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TITLE

Riding for a fall: Bone fractures among mounted archers from the Hungarian Conquest period (10th century CE)

RUNNING TITLE

Bone fractures among Hungarian Conquest period mounted archers

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ABSTRACT AND KEYWORDS

Horse riding, a determinant activity in the history of human cultural evolution, remains unreliably identifiable from the analysis of human skeletal remains due to various sample and methodological limitations. Through a comparison between well-documented series of presumed riders and non-riders, this study aimed to investigate the link between skeletal fractures and that practice in past populations. We relied on a Hungarian Conquest period population (S arr etudvari-H ız f old, Hungary, 10th century CE) known to be composed of mounted archers. We recorded the presence of acute fractures on the main bones of the upper and lower skeleton to analyze their distribution and perform comparisons between the individuals with or without riding-related deposits in their grave and with an out-sample group of presumed non-riders from the documented Lu s Lopes Skeletal Collection (Lisbon). We observed more fractures in the Hungarian series and especially higher rates concerning the upper limb, while the distribution of traumas was more homogenous in the documented collection. There were also significantly more clavicle fractures in the Hungarian group with riding deposit than in the non-riders from Lisbon, whose type can be related to a fall from a height. Our results coincide with sports medicine data on equestrians, whose injuries mostly concern the upper limbs. Such

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traumas, and especially clavicle fractures, are often caused, indeed, by a fall from a horse. Through the use of pertinent anthropological series, this study provides the most reliable association between the presence of skeletal traumas and the practice of horse riding in a past population.

Paleopathology; Activity-related skeletal changes; Traumas; Horse riding; Medieval Period; Carpathian Basin

Accepted Article

MAIN TEXT

Introduction

The reconstruction of activities in past populations relies on various types of pathological and non-pathological bone changes on the human skeleton. The most promising research areas in the reconstruction of activities concern especially the musculoskeletal stress markers (MSMs), or entheseal changes (EC), the secondary degenerative joint disease, and skeletal changes due to the bone's reaction to loading and its ability to adapt its shape and structure in response to it, according to Wolff's law (e.g., Wolff, 1892; Kennedy, 1989; Trinkaus et al., 1994; Capasso et al., 1999; Auerbach & Ruff, 2006; Ruff et al., 2006; Stock, 2006; Shaw & Stock, 2009; Jurmain et al., 2012; Niinimäki, 2012; Ruff & Larsen, 2014; Berthon et al., 2015). Many limitations must, however, be acknowledged, such as the multifactorial etiology and lack of specificity of the markers, problems of equivalence between contemporary references and historical cases, or the relevance of the various scoring methods (e.g., Dutour, 1992; Jurmain et al., 2012). Besides those research areas, and even though they are more anecdotal by nature, traumatic injuries can also be of particular interest in the study of past populations as they mostly result from conflicts or natural accidents, thus providing insights into the environment in which evolved the individuals as well as their activities and behaviors (e.g., Milner et al., 1991; Pálfi, 1992; Stirland, 1996; Larsen, 1997; Martin, 1997; Jurmain, 1999; Williamson et al., 2003; Torres-Rouff & Costa Junqueira, 2006; Buzon & Richman, 2007; Paine et al., 2007; Tung, 2007; Henderson, 2009; de la Cova, 2012; Coqueugniot et al., 2014; Knüsel & Smith, 2014; Martin & Harrod, 2015; Krakowka, 2017; Coutinho Nogueira et al., 2019; Scaffidi & Tung, 2020; Standen et al., 2020).

Among all specific activities that have been investigated by bioarchaeologists, horse riding practice, in particular, is of major importance as it brought profound and lasting changes in the history of human cultural evolution concerning crucial aspects such as trade, settlement, warfare, subsistence, social organization and political ideology (Anthony & Brown, 1991; Anthony, 2007). The use of horses for transportation also considerably contributed to the circulation of languages, Indo-European ones in particular, as well as cultures and diseases, among other things (Anthony, 2007; Outram et al., 2009; Donoghue et al., 2015; Librado et al., 2016; de Barros Damgaard et al., 2018; Gaunitz et al., 2018). Unfortunately, the link between human skeletal changes and the practice of horse riding is not as straightforward (see Berthon, 2019) as it can be regarding some equine skeletal changes, such as the presence of bit wear (Brown & Anthony, 1998; Anthony, 2007; Bendrey, 2007; Taylor et al., 2015; Greenfield et al., 2018).

Although the techniques and style of riding, the equipment, and the morphology of the horses used nowadays by modern riders are not directly comparable with those used by past populations in different regions of the world, clinical sources can bring relevant complementary data (McGrath, 2015). Due to the speed, height, weight, and strength of the horse, riding represents – and has always represented – a potentially dangerous activity that puts the rider at risk for injuries of different types (Bixby-Hammett & Brooks, 1990; Garofalo, 2004; Ball et al., 2007; Havlik, 2010; Schröter et al., 2017). In terms of the potential of injuries, horse riding is currently a practice even more dangerous than activities such as automobile racing, motorcycle riding, skiing, football, and rugby, and it is also considered to be the sport with the highest mortality (Ball et al., 2007).

