Bioarchaeological analysis of the mounted archers from the Hungarian Conquest period (10th century) : Horse riding and activity-related skeletal changes

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Bioarchaeological Analysis of the Mounted Archers from the Hungarian Conquest Period (10th Century): Horse Riding and Activity-Related Skeletal Changes

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This dissertation is dedicated to my mother.

Tout ce qui est mort comme fait, est vivant comme enseignement.

All that is dead as a fact is alive as a teaching.

Victor Hugo, *Paris*, in *Œuvres complètes*, vol. 10, *Politique*, Paris, Robert Laffont, coll. « Bouquins », 1985 [1867], p. 11

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ABSTRACT

Some changes observed on human bones can be related to activities practiced during life. Scholars have considered the reconstruction of activities from skeletal changes in past populations as “Bioarchaeology’s Holy Grail”. Horse riding, in particular, has interested bioarchaeologists and paleopathologists for several decades as it brought profound and lasting changes in the history of human cultural evolution. However, the existence of various confounding factors and the lack of clear contextual evidence in connection with the skeletal remains often result in limited or unreliable interpretations of skeletal changes in terms of specific activities.

Archaeological and historical sources attest that tribes of semi-nomadic populations conquered the Carpathian Basin with powerful armies of mounted archers at the turn of the 9th and 10th centuries, which led to the foundation of the Kingdom of Hungary in the year 1000/1001. Cemeteries from that period often provide cases of deposits of archery and horse riding equipment as well as horse bones associated with the individuals in the graves. 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.

We selected a sample of 67 individuals from the 10th-century Hungarian cemetery of Sárrétudvari-Hízóföld, in order to analyze the individuals according to the presence or absence of riding deposit in their grave. A modern comparison group of 47 presumed non-rider individuals from the documented collection of Lisbon was also selected. Only adult males were included to limit the effect of sex and age on the changes. The main objectives were to identify skeletal changes reliably related to the practice of horse riding and to improve our understanding of the populations from the Hungarian Conquest period.

Various types of skeletal changes were analyzed, including some entheseal changes (at muscles attachment sites), joint changes, vertebral changes, morphological variants, and traumatic lesions. Measurements of the lower limb bones were also used to calculate indices of shape and robusticity.

Statistical analyses mostly revealed significant differences between the Hungarian groups with or without riding deposit and the comparison group from Lisbon. They concerned especially some entheseal changes at the coxal bone, femur, tibia, and calcaneus, a morphological adaptation on the femoral neck, intervertebral disc herniations at the thoracolumbar junction, or the ovalization of the acetabulum on the coxal bone. All these traits

can be linked to the riding posture, and, thus, seem to be promising indicators for the practice of horse riding. On another note, comparisons between groups revealed that the Hungarian individuals without deposit in their grave were likely riding horses as well.

Among the limitations calling for caution is the restricted size of our archaeological samples, which is one of the points that should be improved in the future. In addition, some skeletal changes, such as the entheseal changes, have a multifactorial etiology, which represents a limitation for their interpretation. In that regard, we performed the exploratory analysis of the microarchitecture of an enthesis, the radial tuberosity. Using micro-CT acquisitions and 3D reconstructions of the canals of the cortical bone, we observed that some microstructural variations could allow, with further research, distinguishing entheseal changes related to activity from those related to other factors, thus contributing to more reliable reconstructions of the activities in past populations.

In the end, we emphasize that the selection of a pertinent anthropological collection, with direct evidence of the practice of an activity, and the application of strict methodological criteria, are determinant factors for the reliable identification of activity-related skeletal changes.

RÉSUMÉ COURT

Certaines modifications observées sur les os humains peuvent permettre de reconstituer les activités des populations anciennes. L'équitation représente notamment un intérêt particulier, ayant apporté des changements profonds et durables dans l'histoire de l'évolution culturelle humaine. Cependant, divers facteurs de biais et l'absence de données contextuelles claires liées aux restes osseux donnent souvent lieu à des interprétations limitées ou peu fiables des modifications osseuses en termes d'activités spécifiques.

Les sources archéologiques et historiques attestent que des tribus de populations semi-nomades ont conquis le bassin des Carpates à l'aide d'armées de cavaliers-archers au tournant des 9e et 10e siècles, conduisant ainsi à la fondation du Royaume de Hongrie en l'an 1000/1001. Les cimetières de cette période fournissent des cas de dépôts de matériel lié à l'archerie et à l'équitation ainsi que des ossements de chevaux associés aux individus dans les tombes. Ces populations sont ainsi parmi les plus pertinentes pour mener des études méthodologiques sur les modifications osseuses liées aux activités, et notamment à la pratique cavalière.

Nous avons sélectionné 67 individus issus du cimetière hongrois de Sárrétudvari-Hízóföld (10e siècle), pour les analyser selon la présence ou l'absence de dépôt lié au cheval dans leurs tombes. Un échantillon moderne de comparaison de 47 individus présumés non-cavaliers a également été sélectionné au sein de la collection documentée de Lisbonne. Seuls les sujets adultes masculins ont été inclus afin de limiter l'influence de variations en lien avec le sexe et l'âge. Les objectifs étaient d'identifier des modifications squelettiques liées à la pratique cavalière et d'améliorer nos connaissances sur les populations de la Conquête hongroise.

Nous avons analysé diverses modifications osseuses, au niveau des enthèses (points d'attache des muscles), articulations et vertèbres, ainsi que des variations morphologiques et lésions traumatiques. Des mesures des os des membres inférieurs ont aussi servi à calculer des indices de forme et de robustesse.

