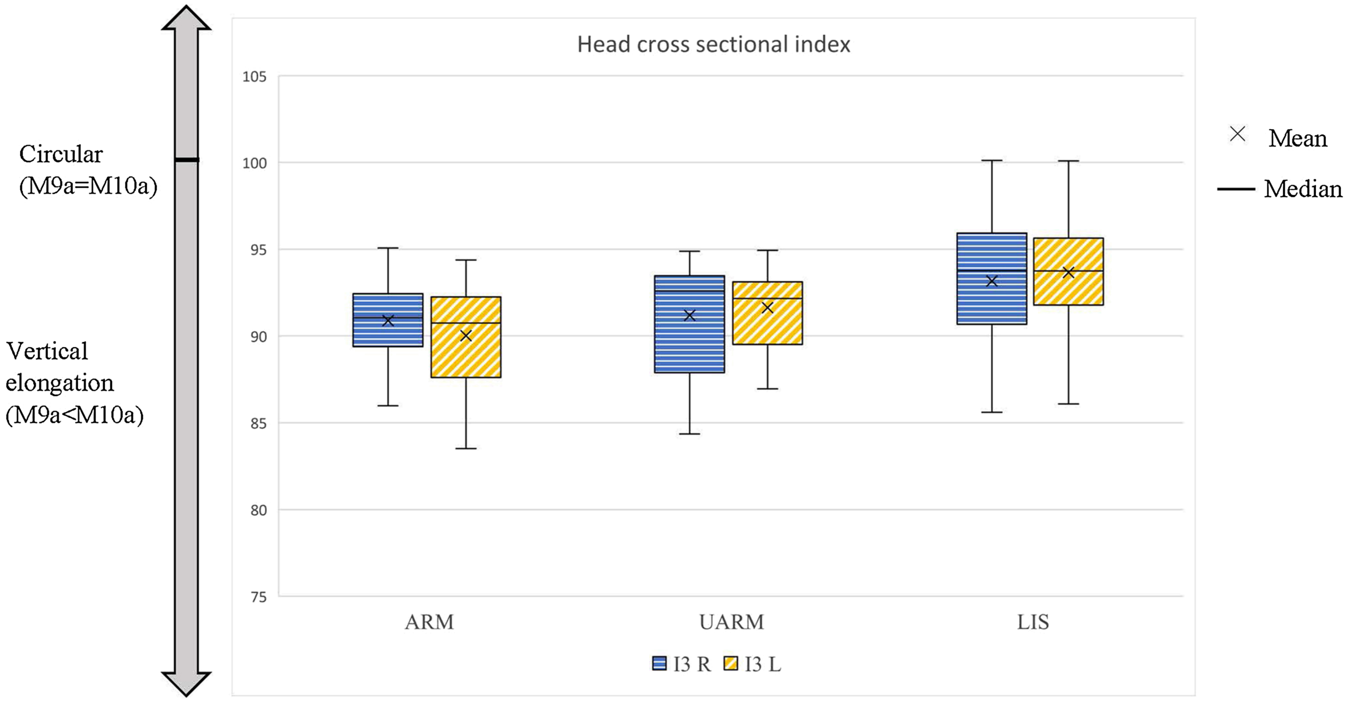

FIGURE 6 Differences between the head cross-sectional indices of the humerus in the Sárrétudvari groups with (ARM) and without (UARM) weapons and in the Lisbon (LIS) group [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 3 Summary statistics of the significant indices of robusticity and shape and results of the statistical analyses in the Sárrétudvari groups with (ARM) and without (UARM) weapons and in the Lisbon (LIS) group

Summary statistics																
		ARM					UARM					LIS				
Index		*n*	Min	Max	Mean	*SD*	*n*	Min	Max	Mean	*SD*	*n*	Min	Max	Mean	*SD*
I1	L	32	17.93	23.00	19.95	1.29	20	18.10	22.01	20.07	1.20	41	15.79	23.31	19.28	1.67
	R	26	18.11	22.77	20.07	1.20	20	17.97	22.42	20.07	1.29	42	15.90	23.55	19.45	1.59
	L + R	58	17.93	23.00	20.00	1.24	40	17.97	22.42	20.07	1.23	83	15.79	23.55	19.37	1.62
I3	L	21	83.51	94.38	89.90	3.23	15	86.96	94.94	91.63	2.37	30	86.09	100.09	93.66	3.31
	R	18	85.99	95.07	90.89	2.20	14	84.36	94.88	91.20	3.31	27	85.61	100.12	93.20	3.59
	L + R	39	83.51	95.07	90.36	2.81	29	84.36	94.94	91.42	2.82	57	85.61	100.12	93.44	3.42