Sports medicine describes the injuries affecting modern riders, whether they perform horse riding in a professional or a leisure context. Based on numerous studies published between 1959 and 1987, concerning European and American individuals, the described injuries concern mostly the upper extremity (from 24 to 61% of the reported cases depending on the sources) followed by the lower extremity (18–36%), while about 20 % of cases concern the head and the face and from 4 to 27% are spinal injuries (Bixby-Hammett & Brooks, 1990). The second most common type of injuries, after the soft tissue injuries and before the concussions, are fractures. While the majority of the accidents occur when the horse is mounted, mostly being due to a fall, 1 to 27% occur while handling or taking care of the horse on foot and are related to the animal itself (kicking, biting, or stepping on the rider). It

was also noted that it is rather common (37%) to suffer horse-related injuries several times during the course of a lifetime (Bixby-Hammett & Brooks, 1990). In a different study that relied on a survey addressed to adult patients who had suffered major equestrian injuries in Alberta, Canada, between 1995 and 2005, that percentage (subjects who had already suffered previous equestrian injuries) reached 47% (Ball et al., 2007). This study also reveals that, as for the cause of traumas, 60% of patients were thrown off or fell off the horse while 16% were crushed by a falling horse, 8% were kicked, 4% were stepped on, and the remaining 13% cases were injured by other mechanisms. It can also be noted that 45% of the patients required surgery, while 7% died because of their equestrian injuries. Furthermore, in this sample, the injuries concerned the chest (54%), head (48%), abdomen (22%), and extremities (17%), with, in particular, skull (18%), extremity (17%), spinal (17%), and pelvic fractures (15%) (Ball et al., 2007). Other studies focusing more precisely on traumas revealed that the extremities were the most commonly affected regions (46.1–54.4%), followed by the trunk (28.9%) and the head and neck (16.6–23.8%) in samples of patients from Sweden and the United States analyzed in the early 2000s (Loder, 2008; Altgårde et al., 2014; Ki et al., 2018). According to a review of the sports medicine literature (Havlik, 2010), most studies confirm that falling from or being thrown from the horse is the most common cause of injury for the rider (in 60% to 80% of cases) and that the upper extremity injuries are the most frequent (especially with the increased use of helmets), followed by the injuries of the head/neck and the trunk/abdomen. Finally, a more recent study (Schröter et al., 2017), based on 503 patients in Germany, revealed that the most common injuries are located at the head and, closely behind, the upper extremities, while various additional sources put the frequency of the traumas in the following descending order: the upper limbs, skull, neck, lower limbs, vertebral column, thorax, and the pelvis (see Baillif-Ducros, 2018). Traumas on the upper extremities, in particular, are essentially related to the attempt of self-protection that occurs during a fall.

In the anthropological literature, acute traumatic injuries on almost all human extra-spinal skeletal elements (i.e., skull, ribs, upper limb bones, and lower limb bones) have been described as being possibly related to the practice of horse riding (e.g., Angel, 1982; Pap, 1985; Pálfi, 1992; Willey, 1997; Reinhard & Wall, 2002; Langlois & Gallien, 2006; Wentz & de Grummond, 2009; Aguayo, 2012; Bagagli et al., 2012; Dutour & Buzhilova, 2014; Pulcini, 2014; Andelinović et al., 2015; Khudaverdyan et al., 2016; Panzarino & Sublimi Saponetti, 2017; Karstens et al., 2018). Most of cases are explained as the direct consequence of a fall from the horse, even though some studies also mention injuries related to other aspects of equestrianism, such as the crushed foot when being stepped on by the animal (Willey, 1997) or finger fractures and injuries that would be caused by the saddle or the bridle (Willey, 1997; Dutour & Buzhilova, 2014). On another note, although they did not perform direct anthropological observations, the study by Ki et al. (2018) is of particular interest as they investigated Korean historical records (Joseon Dynasty) for mentions and descriptions of horse riding-related accidents and injuries. They were mainly the result of a fall from a horse and occurred mostly at the extremities, the trunk, and head, in this order.

In the end, despite the numerous mentions of traumas supposedly associated with the practice of horse riding, it is difficult to determine how reliable can be considered this hypothesis since studies only rarely rely on more than a very few individuals—when not only one—(e.g., Wentz & de Grummond, 2009; Khudaverdyan et al., 2016), nor they include a systematic recording and statistical analysis of the skeletal changes and lesions, or a comparative group. Most importantly, the presence of direct evidence supporting the idea that specific individuals were riders during their life is seldom mentioned. Instead, the link between a lesion and the activity mostly relies either simply on the fact that it was mentioned in previous studies, without any further supporting argument (e.g., Langlois & Gallien, 2006; Bagagli et al., 2012), either on general archaeological, textual, or ethnological sources suggesting that a population of interest as a whole used to practice horse riding (e.g., Reinhard & Wall, 2002; Wentz & de Grummond, 2009; Panzarino & Sublimi Saponetti, 2017; Karstens et al., 2018). The presence of funeral deposits can raise various hypotheses regarding their meaning (e.g., functional, social, ritual, symbolic aspects; see Härke, 1997). While it must not be considered as absolute evidence, only the presence of archaeological items related to equestrian activity in the grave can, with the support of other types of contextual information, represent a robust indicator that

specific individuals may have been riders during their life, and thus, allow to analyze skeletal changes under the scope of this hypothesis in a relevant way.

Archaeological and textual sources attest that tribes of semi-nomadic populations conquered the Carpathian Basin with powerful armies of mounted archers (Figure 1) at the turn of the 9th and 10th centuries, which led to the foundation of the Kingdom of Hungary a hundred years later. Cemeteries from the Hungarian Conquest period, which, in archaeology, refers to a period of time mostly covering the 10th century (e.g., Hampel, 1900; Langó, 2007), often provide cases of deposits of archery and horse riding equipment as well as horse bones associated with the individuals in the graves (e.g., Kovács, 1986; Révész, 2020). The close association between these items and the skeletons, together with the well-known historical context, allows postulating that the concerned individuals practiced horse riding during their life. Those populations are, thus, among the most pertinent to be used to perform methodological investigations on activity-related skeletal changes and on horse riding, in particular.

This paper is part of a research project devoted to the reconstruction of activities in past populations and, more specifically, to the identification of skeletal changes reliably related to horse riding practice (Berthon, 2019). We studied a skeletal collection from a cemetery dating from the Hungarian Conquest period, with deposits of horse riding equipment and horse bones in some graves. We analyzed metric data and the prevalence of various types of skeletal changes (enthesal changes, joint changes, morphological variants, traumatic lesions, spinal changes) according to the presence or absence of riding-related deposits in the graves. An out-sample group of non-riders was also used for comparison. Several skeletal changes were considered as promising indicators for the practice of horse riding (Berthon, 2019; Berthon et al., 2019). We present here the results concerning the traumatic injuries observed on the skull, appendicular skeleton, ribs, and sacrum. The objective was to identify differences between groups that could be interpreted as a consequence of the practice of horse riding by the Hungarian Conquest period individuals.