Les analyses statistiques ont principalement révélé des différences significatives entre les groupes hongrois avec ou sans mobilier et le groupe de comparaison. Celles-ci concernent notamment les modifications de certaines enthèses de l'os coxal, du fémur, du tibia et du calcanéus, une adaptation morphologique sur le col du fémur, les hernies discales à la jonction thoraco-lombaire, ou encore l'ovalisation de l'acétabulum de l'os coxal. Ces traits peuvent tous être liés à la posture du cavalier et semblent donc être des indicateurs prometteurs pour la

pratique cavalière. Par ailleurs, les comparaisons ont montré que les individus hongrois sans dépôt dans leur tombe montaient aussi vraisemblablement à cheval.

Parmi les limitations, appelant malgré tout à la prudence, figure la taille restreinte de nos échantillons archéologiques, qui est l’un des points qui devront être améliorés à l'avenir. En outre, certaines modifications osseuses, comme celles des enthèses, ont une étiologie multifactorielle, limitant ainsi leur interprétation. À cet égard, nous avons mené l’analyse exploratoire de la microarchitecture d'une enthèse, la tubérosité du radius. À l’aide d’acquisitions micro-CT et de reconstructions 3D des canaux de l'os cortical, nous avons observé que des variations microstructurales pourraient permettre, avec des recherches supplémentaires, de distinguer les modifications des enthèses liées aux activités de celles liées à d’autres facteurs, contribuant ainsi à de plus fiables reconstructions des activités des populations anciennes.

Au final, le choix d'une collection anthropologique pertinente, avec des preuves directes de la pratique d'une activité, ainsi que l'application de critères méthodologiques stricts, sont autant d’éléments déterminants pour l'identification fiable de modifications squelettiques liées aux activités.

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LIST OF ABBREVIATIONS

DISH	diffuse idiopathic skeletal hyperostosis
EC	entheseal changes
FPH	foot phalanges
HPH	hand phalanges
HRSC	horse riding-related skeletal changes
IOA	index of ovalization of the acetabulum
L1-5	first-fifth lumbar vertebra
LIS	Lisbon (comparison group from the documented collection of Lisbon)
µ-CT	micro-computed tomography (or also micro-CT)
NRD	no riding deposit (group of individuals from the Hungarian Conquest period)
RD	riding deposit (group of individuals from the Hungarian Conquest period)
S1	first sacral vertebra
SN	Schmorl's nodes
T1-12	first-twelfth thoracic vertebra
YMA	young and mature adult

CHAPTER 1. INTRODUCTION

I. The reconstruction of activities in ancient populations

I.A. The research on activity-related skeletal changes

The study of the activities and behaviors in ancient populations represents a particularly active research area in bioarchaeology, even considered by some scholars as the "Bioarchaeology's Holy Grail" (Jurmain et al., 2012). Bone changes of different types have been considered and interpreted for decades as activity, occupational or stress markers, with the aim of providing information about the activities of the individuals. Their analysis has involved many bioanthropologists and paleopathologists, with an important step forward accomplished from the 1980's (e.g., Angel, 1982; Merbs, 1983; Ruff et al., 1984; Dutour, 1986; Kennedy, 1989; Hawkey & Merbs, 1995; Pálfi & Dutour, 1996; Robb, 1998; Jurmain, 1999; Al-Oumaoui et al., 2004; Mariotti et al., 2004; Rhodes & Knüsel, 2005; Molnar, 2006; Mariotti et al., 2007; Perréard Lopreno, 2007; Weiss, 2007; Villotte et al., 2010; Jurmain et al., 2012; Niinimäki, 2012b; Alves Cardoso & Henderson, 2013; Henderson & Alves Cardoso, 2013; Milella et al., 2015; Henderson et al., 2016).

In some cases, material archaeological remains such as artifacts or built structures are not indicative of the activities performed by individuals during their life. The analysis of the individuals' skeletal remains represents the most direct or sometimes the only way to address the question, even if many limitations must be considered for the reconstruction of activities. The main questions addressed in this research area concern mostly locomotion, mobility, and asymmetry patterns as well as the sexual division of labor, the socio-economic organization, and, more generally, the reconstruction of the lifestyles and behaviors in past societies.

I.B. Brief biological background

Intense and regular physical activity can lead to some pathological or non-pathological bone changes of different types. The most promising research areas in the reconstruction of activities concern especially the musculoskeletal stress markers (MSMs), nowadays rather called entheseal changes (EC), as well as osteoarthritis and bone biomechanical properties, even though other types of changes are also used as activity-related markers (Kennedy, 1989; Larsen, 1997; Capasso et al., 1999; Jurmain et al., 2012).

The studies in the field of activity reconstruction are based on the bone's reaction to loading and its ability to adapt its shape and structure in response to it (Niinimäki, 2012a). The performance of any physical activity involves the musculoskeletal system as the body is in motion. External loads and muscle loads are transferred to the tissues. Those mechanical stimuli, or forces, generate signals to bone cells that are transduced into a biological response, including bone remodeling, the process that removes old and damaged bone and replaces it with new tissue. Bone resorption is initiated by osteoclasts, and bone formation is initiated then by osteoblasts. In normal bone, the balance between osteoblastic and osteoclastic activity is disturbed due to an increase in loading and new bone is deposited on periosteal and endosteal surfaces of cortical bone and on trabecular surfaces in cancellous bone (Mellon & Tanner, 2012). This results in bone mass and morphology changes that make the bone more suitable to resist to mechanical loading, according to Wolff's law (1892). Bone cross-sectional geometry allows, for instance, to study the biomechanical properties that are adapted in response to physical activity, but it mostly provides information regarding general loading patterns (Niinimäki, 2012a; Tichnell, 2012).