Test of significance									
				ARM-UARM		ARM-LIS		UARM-LIS	
Index		*H* (*df* = 2)	*p* value Monte-Carlo	*U*	*p* exact adjusted	*U*	*p* exact adjusted	*U*	*p* exact adjusted
I1	L	4.914	.087						
	R	3.394	.186						
	L + R	7.911	.019*	293	.618	499	.173	286.5	.173
I3	L	14.085	<.001*	107.5	.111	130.5	<.001*	137	.068
	R	7.137	.026*	102	.377	137	<.001*	126	.172
	L + R	20.929	<.001*	420	.072	531	<.001*	538	.016*

Note. Kruskal-Wallis H tests (Monte Carlo estimate for an exact test based on 10,000 sampled tables); two-tailed Mann–Whitney U tests (using the Holm-Bonferroni correction) for pairwise comparisons; L = left side; R = right side. For the full data on summary statistics of indices of robusticity and shape and results of statistical analysis see Table S4

*Statistically significant difference.

TABLE 4 Summary statistics of the bilateral asymmetry analysis of the significant indices of robusticity and shape and results of the intra-group statistical analyses on paired bones in the Sárrétudvari groups with (ARM) and without (UARM) weapons and in the Lisbon (LIS) group

Summary statistics

Index		ARM					UARM					LIS				
		n	Min	Max	Mean	*SD*	*n*	Min	Max	Mean	*SD*	*n*	Min	Max	Mean	*SD*
I1	L	15	18.13	23.00	19.81	1.52	7	19	22.01	20.71	1.04	15	15.79	23.31	19.39	1.81
	R	15	18.11	22.77	20.01	1.25	7	19.43	22.42	20.93	1.08	15	15.9	23.55	19.49	1.85
I2	L	15	72.39	91.97	83.73	5.83	7	80.17	90.53	84.08	3.77	15	64.89	87.56	79.02	5.51
	R	15	71.90	87.74	81.88	4.57	7	79.41	89.23	83.73	3.81	15	66.58	88.71	78.20	5.74

Test for intragroup asymmetry

Index	ARM				UARM				LIS			
	n pairs	*Z*	*p* exact	Direction of asymmetry	*n* pairs	*Z*	*p* exact	Direction of asymmetry	*n* pairs	*Z*	*p* exact	Direction of asymmetry
I1	24	−2.327	.018*	R > L	17	−2.627	.007*	R > L	38	−1.086	.283	
I2	32	−1.449	.150		23	−1.551	.126		45	1.964	.049*	L > R

Note. Wilcoxon signed-rank tests (two-tailed) for intragroup asymmetry; *n* = total number of observable cases; L = left side; R = right side. For the full data on the bilateral asymmetry analysis of indices of robusticity and shape and results of the intragroup and intergroup statistical analysis see Table S5.

*Statistically significant difference.

unarmed and Lisbon groups, which means that the shape of the head is more longitudinal than in the other groups. Moreover, there is a significant difference between the ARM and LIS groups on both sides (p < .001). Besides, the difference is significant between both Sárrétudvari groups and Lisbon (p < .001; p = .015) when we combine the left and right sides. The values are higher on the right side in the armed and unarmed groups, although we did not find significant differences related to asymmetry. The values of the trochlea-epicondyle index (I4) are slightly different between the Sárrétudvari and Lisbon groups, and the values vary on a greater range in the LIS group. We did not find, however, any significant differences.

4 | DISCUSSION AND CONCLUSION

The main goal of this study was to find reliable activity-related differences between the armed and unarmed subgroups of a mediaeval population and a reference sample represented by an urban civilian population which mainly lived and died during the first half of the 20th century. We were interested especially in the analysis of the armed group constituted by the individuals who had weapons (i.e., archery equipment) in their graves. We did not, however, focus on one activity in particular. Although populational/genetic differences are among the main nonmechanical factors influencing the development of the different morphological changes and limiting their evaluation (e.g., Nikita et al., 2019; Thomas, 2014), we have found differences of symmetries (e.g., I1 and I2) and intergroup differences (e.g., the difference was significant only between UARM and LIS concerning E2 combined and E3 right). These suggest the influence of physical stress on the development of these bone changes. Among the qualitative variables, entheseal changes were dominant while morphological variants and traumas were only occasional. Therefore, morphological variants and macrotraumas of the humerus did not make the case for discussing activity-related markers in the armed group. The armed group shows higher rates of entheseal changes at the sites of the *latissimus dorsi*/*teres major* (E3), *pectoralis major* (E4) and the common extensor muscles (E7, E8). Among these entheses, the common extensors belong to the fibrocartilaginous group (e.g., Henderson et al., 2016), an anatomical type which can provide more reliable information (e.g., Thomas, 2014; Villotte et al., 2010). In general, the results concerning the entheseal changes support the idea that armed individuals practised complex movements involving the trunk, arms and forearms, even though the populational differences cannot be excluded as both Sárrétudvari groups showed significant differences with the Lisbon group (E3R, R + L; E4 R, R + L; E7). It is unexpected to observe that the rates of changes at the shoulder entheses (E1, E2, E5) are so low in the armed group, whereas anatomical and anthropological studies highlighted the importance of this region for activities such as archery (e.g., Axford, 1995; Niestroj et al., 2018; Thomas, 2014). The explanation can be related to—among others—methodological (e.g., scoring of entheseal changes), anatomical (work of not a single muscle but the group of muscles; see Stirland, 1998) or technological (e.g., different types of bows) factors; therefore, further investigation is needed.