Materials and Methods

The cemetery of Sárrétudvari-Hízóföld, located in the Northern Great Plain region of eastern Hungary, was excavated by Ibolya M. Nepper between 1983 and 1985. There, 262 graves from the Hungarian Conquest period provided a total of 265 individuals. This cemetery was notably selected because it is one with the highest number of graves with grave goods related to horse riding, in particular. Indeed, a total of 32 graves delivered, among other goods, elements of horse riding equipment, such as stirrups, bits, girth buckles, and saddles, as well as, in some cases, horse bones (skull and extremities) that were usually folded inside the horsehide and placed in the grave in association with the deceased (Figure 2; Nepper, 2002; Révész, 2003). This series was the subject of previous anthropological analyses, and various observed skeletal changes had already been linked to the practice of horse riding as well as archery (Oláh, 1990; Pálfi, 1992; Pálfi & Dutour, 1996; Pálfi, 1997; Tihanyi et al., 2015; Berthon et al., 2019; Tihanyi, 2020; Tihanyi et al., 2020).

Numerous bias factors must be acknowledged in the study of activity-related skeletal changes (e.g., Dutour, 1992; Jurmain et al., 2012). In that respect, and in the frame of a more comprehensive investigation involving different types of skeletal changes other than traumas, we included only adult males in our sample in order to limit the influence of nonmechanical factors such as hormonal and developmental changes. In addition, it should be mentioned that most of the Hungarian Conquest period graves with horse riding-related deposit belong to male individuals, and that, in Sárrétudvari-Hízóföld, in particular, a unique case of a female individual with riding-related deposit was identified (Nepper, 2002; Révész, 2020). All adult age categories were, however, included in this study as acute traumas are not directly related to degenerative processes.

On the basis of a reassessed sex diagnosis (Bruzek, 2002; Murail et al., 2005; Bruzek et al., 2017) and age estimation (Scheuer & Black, 2004; Bruzek et al., 2005), we selected a sample of 67 adult male individuals from the series. This sample was divided into two groups of individuals, according to the

presence (“RD”) or absence (“NRD”) of riding deposit in their grave (17 and 50 individuals, respectively). We must highlight that this sample of 17 adult males with riding-related deposits in their grave represents, to the best of our knowledge, the largest homogeneous anthropological sample investigated for horse riding-related skeletal changes for which archaeological evidence provides a direct link between each individual and this activity.

The absence of riding-related deposit in the graves does not prove that the individuals were not riders, in the same way as their presence is not an absolute evidence for this activity. Therefore, we also compared the Hungarian archaeological groups with a sample of individuals for which the absence of practice of horse riding was very probable. For this purpose, we used the Luís Lopes Skeletal Collection, curated in the National Museum of Natural History and Science (MUHNAC), in Lisbon, Portugal. It is a modern documented collection with individual data available regarding the sex, age at death, occupation, or the cause of death (Cardoso, 2006; Alves Cardoso & Henderson, 2013). The individuals were Portuguese people who had mainly lived during the first half of the 20th century, in the urban area of Lisbon, with electricity and modern means of transport, and thus, were very likely non-riders. Among the available adult males, we attempted to select only individuals who, based on their known occupation, could be considered as having been generally physically “active” during their life (e.g., carpenter, baker, fitter, paver). The underlying idea was that individuals who presumably had a rather limited level of physical activity during their life (e.g., office worker, student) were probably facing less risk of injury on a daily basis. Including such individuals in our analysis of the prevalence of bone fractures would therefore have contributed to bias the comparison with the Hungarian samples. Based on these criteria, we selected a sample of 47 adult males (“LIS”) from the collection of Lisbon.

Signs of acute fractures were systematically recorded as “present”, “absent”, or “not observable”, which allowed calculating true prevalence rates. Bones were considered as observable when at least half of the segments (e.g., proximal extremity, proximal and distal diaphysis, and distal extremity for long bones) were observable, and groups of bones or anatomical regions were considered as observable when at least half of elements composing them (e.g., at least four of the eight carpal bones) were present. Segments were considered observable when 50% or more of bone was preserved (Robb, 1997; White, 1992, cited in Judd, 2002). Skeletal elements and anatomical regions, as presented in Table 1, were then given a binary score for analyses. Traumas were recorded on both sides in the case of paired bones, but the results were combined and asymmetry was not considered for this analysis. Except for the sacrum, which is part of the pelvis, bones from the spine were not included in this paper, considering that the analysis of vertebrae requires more specific methodological approaches. We included only fractures for which traces were macroscopically observable, with clearly discernible signs of the presence of a primary bone callus, bone deformation such as shortening or angulation, and loss of joint morphology. Microtraumatic lesions or cases of *myositis ossificans*, i.e., ossification of injured muscles, were not considered here. Cases of surgical or symbolic trepanations in the Hungarian series were not included in this analysis. Furthermore, we must emphasize that the recording of all data was performed without knowledge of the presence or absence of horse riding-related deposits associated with the individuals in the graves, in the case of the Hungarian series.

The Fisher’s exact test was used for comparison between the three groups, as well as for pairwise comparisons when a significant difference was noted. In that case, the obtained *p* values were corrected following the Holm-Bonferroni method (see Nikita, 2017).

Results

Reliable signs of acute fractures were observed on 38 individuals (33%) out of 114 ones composing the entire sample. The metacarpals and hand phalanges were the most affected (11%), followed by the ribs (10%) and the clavicle (6%), while the skull (cranium and mandible), sacrum, patella, and tarsal bones were not affected. Regarding anatomical regions, the upper limb was the most affected (21%), followed by the thorax (ribs, 10%) and the lower limb (8%).