Unlike cross-sectional geometry, the analysis of EC is more adapted if we are interested in the study of specific activities (Tichnell, 2012). Entheses are the insertion sites of tendons, ligaments, and joint capsules on the bone. A distinction can be made between two types of entheses. Fibrous entheses are mainly encountered at the metaphyseal or diaphyseal areas while fibrocartilaginous entheses include the insertions at the epiphyses and processes of long bones as well as the short bones of hands and feet and several ligaments in the spine (Benjamin & Ralphs, 1998; Benjamin & McGonagle, 2001). EC are pathological or non-pathological modifications at the insertion sites (La Cava, 1959; Niepel & Sit'aj, 1979; Lagier, 1991; Benjamin et al., 2002). These alterations are visually observable on dry bone and can take the form of new bone formation (raised margins, enthesophytes, irregular or rugose surfaces) or bone destruction (porosity, cavitations, cortical defects, erosive areas) (e.g., Hawkey & Merbs, 1995; Robb, 1998; Mariotti et al., 2004; Villotte, 2009; Henderson et al., 2016; Villotte et al., 2016). The precise etiology of these features remains however debated as many factors, age above all, need to be considered (Henderson et al., 2017a). Theoretically, the tissues forming the enthesis remodel in order to resist muscle tension (Tichnell, 2012) and osteophytic and osteolytic processes develop according to the type, level, and direction of loading applied and the deposition or resorption thresholds of the bones (Niinimäki, 2012a). Muscular activity is considered to stimulate bone remodeling by an increase in blood flow at the entheses resulting in hypertrophic muscle insertion sites, while osteophytes are thought to result from muscular tear (which leads to bone avulsion and ossification exostosis) (Hawkey & Merbs, 1995; Tichnell, 2012) and osteolytic processes might be due to continual microtrauma (Hawkey & Merbs, 1995). Regarding these, some scholars also suggest that they might be related to blood vascularization in the entheses or that they could be due to the absence of a layer of cortical bone in some entheseal regions and represent remains from developmental phases during adolescence (Henderson et al., 2017a). In the end, although various determinant factors need to be considered, EC are more promising for studying the effect of specific activities as each activity involves specific muscles and continual stress of a muscle can presumably result in changes observed at the level of the involved entheses (Tichnell, 2012).

Osteoarthritis, or degenerative joint disease, represents the third main research area in the reconstruction of activities, partly because it has been used widely and relatively early as a marker of activity (Ortner, 1968; Jurmain, 1977; Angel, 1982; Merbs, 1983). Apart from dental lesions, osteoarthritis is also the most commonly observed condition in skeletal remains (Waldron, 2009). The bone changes observed at the synovial joints include marginal osteophytes and contour deformation, as well as porosity, bone formation, and eburnation on the joint surface (Buikstra & Ubelaker, 1994; Waldron, 2009; Jurmain et al., 2012). These alterations appear following the breakdown of the articular cartilage of the joint and the inflammation in the synovial membrane. Vascularization of the subchondral bone, in particular, is responsible for the formation of new bone (Waldron, 2009). The discussions on the link between osteoarthritis and activities are based on the fact that it has been considered as resulting from repetitive mechanical loading and that repetitive tasks could, therefore, lead to severe osteoarthritic features on specific joints (Weiss & Jurmain, 2007). Nowadays, it is acknowledged from clinical research that the etiology of osteoarthritis is multifactorial (Larsen, 1997; Resnick, 2002; Ortner, 2003; Weiss & Jurmain, 2007; Waldron, 2009; Jurmain et al., 2012).

I.C. Main limitations in the research on activity-related skeletal changes

Several authors reviewed the challenges related to the use of skeletal changes for the reconstruction of activities in past societies and suggest to use them with caution (Dutour, 1992, 2000; Weiss & Jurmain, 2007; Jurmain et al., 2012; Villotte & Knüsel, 2013). A major issue with activity-related skeletal changes (ARSC) is their lack of specificity, which is closely related to their multifactorial etiology: not only physical activity but also age, sex, body weight, body size, genetic factors, ancestry, diet or pathological conditions can indeed influence the expression of entheseal changes (EC), osteoarthritis, or bone geometry (e.g., Dutour, 1992; Rogers & Waldron, 1995; Wilczak, 1998; Knüsel, 2000b; Crubezy et al., 2002; Weiss & Jurmain, 2007; Niinimäki, 2011; Jurmain et al., 2012; Milella et al., 2012; Weiss et al., 2012; Niinimäki & Baiges Sotos, 2013; Ruff & Larsen, 2014; Schrader, 2019). These systemic factors can expose an individual to risk for developing changes, while other factors can also have a local influence, such as musculoskeletal anomalies, joint alignment or injury, which can, for instance, expose directly a joint to risk for osteoarthritis (Dutour, 1992; Schrader, 2019) (Figure 1).

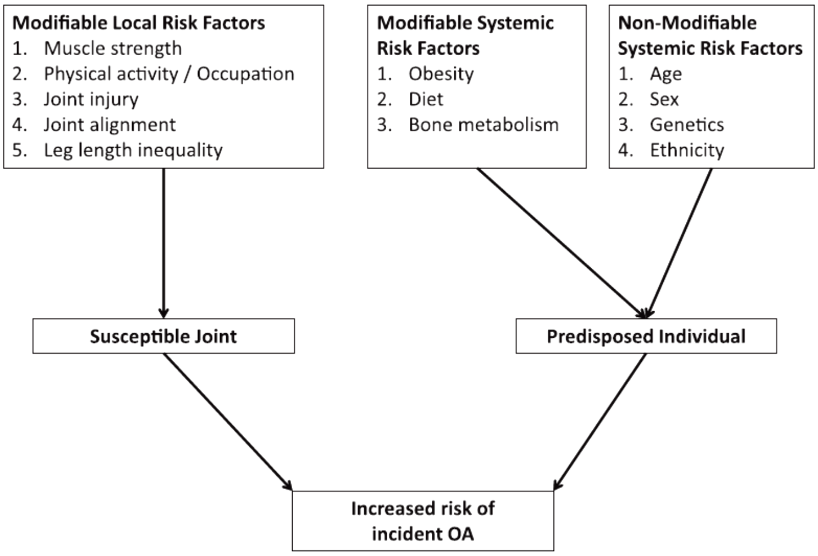

Figure 1. Summary of the potential risk factors for osteoarthritis (Johnson and Hunter, 2014)