We observed the presence of joint changes only in some cases, possibly due to the age-related restrictions that we used for this study. Even though joint changes did not show any statistically significant differences between groups, they may still be an important tool in the future research in combination with other types of changes. The armed group shows, indeed, higher rates, especially at the elbow, which correlates well with the high number of the entheseal changes of the epicondyle region (E7, E8). In earlier papers, some entheseal and joint changes of the elbow region have already been associated with the practice of archery (Dutour, 1986; Pálfi, 1997). Thomas (2014) also highlighted the importance of the elbow region (especially the entheseal changes of *m. biceps brachii*) in her investigation concerning the activity-related skeletal changes of the "arrowmen" from the Cerny culture. She did not find, however, any unique patterns, but a set of bilateral markers that can correspond to activities including archery (Thomas, 2014).

Comparative analyses of indices resulted in differences concerning the shape of the humeral head, as it is more longitudinal on the right side in the ARM group compared with the UARM and LIS groups. The effect of activities on the humeral shape and robusticity has been widely discussed (e.g., Stirland, 1993; Rhodes & Knüssel, 2005; Shaw & Stock, 2009; Ibáñez-Gimeno et al., 2013), and some biomechanical studies found a relationship between the shape of the humeral head and the kinematic properties (e.g., Jun et al., 2013; Wataru et al., 2005). Based on these results, we can assume that the long-term practice with different weapons can also lead to the elongation of the humeral head, and this elongation helps to stabilise the joint against the physical loads. Additionally, directional asymmetry can be related, among other causes, to the use of a dominant hand (Steele, 2000; Steele & Mays, 1995), as well as to differences in tactics and preferred types of weapon (Rhodes & Knüsel, 2005). In the case of the Sárrétudvari armed and unarmed groups, right-side robusticity dominance can be detected, but the changes appeared mostly bilaterally, suggesting a slight dominance of the right arm, but also the predominant practice of two-handed activities. This, for instance, is consistent with the archaeological and historical sources, which attest the dominance of archery among all the fighting styles.

We found significant differences between the Sárrétudvari groups and Lisbon, but we did not observe any statistically significant difference between the armed and unarmed Sárrétudvari groups. The similarities support our earlier results (Tihanyi et al., 2015) and might result from the practice of similar activities by the individuals, regardless of the funerary rituals. Consequently, the absence of weapons in the grave is not an evidence that such weapons were not used by the individuals during their life.

Even without any weapon in their grave, individuals from the Sárrétudvari group could have been "brothers in arms" of other warriors with weapons in their grave. This phenomenon perfectly correlates with the tendencies of activity-related changes on the lower limb bones. A recent study on the possible horse riding-related changes in the Sárrétudvari series concluded, indeed, that there were more riders in the population than the number of graves with riding deposits (Berthon, 2019).

Although the multifactorial aetiology of the skeletal changes limits the interpretations, our results are consistent with previous studies (Thomas, 2014), showing that if no skeletal marker observed on the humerus is specific by itself to one activity, a set of skeletal changes can be highly indicative of the practice of activities, including archery and other fighting styles. These indicators include a vertical elongation of the humeral head, the changes at the entheses of *m. latissimus dorsi*/*teres major* and at the entheses and joints of the elbow region.

We consider that we successfully reached our objective to evidence possible lifestyle-related statistically significant differences on the humerus between each of the two Hungarian groups and the modern control group. Therefore, our results can provide relevant information for further anthropological and archaeological studies of populations from the 10th-century Carpathian Basin.

In conclusion, a systematic analysis of the above-mentioned skeletal changes could help with the identification of the use of weapons, including a bow, by individuals from graves without such deposits. We assess that a thorough macromorphological and metric analysis of the humerus allows identifying, at least at a populational level, that individuals sharing those skeletal indicators, buried with or without weapons, might have been brothers in arms during their life.

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CONFLICTS OF INTEREST

The authors have no conflict of interest to declare.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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