For intergroup comparisons, we calculated for each group and skeletal element or anatomical region the ratio of the number of individuals affected by at least one fracture / total number of observable individuals for the element (Table 2). Comparisons revealed that the prevalence of fractures was higher in the RD group (41%) compared to the NRD (34%) and the LIS groups (30%; Table 2). It was the case only for the upper limb (35%, 24%, and 13%, respectively), while frequencies of fractures in the thorax were more equivalent between groups (9%, 9%, and 11%, respectively), and there were no fractures in the lower limb for the RD group but 10% and 9% in the NRD and LIS groups, respectively. However, the only statistically significant difference was observed in the case of the clavicle: pairwise comparisons with corrected p values indicated that there were significantly more individuals with clavicle fractures in the RD group (24%) than in the LIS group (0%, p adjusted = .013; Table 2). Fractures of the clavicle were mostly detectable due to the presence of a callus, angular deformity, and diaphyseal shortening. A total of 8 clavicle fractures were observed in 7 individuals: 4 from the RD group and 3 from the NRD group. In the RD group, in particular, we recorded 3 oblique midshaft fractures and 1 fracture at the lateral extremity.

Furthermore, we also calculated for each group the ratio of the number of fractures by element or anatomical region / total number of fractures in the group, in order to analyze the distribution of fractures (Figure 3). The LIS group was the most homogenous, with an approximate balance of fractures according to the anatomical region (38% in the upper limb, 31% in the thorax, and 31% in the lower limb). In contrast, 89%, 11%, and 0% of fractures in the RD group and 63%, 13%, and 25% of fractures in the NRD group were observed for the upper limb, the thorax, and the lower limb, respectively. The differences observed between groups for each anatomical region were not statistically significant, but the higher frequency of upper limb fractures compared to thorax and lower limb fractures was statistically significant in the RD group (upper limb versus thorax: p adjusted = .007; upper limb versus lower limb: p adjusted = .001) and the NRD group (upper limb versus thorax: p adjusted = .002; upper limb versus lower limb: p adjusted = .038). Regarding clavicle fractures, in particular, they account for 44% (4/9) of all fractures observed in the RD group and 17% (4/24) of those observed in the NRD group. The difference was, in that case as well, statistically significant between the RD group and the LIS group, in which no clavicle fracture was observed among the 16 fractures that were recorded (p adjusted = .030).

On another note, we observed cases of polytraumatism in 10 individuals, where different skeletal elements or anatomical regions considered in the study (as presented in Table 1) were affected by a fracture. There were 2 cases in the RD group (12%), 6 in the NRD group (12%), and 2 in the LIS group (4%), and this difference between groups was not statistically significant. Only one individual, from the NRD group, showed a fracture both at the upper and lower limb, while two individuals, also from the NRD group, had fractures on the same bone on both sides, on the clavicles for one, and the radiuses for the other (Figure 4).

Discussion

Although macrotraumas can be considered as anecdotal, reflecting accidental wounds or interpersonal injuries, they can nevertheless provide information on the lifestyles and behaviors in past populations, completed by the analysis of other types of skeletal changes.

Our analysis of acute fractures on the upper and lower body reveals that the upper limb was the most affected anatomical region in our sample and that there were generally higher frequencies of fractures in the Hungarian groups compared to the group from Lisbon. This difference was statistically significant only for the clavicle between the Hungarian group with riding deposit (RD) and the comparison group from Lisbon (LIS), in particular (Table 2, Figure 3). Most clavicle fractures in the RD group were oblique fractures at midshaft (Figure 5), with a visible fracture line extending diagonally across the longitudinal axis (Lovell, 2008; Waldron, 2009; Dittmar et al., 2021), while no clavicle fracture was observed in the LIS group.

Clinical data reveal that midshaft clavicle fractures are dominant (approximately 70–80% of all clavicle fractures), the middle third of the clavicle being its weak point, and they often occur from falls from a moderate height, such as from a bicycle, motorcycle, or a horse (Nordqvist & Petersson, 1994; Robinson, 1998; Postacchini et al., 2002; Jeray, 2007; Lovell, 2008; O'Neill et al., 2011; Sigurdardottir et al., 2011; Wedel & Galloway, 2013; Van Tassel et al., 2014; Familiari et al., 2017; Kihlström et al., 2017). Such fractures commonly result from a direct blow to the point of the shoulder due to a fall with landing on it, but also, to a lesser extent, from a fall on the outstretched hand or from direct trauma to the clavicle (Stanley et al., 1988; Wedel & Galloway, 2013; Familiari et al., 2017). Khan et al. (2009) notably describe how those fractures “occur commonly in equestrian sports and cycling, when, as a result of inertia when the horse or bicycle stops suddenly, the rider is thrown forward and lands on the unprotected shoulder” (p. 447). In the most common case of lateral direct impaction at the shoulder, a compressive force acts along the diaphysis of the clavicle, and this axial load applied to the bone can cause the fracture (Stanley et al., 1988; Nordqvist & Petersson, 1994; Bhatia et al., 2017; Holder et al., 2017; Moverley et al., 2020). The proximal fragment is generally pulled superiorly and posteriorly by the sternocleidomastoid muscle while the weight of the arm and the pectoralis muscle on the humerus contribute to pull the distal fragment laterally, forward, and downward, which can result in a displaced fracture with an oblique pattern (Jeray, 2007; Bhatia et al., 2017).

In the anthropological literature, fractures at almost all anatomical regions were at least once described as potentially related to the practice of horse riding, with more or less valid arguments, but the clavicle is one of the most cited elements (see Introduction). Among other studies, Khudaverdyan et al. (2016) notably describe a case of severe oblique fracture with an angular deformity on the clavicle of an individual from a Late Iron Age cemetery in Armenia. The individual showed multiple traumas, and the pattern of lesions suggested, according to the authors, the practice of horse riding. The individual was, in fact, buried together with a horse.