Among all those factors, age is probably the most important one to be considered when dealing with ARSC. Older individuals are logically more likely to develop degenerative joint changes. This could be linked with "cumulative wear-and-tear (i.e., the repetitive use of a joint over one's life course), sarcopenia, decreased bone turn over, as well as a reduced capacity for soft tissue repair" in the case of osteoarthritis (Schrader, 2019: 61). Regarding EC, while the high correlation with age is now widely recognized (e.g., Weiss, 2003, 2004; Alves Cardoso & Henderson, 2010; Milella et al., 2012), it is still unclear if it is the consequence of their accretion over life, an increased susceptibility to remodeling, a reduction in tendon vascularity, a decrease in cortical bone, or the loss of muscle mass (see Schrader, 2019). Sex must also be considered as females seem to be at higher risk of developing osteoarthritis. Possible reasons are a post-menopause reduction in estrogen levels, lessened bone mineral density, bone composition, ligament laxity, lower cartilage volume, pregnancy, and neuromuscular strength (see Schrader, 2019). Moreover, the differences in muscle mass between females and males could also affect entheses, with males being more susceptible to develop larger and severe EC (Weiss, 2003, 2004; Weiss et al., 2012; Nikita, 2017; Schrader, 2019). Besides sex and age, it has also been suggested that there is an inter-individual variation in bone production and bone resorption which may affect the expression of ARSC, with individuals who would be "bone-formers", and others who would rather be "bone-losers" (Rogers et al., 1997; Mays, 2016; Schrader, 2019). Furthermore, it is now widely acknowledged that metabolic and inflammatory disorders like diffuse idiopathic skeletal hyperostosis (DISH) or seronegative spondyloarthropathies can lead to the development of EC (e.g., Villotte & Knüsel, 2013). While there were early warnings of caution regarding this aspect (Dutour, 1986, 1992; Pálfi, 1992), it is only recently that studies relying on EC tend to exclude systematically the individuals affected by such diseases from samples.

A further limitation in the analysis of activity-related markers is the large variety of scoring methods, concerning osteoarthritis (Crubézy, 1988; Buikstra & Ubelaker, 1994; Rogers & Waldron, 1995) and entheseal changes (Crubézy, 1988; Hawkey & Merbs, 1995; Mariotti et al., 2004; Villotte, 2006; Mariotti et al., 2007; Villotte et al., 2010; Henderson et al., 2013), as well as the large scale of methods of statistical analysis used in this type of research (Nikita, 2017; Schrader, 2019). This makes very difficult the comparisons between studies. Regarding EC, in particular, their relation to activity has proven not to be straightforward and the scoring methods appear not to be entirely adequate, leading some to go further and investigate the microarchitecture of the entheses. The results of the study by Djukic and collaborators (2015), who scanned several entheses using microcomputed tomography, suggest that stages of scored macroscopic EC do not reflect the microscopic organization of entheses, except maybe in the most severe cases. Furthermore, Michopoulou and colleagues (2015; 2017) tested the correlation between several scoring methods and activity and observed that activity was rarely significant as a factor affecting EC expression (compared to age and body mass for instance), suggesting that the tested scoring methods do no effectively reflect activity. Regarding the analysis of bone geometrical features for research on activities, external macroscopic measurements are commonly used for quantifying robusticity but are limited compared to the potential of cross-sectional bone geometry, which is however characterized by technical, financial, and time challenges as it ideally requires the use of computed tomography, more accurate than plane radiography for example (Stock & Shaw, 2007; Jurmain et al., 2012; Ruff & Larsen, 2014). In general, the sample size has also often been recognized as problematic in the field of activity reconstruction (e.g., Henderson & Nikita, 2016) — being closely dependent on bone preservation — as well as, in particular, the lack of documented out-groups of sufficient size for comparison (Knüsel, 2000b).

Another issue that concerns EC, in particular, comes from the demonstration of the distinction between two types of entheses, fibrocartilaginous and fibrous ones, as mentioned earlier (Benjamin & McGonagle, 2001; Benjamin et al., 2002). Several studies suggest that fibrocartilaginous entheses have a stronger correlation with activity than fibrous ones (Villotte et al., 2010; Havelková et al., 2011; Villotte & Knüsel, 2013; Weiss, 2015), which could be explained by differences in their structure and the way tendons attach to the bone (Benjamin et al., 2002). Fibrous entheses would also be less promising activity markers due to the difficulty to identify their limits and to describe their changes compared to their "normal" aspect, which is not clearly defined (Villotte & Knüsel, 2013; Villotte et al., 2016; Nikita, 2017).