The populations from the Hungarian Conquest period were semi-nomadic societies, in which horses took an essential role (Róna-Tas, 1999; Engel, 2001). The presence of equipment related to horse riding (stirrups, girth buckles, bits) or horse bones associated with the individuals in the graves in cemeteries from that period like Sárrétudvari-Hízófold strongly suggests the presence of horse riders in the population. Clavicle fractures observed in the Hungarian group with riding deposit, at least, are compatible with a possible fall from a horse, based on clinical data. The idea that the significant difference observed for clavicle fractures between this group (RD) and the comparison group from a non-riding population (LIS) could reflect the practice of horse riding in the first one thus represents a very reasonable hypothesis.

Clavicle fractures account for 2,6% to 5% of all fractures in adult populations, according to epidemiological data (Robinson, 1998; Postacchini et al., 2002; Khan et al., 2009; Familiari et al., 2017). In sports medicine literature on amateur or professional equestrians, we note that the methodology for reporting fracture rates can greatly differ between papers. Clavicle fracture rates are rarely provided as they are rather included among shoulder fractures or even upper extremity fractures in most studies. In a retrospective review of equestrian injuries in Great Britain and Ireland during 1993–2006, Balendra et al. (2007) analyzed data from 270 557 rides, 36 089 falls, and 5177 injuries in amateur jockeys. They distinguished clavicle fractures from other elements of the upper extremity and observed that most fractures occurred at the clavicle, accounting for 52.32% to 54.74% of all fractures. These data were compared with statistics on injuries in professional jockeys (Great Britain, 1993–2003 and Ireland, 1992–2004), and clavicle fractures accounted for 42.37% to 44.40% of all fractures. Although it is problematic to compare archaeological populations and contemporary ones using clinical data (e.g., Dutour, 1992), we can nevertheless note that the proportion of clavicle fractures in the RD group is particularly high since they account for 44% of the total of fractures observed in that group, versus 17% and 0% in the NRD and LIS groups, respectively (Figure 3). This supports further the hypothesis of a link between the clavicle fractures that we observed and the practice of horse riding.

The distribution of fractures was almost equivalent between the upper limb (38%), the thorax (ribs), and the lower limb in the LIS group, while significantly higher rates of fractures were observed in the upper limb in both Hungarian groups (89% in the RD group and 63% in the NRD group), compared to the other anatomical regions (Figure 3). These results also coincide with observations from sports medicine on horse riders. In different reviews of injuries in amateur or professional equestrians, the upper limb is indeed often revealed to be the most common location for riding-related injuries and fractures, with various frequencies, compared to the other anatomical regions (Bixby-Hammett & Brooks, 1990; Balendra et al., 2007; Craven, 2008; Loder, 2008; Havlik, 2010). This would notably be related to the attempt of self-protection that occurs during a fall. Furthermore, clinical studies also often show a relatively low incidence of injuries of the lower extremity (Havlik, 2010). In one of the rare systematic and methodological bioarchaeological investigations of horse riding-related skeletal changes (Baillif-Ducros, 2018), most of the traumas that were recorded on a sample of Merovingian populations including individuals with horse riding-related grave goods concerned bones of the upper limb, and, more precisely, of the forearm. The particular individuals that were affected did not have, however, any riding-related deposit in their grave, and horse riding was not presented as a specific explanation for those traumas.

We observed a relative similarity of the distribution of traumas between both Hungarian groups, with and without riding deposit (RD and NRD, respectively), compared to the LIS group, with a higher frequency of fractures of the upper limb, and, especially, of the clavicle (Table 2; Figure 3). This tends to indicate that the individuals in both groups had a comparable lifestyle and, thus, that individuals without riding deposits in their graves were probably riders during their life as well. In particular, a clavicle from the NRD group shows, for instance, a severe case of midshaft oblique fracture with angular deformity in alignment and diaphyseal shortening (Figure 6), which could be the consequence of a fall from a height based on clinical data discussed above, and which strongly resembles the case previously mentioned that was described by Khudaverdyan et al. (2016) in the skeleton of a probable rider. The hypothesis that, in the cemetery of Sárrétudvari-Hízófold, the individuals without a riding deposit in their graves might have been practicing horse riding as well is also strongly supported by the analysis of other types of skeletal changes (enthesal changes, joint changes, morphological variants, Schmorl's nodes) and indices of shape and robusticity of the lower limb. This would lead to the conclusion that the funerary practice of a riding deposit in the grave is not directly related to the activity in this population but would rather be related to other social or symbolic aspects (Berthon, 2019).

With the exception of a cut wound and symbolic or surgical trepanations in the Hungarian series, which were not recorded in this analysis, we did not observe traumas of the skull in the whole sample, while it could be expected in the case of the Hungarian groups if some individuals were practicing horse riding. The head is indeed the second element the most affected by macrotraumas related to horse riding in most of the studies on modern riders, and head injuries are also the first cause of death of riders (Bixby-Hammett & Brooks, 1990; Ball et al., 2007). This absence could partly be related to limited bone preservation of skulls, often retrieved in a fragmentary state in the archaeological materials. Some traumatic injuries may also have not left osseous signs. Cerebral contusions are indeed among the most frequent lesions observed in modern riders and contribute to the high rates of head traumas (Auvinet & Ginet, 1980), even despite the protection equipment, which is very likely safer today than any kind of equipment from the Medieval period.

The decades that followed the conquest of the Carpathian Basin, at the turn of the 9th and 10th centuries, were marked by raid expeditions and conflicts, which involved the populations who settled there. This is attested, for instance, by the presence of weapons in Hungarian Conquest period cemeteries found in association with the individuals in their graves (Révész, 2003). Compared to individuals who were mostly urban workers living in Lisbon during the first half of the 20th century, higher rates of traumatic injuries were expected. However, the differences were not significant for almost all bones or anatomical regions, and we observed, in fact, only exceptional cases of traumas likely resulting from interpersonal violence in the Hungarian series, such as a cut wound on the skull probably inflicted by a saber (individual SH9; Pálfi, 1997). This could partly reflect the fact that our

sample from Lisbon was mainly composed of manual workers, relatively prone to accidental injuries (Alves Cardoso, 2008).

Finally, the higher frequency of polytraumatism in the Hungarian groups compared to the comparison group from the collection of Lisbon would coincide with the clinical observations that it is common for riders to suffer multiple injuries related to equestrianism as a consequence of a single accident or during their life (Bixby-Hammett & Brooks, 1990; Waller et al., 2000; Ball et al., 2007) but the difference between groups was not significant and we cannot, therefore, support further this hypothesis.

As previously mentioned, this study is part of a broader research project that investigated various types of skeletal changes as possible indicators for the practice of horse riding (Berthon, 2019). Unlike most of the research on this topic, we relied on a collection with several individuals directly associated with archaeological evidence of the practice of horse riding. In addition, although its size should be increased in further studies, our sample was large enough to perform a systematic recording of skeletal changes, as well as statistical analyses, including a comparative group of non-riders. Taking into account multiple methodological bias factors (i.e., sex, age, pathological disorders), and in the light of anatomical and functional aspects, we were previously able to identify different skeletal changes (e.g., enthesal changes, morphological variants, vertebral changes) that can be reliably related to the practice of horse riding, and contribute to identifying, statistically, this activity in a group or population of interest (Berthon, 2019; Berthon et al., 2019). Based on the present results, we can suggest that, in addition to other skeletal changes, the high frequency of fractures observed on the bones of the upper limb, and notably on the clavicle, compared to other anatomical regions, can represent a complementary indication. This study provides, so far, the most reliable association between the presence of human bone traumas and the determinant activity among past populations that is horse riding.

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DATA AVAILABILITY STATEMENT

Additional data are available from the corresponding author upon request.

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Table 1. Skeletal elements and anatomical regions examined for bone fractures

Region	Bones
Skull	Cranium
	Mandible
Upper limb	Scapula
	Clavicle
	Humerus
	Radius, Ulna
	Carpal bones
	Metacarpals, Hand phalanges
Thorax	Ribs
Sacral spine	Sacrum
Lower limb	Coxal bone
	Femur
	Patella
	Tibia, Fibula
	Tarsal bones
	Metatarsals, Foot phalanges

Table 2. Prevalence rate of individuals with fractures by skeletal elements and anatomical regions in the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

Skeletal element/region	RD			NRD			LIS			<i>p exact</i>	<i>p exact adjusted</i>		
	<i>N</i>	<i>n</i>	<i>n/N</i>	<i>N</i>	<i>n</i>	<i>n/N</i>	<i>N</i>	<i>n</i>	<i>n/N</i>		RD-NRD	RD-LIS	NRD-LIS
Skull	15	0	0%	43	0	0%	46	0	0%	-	-	-	-
Clavicle	17	4	24%	49	3	6%	45	0	0%	.003	.133	.013	.243
Scapula	15	1	7%	44	1	2%	46	0	0%	.140	-	-	-
Humerus	17	1	6%	48	0	0%	47	1	2%	.150	-	-	-
Radius, Ulna	17	1	6%	49	2	4%	46	1	2%	.804	-	-	-
Carpal bones	5	0	0%	20	0	0%	21	1	5%	1	-	-	-
Metacarpals, HPh	16	1	6%	46	7	15%	41	3	7%	.519	-	-	-
Upper limb	17	6	35%	50	12	24%	45	6	13%	.131	-	-	-
Thorax (ribs)	11	1	9%	35	3	9%	44	5	11%	1	-	-	-
Sacral spine (sacrum)	14	0	0%	40	0	0%	46	0	0%	-	-	-	-
Coxal bone	17	0	0%	49	0	0%	47	1	2%	.566	-	-	-
Femur	17	0	0%	50	2	4%	47	1	2%	1	-	-	-
Patella	15	0	0%	41	0	0%	39	0	0%	-	-	-	-
Tibia, Fibula	17	0	0%	49	3	6%	47	2	4%	.846	-	-	-
Tarsal bones	14	0	0%	37	0	0%	44	0	0%	-	-	-	-
Metatarsals, FPh	13	0	0%	42	1	2%	43	1	2%	1	-	-	-
Lower limb	17	0	0%	50	5	10%	47	4	9%	.572	-	-	-
All	17	7	41%	50	17	34%	47	14	30%	.716	-	-	-

Fisher's exact test, two-tailed; *p* values were adjusted using the Holm-Bonferroni correction for pairwise comparisons; *p* values in bold indicate a statistical significance at the .05 level; *N*, number of observable individuals for each element; *n*, number of individuals affected by at least one fracture; HPh, hand phalanges; FPh, foot phalanges



Figure 1. Reconstruction of the fighting style of the mounted archers from the Hungarian Conquest period (László, 1982)