Furthermore, besides the multifactorial etiology of ARSC, other general analytical pitfalls must be acknowledged and avoided in the attempt to reconstruct activities in past populations from the analysis of skeletal changes. They concern the problem of transposition between present and past activities (i.e., the manner in which they are and were performed), the lack of clinical evidence for validation of the link between a specific activity and a specific marker identified from archaeological materials, or the lack of analogy regarding activities that are no longer practiced today (Dutour, 1992, 2000). Besides the lack of specificity of the markers mentioned previously, which means that identical skeletal changes in different individuals can result from different activities or various other causes, the relative sensitivity of the markers should also be acknowledged. A specific activity may not systematically lead to the expression of similar skeletal changes in different individuals, or even to the expression of any skeletal changes at all (Dutour, 2000). In addition, a specific activity rarely results in a single type of change, therefore a single specific marker should not be enough to confirm an activity hypothesis; only the combination of several different markers, consistent with each other, may allow making a reliable association with a particular activity (Dutour, 1992, 2000). The existence of relevant archaeological data that can be linked whether in a conclusive or a compatible way to an activity is determinant for the selection of any study material in order to limit the influence of the methodological biases mentioned above (Dutour, 1992, 2000).

Finally, we should keep in mind that bone changes do not reflect the consequences of a single activity performed during life, but that "the skeleton registers a mosaic of activities over the course of each individual's lifetime" (Kennedy, 1998: 308).

II. The identification of horse riding

II.A. Why is horse riding so interesting?

Among all activities, horse riding brought profound and lasting changes in the history of human cultural evolution concerning major 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; Librado et al., 2016; de Barros Damgaard et al., 2018; Gaunitz et al., 2018).

Archaeological evidence suggests that horse domestication likely started in the Copper Age Botai hunter-herder culture, in the northern Kazakh steppe, around 3500-3000 years BCE (Outram et al., 2009; de Barros Damgaard et al., 2018; Gaunitz et al., 2018). There, not only horse burials were discovered but also remains of tools associated with the production of leather thong and traces of equine milk fats in ceramics. These elements, combined with bit-related pathologies on the teeth in horse remains tend to support the practice of milking and harnessing, and thus, of pastoral husbandry (Outram et al., 2009; Gaunitz et al., 2018).

Horses can be involved as much for transportation than for agricultural and warfare activities. Their importance for humans can be detected in numerous artistic representations, in the material culture, in historical texts as well as in the funerary practices (Hyland, 1996; Garofalo, 2004; Outram et al., 2011; Baillif-Ducros, 2018). As an example of their social importance, we can mention the development of relay stations for horses in different societies since Antiquity. They allowed the fast transportation of people (for private or professional purposes) and materials through territories over long distances and thereby contributed to the shaping of road networks, such as in France between the 17th and the 19th centuries (Bretagnolle & Verdier, 2014). On another note, the Bayeux Tapestry, which depicts the events that lead to the Norman Conquest of England by William the Conqueror in 1066, offers a vivid illustration of the importance of horses in warfare. Through numerous animal representations, the tapestry reveals the significant place of horses in the Norman society and the fundamental role played by the cavalry (especially mounted lancers) during the Battle of Hastings, after the transportation of several thousands of horses across the Channel (Bouet, 2015) (Figure 2).

Figure 2. Norman horsemen depicted on the Bayeux Tapestry, ca. 1080. Embroidery, Bayeux Tapestry Museum, Bayeux, France. From http://www.hs-augsburg.de

The practice of depositing complete horses in graves seems to go back to the late Roman Iron Age (1-375 CE) while separate horse burials can be found in central and northern Europe from the early and the late Iron Age (Jennbert, 2003). When an animal is deposited in a separate pit, it can be considered as an animal grave. In such cases, it is possible to state that the people responsible for this burial cared for the animal and had a purpose (Jennbert, 2003).

Replacing oxen, onagers, and donkeys as draught animals, horses were considered as a prestige animal (Garofalo, 2004). During different eras, like in the Middle Ages, riding a horse was often a sign of social distinction, as owning horses required specific infrastructures, equipment, and assigned workforce for care and maintenance (Hyland, 1999; Baillif-Ducros, 2018). Horse riding was regularly performed by particular subgroups in societies and was, therefore, an activity associated with the identities of those specific groups and was bearing symbolic meaning (Hyland, 1999; Tichnell, 2012). Furthermore, in many cultures (e.g., Scythians, Celts, Gauls, Avars, Magyars), the horse had strong spiritual importance and played a role during various funerary rituals and practices (Garofalo, 2004; Bede, 2015).

With this in mind, it is clear that a better understanding of who exactly were horse riders during their life can shed light on different aspects of past societies. For instance, for some ancient populations of nomadic pastoralists, the sparseness of archaeological remains and the lack of internal textual evidence, among other causes, may result in a partial or oversimplified understanding regarding different aspects of the societal organization (Tichnell, 2012). Considering the extreme importance of horse riding in their life, the analysis of this practice in those populations can bring elements of answers, and, while ethnographic studies can be very informative, the examination of skeletal remains for horse riding-related bone changes represents the most direct source of information (Tichnell, 2012).

II.B. What do we know from sports medicine and modern riders?

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). For both modern and ancient riders, some features must, indeed, be common in relation to the posture on the horse and the muscles needed to maintain it, notably if stirrups were used.

In the position privileged by riders, the pelvis is in retroversion (tilted backward), the back is vertical and straight, and the lumbar lordosis is diminished, allowing better absorption of vertical stresses (Auvinet, 1999; Humbert, 2000). Sitting astride forces the femurs into abduction while pointing the toes ahead rotates them medially and gripping the horse engages the adductors. While it is recommended that the heel be aligned with the shoulder and the hip, leading to a semi-flexed knee, variations in the riding style also see the knee being semi-extended, with the heel put forward (Garofalo, 2004).

The muscles that are engaged in horse riding cover a wide range of movements and include especially the adductors (hip adduction), the gluteals (hip extension, abduction, medial and lateral rotation), the quadriceps (knee extension, hip flexion), the hamstrings (knee flexion, hip extension), the hip rotators (hip lateral rotation) and the calf muscle (plantarflexion). Among them, the adductors are often presented as particularly important for riding as they keep the legs together on the horse, which is not a common action otherwise in daily life (Baillif-Ducros et al., 2012; Willson, 2013; Djukic et al., 2018). The abdominal muscles are also determinant for the balance and the control and stabilization of the posture. Finally, the shoulder and trunk stabilizers are important notably for accurate movements of the arms that control the reins (when used) and for the head posture (Willson, 2013). The regular and intensive use of those muscles for the highly demanding activity that is horse riding is likely to lead to muscular injuries. Furthermore, 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). In terms of potential of injuries, horse riding is 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 several times horse-related injuries 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; Altgärde et al., 2014; Ki et al., 2018). 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 (Baillif-Ducros, 2018). Traumas on the upper extremities, in particular, are essentially related to the attempt of self-protection that occurs during a fall. Moreover, pubic symphysis diastasis can also be observed, although rarely, on horse riders. A violent impact on the horse, with the pommel of the saddle, or from a fall, can, indeed, lead to a partial or complete rupture of the joint, without fracture (Garofalo, 2004; Baillif-Ducros, 2018).

Sports medicine also describes other types of injuries, including some being the result of overuse. In polo players from Argentina, for instance, despite fractures (39 % of injuries) were also recorded sprains and strains (19 %), head concussions (19 %), muscular injuries (13 %), such as hip adductor tendinitis, and also dislocations (5 %), post-traumatic back pain (5 %) and complex lesion of the eye (2 %), as well as facial lacerations (Costa-Paz et al., 1999; Garofalo, 2004).

Baillif-Ducros (2018) delivers a review of the bone lesions that can be observed on equestrian athletes. They include, on the vertebral column, lumbar hyperlordosis, spondylolysis (stress fracture on the vertebral arch) and spondylolisthesis (forward displacement of a vertebra compared to the inferior one), osteoarthritis, disc deteriorations and Schmorl's nodes (or intraosseous disc herniations), and Scheuermann's disease (kyphosis of the lower thoracic region, with wedging of the anterior portion of the vertebral bodies) (e.g., Auvinet, 1980b; Lang, 1995; Auvinet, 1999; Humbert, 2000; Pugh & Bolin, 2004).

The hip, a determinant region for the posture and the communication between the rider and the horse, is also affected (Baillif-Ducros, 2018). Microtraumatic injuries, due to muscular overuse, are recorded: adductor strain, myositis ossificans in the adductors (or rider's bone, although this lesion is not observed anymore in modern riders), and enthesopathies of the adductors (e.g., Auvinet, 1980a; Auvinet & Ginet, 1980). In the riding position, the retroversion of the pelvis can also be the cause of the femoroacetabular impingement (FAI) (Baillif-Ducros, 2018). In this position, the femoral head-neck junction is abnormally in contact with the acetabular rim. The repetition of this contact can lead to coxarthrosis and, presumably, to the presence of non-metric traits such as the Poirier's facet (extension of the femoral head articular surface onto the neck) and the fossa of Allen (pitted area or cortical erosion with exposition of the trabecular bone) (Villotte & Knüsel, 2009; Radi et al., 2013). Furthermore, perifoveal osteophytes can also be observed, as well as pubic inguinal lesions (Baillif-Ducros, 2018).

The use of stirrups provides a point of stability for the rider. The subsequent loading for the knee joint can lead to gonarthrosis. The level of pressure and the possible lesions would notably depend on the length of the stirrups as it influences the degree of flexion of the knee (Baillif-Ducros, 2018).

However, some of those lesions have been observed only in low frequencies in riders and are not specific to horse riding. Scheuermann's disease, the FAI, or the perifoveal osteophytes, for instance, are common in other high-level athletes (Auvinet, 1999; Baillif-Ducros, 2018). Despite problems of transposition between modern and ancient riders, clinical data from sports medicine are a good indicator of what skeletal changes should be investigated in particular in archaeological populations.

II.C. Archaeozoology and equestrian activity

Various studies have attempted to infer activities from the paleopathological analysis of horse skeletal remains (e.g., Levine et al., 2000; Pluskowski et al., 2010; Bulatović et al., 2014; Marković et al., 2014; Taylor et al., 2014; Bindé et al., 2018). Among several promising markers that could be identified, the presence of bit wear is even often considered as a direct and unmistakable sign of riding (Brown & Anthony, 1998; Anthony, 2007; Bendrey, 2007; Taylor et al., 2015; Greenfield et al., 2018). While the analysis of entheseal changes for the reconstruction of activities in human past populations is largely spread, their study on animal skeletal remains was often unconsidered. With the aim of a better understanding of their status and the activities in which they were involved in past societies, scholars recently focused their interest on the entheseal changes developed by riding, draft and pack animals, including, especially, horses (Bendrey, 2008; Taylor et al., 2015; Bertin et al., 2016; Bindé et al., 2019) and reindeers (Niinimäki & Salmi, 2016; Salmi & Niinimäki, 2016). Other approaches focusing on the horses include the study of different vertebral paleopathological conditions, such as ankylosing spondylitis (or "bamboo spine") or deforming spondyloarthrosis (Jeffcott, 1980; Lignereux et al., 1998; Levine et al., 2000; Bartosiewicz & Bartosiewicz, 2002; Janeczek et al., 2014; Lignereux & Bouet, 2015), as well as the analysis of morphological changes on the skulls, such as on the nasal bones and the premaxilla (Taylor et al., 2015; Taylor & Tuvshinjargal, 2018), even if such changes may depend on the equipment used and the riding style.