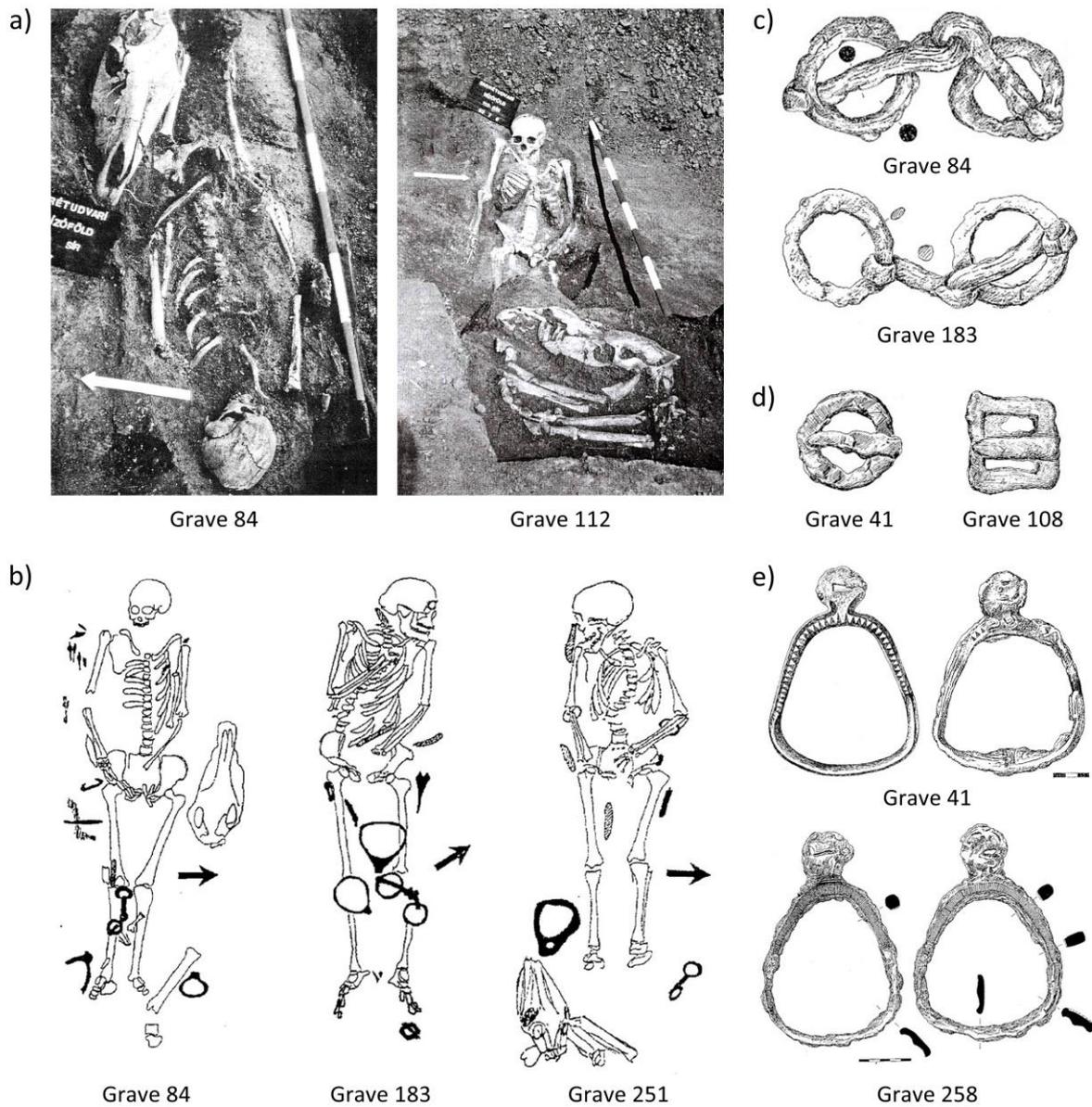


Figure 2. Examples of graves from the Hungarian Conquest period cemetery of Sárrétudvari-Hízófold (10th century CE) with deposits of horse riding equipment or horse bones, or both: a) field photographs, and b) archaeological drawings of graves; and drawings of riding equipment found in the graves: c) bits, d) girth buckles, and e) stirrups (Nepper, 2002)