Although those bone changes are promising for the identification of riding from horse skeletal remains, the existence of a direct link between specific changes and the practice of horse riding has not yet been unarguably demonstrated with regard to human skeletal remains.

II.D. Bioanthropology and horse riding

II.D.1. Previous research on skeletal changes related to horse riding

Bioanthropological research on horse riding in ancient populations has developed in the past decades, with a growing interest from the beginning of the 1990s, especially. Among the early contributions on this topic, the work of Miller and collaborators on historic Native American Omaha and Ponca skeletal remains (Miller & Reinhard, 1991; Miller, 1992; Reinhard et al., 1994) and the paleopathological investigation performed by Pálfi and Dutour on a Hungarian cemetery of the 10th century CE (Pálfi, 1992; Pálfi & Dutour, 1996; Pálfi, 1997) particularly played an influential role.

A combination of skeletal changes, repeatedly observed and interpreted as signs of riding in past populations, is sometimes referred to as *horse riding syndrome* or *horseback riding syndrome* in the literature since Pálfi (1992, "*syndrome du cavalier*"). It covers pathological and nonpathological changes of various types, most of them having previously been reviewed (Garofalo, 2004; Baillif-Ducros et al., 2012; McGrath, 2015; Baillif-Ducros, 2018). To synthetize, those skeletal changes can be categorized in several groups: (a) spinal changes; (b) extraspinal joint changes; (c) entheseal changes; (d) morphological variants; and (e) extraspinal traumatic lesions. For clarity, we group them under the term *horse riding-related skeletal changes* (abbreviated as HRSC), even though their association with the practice of horse riding is, in the great majority of cases, simply assumed and not demonstrated.

We present here in distinct tables a summary of the main HRSC (Table 1, 2, 3, 4, and 5). Those are the skeletal changes previously observed and described by scholars on anthropological samples from archaeological context for which the practice of horse riding was presented as a possible or compatible cause. Our aim with this synthetic review is to be as exhaustive as possible. The signs that were only mentioned but not directly observed and described by the scholars are not referred to, along with the changes that were observed on the skeletons of presumed riders but not explicitly associated with the practice of horse riding. Some studies that were presented as conference communications were available to us only through their abstracts, which sometimes did not provide enough data or details to be included here (e.g., Jacquemard et al., 2011; Eng, 2013; Storch et al., 2013). The studies that mention HRSC but that are not specific enough regarding their nature or their localization are briefly discussed under the relevant tables when it is relevant. Furthermore, studies focusing on HRSC but that could not obtain conclusive results (i.e., a probable association between specific changes and horse riding) are not referred to (e.g., Eng, 2013; Sarry et al., 2016, on the shape of the acetabulum). Finally, when the authors describe the same horse riding-related changes on the same skeletal series in different publications, the earliest reference that was available to us is given.

Table 1. Summary of the spinal skeletal changes associated with horse riding in the anthropological literature

Spinal changes observed	References
Intervertebral disk degeneration; Facet joint osteoarthritis (including at the cervical level)	Edynak, 1976 (lumbar); Bradtmiller, 1983; Angel et al., 1987; Miller & Reinhard, 1991; Pálfi, 1992; Sandness & Reinhard, 1992; Blondiaux, 1994; Willey, 1997; Courtaud & Rajev, 1998; Charlier, 2006; Langlois & Gallien, 2006; Fornaciari et al., 2007; Wentz & de Grummond, 2009; Bagagli et al., 2012; Baillif-Ducros et al., 2012; Anđelinović et al., 2015; Eng, 2016; Khudaverdyan et al., 2016; Sarry et al., 2016; Panzarino & Sublimi Saponetti, 2017 (apophyses, asymmetrical, post-traumatic after a fall); Karstens et al., 2018
Schmorl's nodes/herniations	Miller & Reinhard, 1991; Sandness & Reinhard, 1992; Willey, 1997; Reinhard & Wall, 2002; Langlois & Gallien, 2006; Wentz & de Grummond, 2009; Üstündağ & Deveci, 2011; Bagagli et al., 2012; Fornaciari et al., 2014; Anđelinović et al., 2015; Serna et al., 2015; Antikas & Wynn-Antikas, 2016; Sarry et al., 2016; Karstens et al., 2018
Accentuated thoracic kyphosis and lumbar lordosis/Scheuermann's disease; Compression fractures	Blondiaux, 1994; Üstündağ & Deveci, 2011; Baillif-Ducros et al., 2012; Fornaciari et al., 2014; Sarry et al., 2016
Spondylolysis	Miller & Reinhard, 1991; Pálfi, 1992; Dutour & Buzhilova, 2014; Fornaciari et al., 2014
Vertebral fusion	Miller & Reinhard, 1991; Wentz & de Grummond, 2009
Kissing spine (or Baastrup's disease)	Miller & Reinhard, 1991

Sandness and Reinhard (1992) also describe a higher frequency of spondylolysis in historic Omaha and Ponca series compared to prehistoric ones. They associate this observation with the activities that predisposed the individuals "either to greater habitual stress, or incidences of trauma" (p. 306), without, however, explicitly mentioning horse riding, unlike they do as a possible explanation for the higher frequency of Schmorl's nodes.