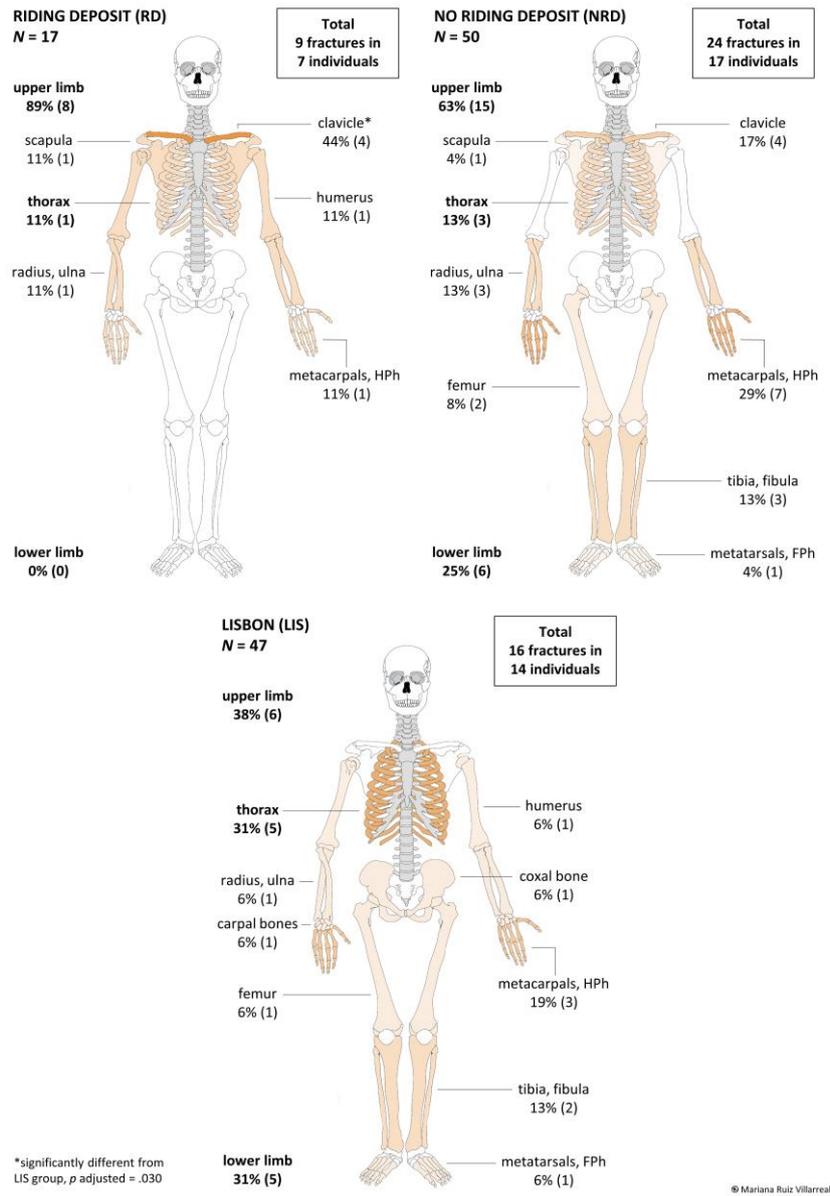


Figure 3. Visual representation of the frequency of fractures by skeletal elements and anatomical region in individuals from the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS). * indicates a statistically significant difference between groups; no fractures were observed concerning all bones in white in each group; the vertebrae, sternum, and coccyx were not included in this study; HPh, hand phalanges; FPh, foot phalanges

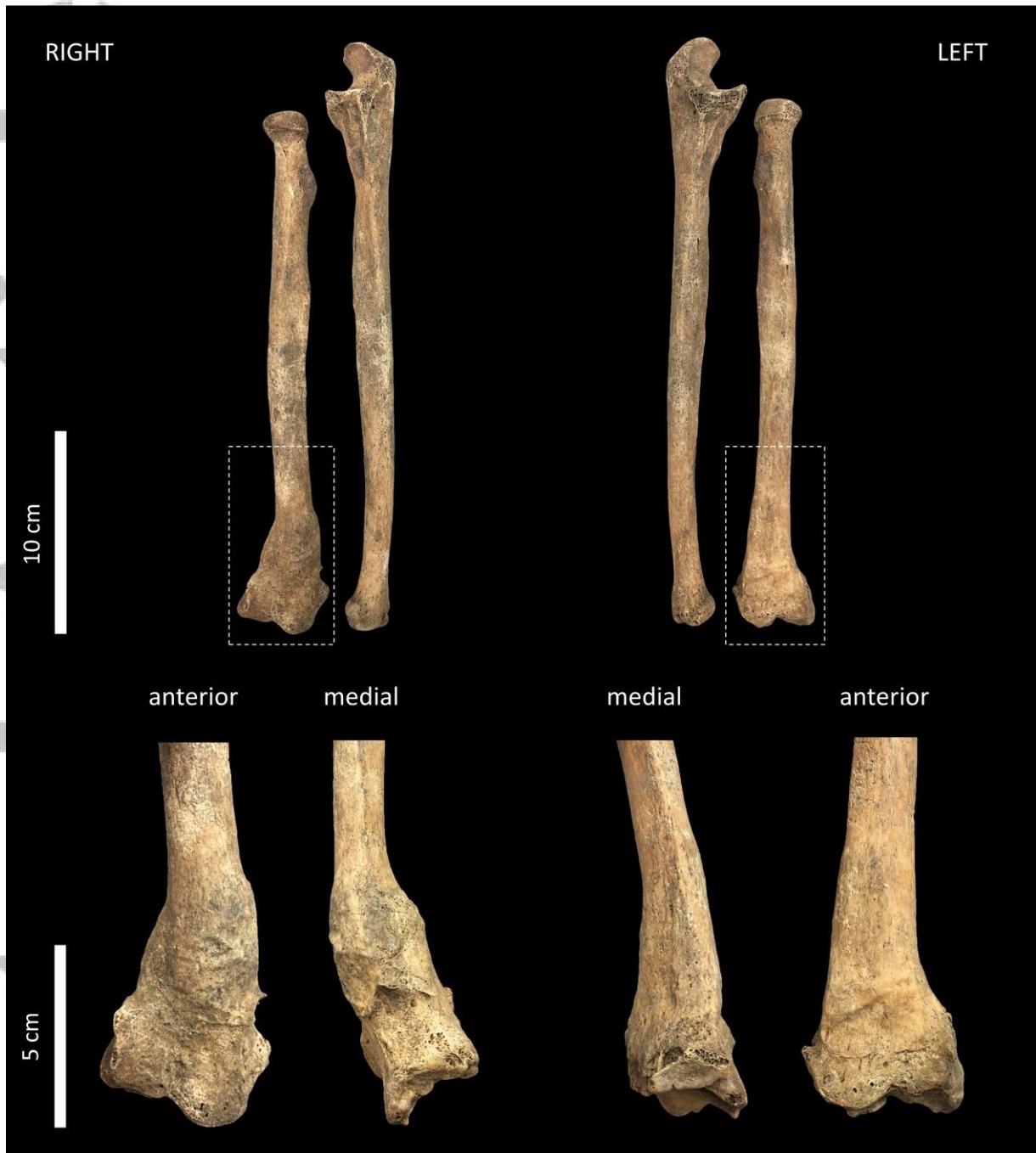


Figure 4. Example of a case of polytraumatism in an individual (SH11) from the Hungarian Conquest period cemetery of Sárrétudvari-Hízófold (10th century CE): distal fracture of both left and right radii



Figure 5. Cases of oblique midshaft fractures of the clavicle in individuals of the group with riding deposit (RD) from the Hungarian Conquest period cemetery of Sárrétudvari-Hízófold (10th century CE): a) fractured left clavicle and non-fractured right clavicle from individual SH81, b) fractured left clavicle and non-fractured right clavicle from individual SH160, and c) fractured left clavicle from individual SH259



Figure 6. Severe case of oblique midshaft fracture of a left clavicle that might result from a fall from a horse in an individual (SH71) of the group without riding deposit (NRD) from the Hungarian Conquest period cemetery of Sárrétudvari-Hízófold (10th century CE)