Table 2. Summary of the extraspinal joint changes associated with horse riding in the anthropological literature

Anatomical region	Localization of observed extraspinal joint changes	References
Pelvis	Sacroiliac joint	Bradtmiller, 1983; Üstündağ & Deveci, 2011
Hip	Coxofemoral joint	Bradtmiller, 1983; Miller & Reinhard, 1991; Pálfi, 1992; Courtaud & Rajev, 1998; Garofalo, 2004; Charlier, 2006; Fornaciari et al., 2007; Robin, 2011 (asymmetrical); Fornaciari et al., 2014; Sarry et al., 2016; Baillif-Ducros, 2018
	Perifoveal osteophytes on the femoral head (mentioned apart from other hip joint changes)	Blondiaux, 1994; Fornaciari et al., 2003; Garofalo, 2004; Fornaciari et al., 2007; Baillif-Ducros et al., 2012; Sarry et al., 2016; Panzarino & Sublimi Saponetti, 2017; Baillif-Ducros, 2018
Knee	Patellofemoral joint	Robin, 2011 (asymmetrical); Baillif-Ducros & McGlynn, 2013; Baillif-Ducros, 2018
	Tibiofemoral joint (left medial condyle)	Molleson, 2007; Robin, 2011
	Unspecified	Bradtmiller, 1983; Miller & Reinhard, 1991; Eng, 2016
Ankle	Talocrural joint	Panzarino & Sublimi Saponetti, 2017
	Unspecified	Bradtmiller, 1983
Foot	Distal first metatarsal (“toe stirrup”)	Miller & Reinhard, 1991
Shoulder	Glenohumeral joint	Anđelinović et al., 2015; Karstens et al., 2018
	Acromioclavicular joint	Karstens et al., 2018
Elbow	Unspecified	Miller & Reinhard, 1991; Anđelinović et al., 2015; Eng, 2016
Thorax	Sternal ends of ribs and clavicles	Miller, 1992

It should be clarified that the authors who mention extraspinal joint changes of the upper part of the body explain it, in most cases, as being the consequence of rein or bridle tension (Eng, 2016; Karstens et al., 2018).

Considering the relatively early date of the following study, we should also mention that Edynak (1976), referred to by Larsen (1987) and Gibbon (1984), examined a series of skeletons from Yugoslavian mounds dated from Iron Age to the medieval period, and “found that articular joints of the males’ pelvic regions were more severely affected by osteoarthritis than any other joints” (Larsen, 1987: 391). The author associated this observation with the absorption of shock that occurs in horse riding, as the population included presumed riders. However, there is no precision regarding which joint, in particular, is concerned (i.e., sacroiliac or coxofemoral joint). According to Gibbon (1984), Edynak observed that “males exhibited a pattern of more direct stress on all joints, and pelvic-lumbar degenerative arthritis related to the absorption of shock from below" (p. 206).

Finally, Panzarino and Sublimi Saponetti (2017), studying the remains of a Southern Italian (Apulia) individual from the 15th century, attribute the presence of osteochondritis dissecans at the acetabulum, femoral head, and talus to the stress related to galloping.

Table 3. Summary of the entheseal changes associated with horse riding in the anthropological literature (1/2)

Bone	Site of the observed entheseal changes	Muscles attached to the site (o. = origin site; i. = insertion site)	References
Coxal bone	Ilium posterior (superior and posterior to the inferior gluteal line)	*Gluteus maximus* (o.); *Gluteus medius* (o.); *Gluteus minimus* (o.)	Miller, 1992; Pálfi, 1992; Anđelinović et al., 2015; Ciurletti, 2017
	Pubic body	*Adductor brevis* (o.)	Miller, 1992
	Ischial tuberosity	*Semimembranosus* (o.); *Semitendinosus* (o.); *Biceps femoris* (o., long head)	Pálfi, 1992; Molleson & Hodgson, 1993; Ciurletti, 2017; Djukic et al., 2018
	Inferior pubic ramus and ramus of ischium (medial border)	*Adductor magnus* (o.)	Miller, 1992; Pálfi, 1992; Ciurletti, 2017
Femur	Greater trochanter	*Gluteus medius* (i.); *Gluteus minimus* (i.)	Miller & Reinhard, 1991; Pálfi, 1992; Molleson & Hodgson, 1993; Blondiaux, 1994; Molleson & Blondiaux, 1994; Knüsel, 2000a (medius); Fornaciari et al., 2003; Garofalo, 2004 (medius); Üstündağ & Deveci, 2011; Anđelinović et al., 2015; Antikas & Wynn-Antikas, 2016; Khudaverdyan et al., 2016; Ciurletti, 2017; Panzarino & Sublimi Saponetti, 2017
	Trochanteric fossa	*Obturator externus* (i.); *Obturator internus* (i.)	Blondiaux, 1989; Molleson & Hodgson, 1993; Blondiaux, 1994; Molleson & Blondiaux, 1994; Belcastro et al., 2001; Fornaciari et al., 2007; Bartsiokas et al., 2015; Khudaverdyan et al., 2016; Ciurletti, 2017
	Lesser trochanter	*Iliopsoas* (i.): *iliacus*, *psoas major*, *psoas minor*	Pálfi, 1992; Molleson & Hodgson, 1993; Belcastro et al., 2001; Charlier, 2006; Fornaciari et al., 2014; Panzarino & Sublimi Saponetti, 2017; Djukic et al., 2018
	Gluteal tuberosity	*Gluteus maximus* (i.)	Pálfi, 1992; Blondiaux, 1994; Molleson & Blondiaux, 1994; Belcastro et al., 2001; Fornaciari et al., 2003; Charlier, 2006; Uerpmann et al., 2006; Tichnell, 2012; Pulcini, 2014; Bartsiokas et al., 2015; Ciurletti, 2017
	Pectineal line	*Pectineus* (i.)	Pálfi, 1992; Charlier, 2006; Fornaciari et al., 2007

Table 3. Summary of the entheseal changes associated with horse riding in the anthropological literature (2/2)

Bone	Site of the observed entheseal changes	Muscles attached to the site (o. = origin site; i. = insertion site)	References
Femur	Middle medial lip of *linea aspera*	*Adductor magnus* (i.); *Adductor longus* (i.); *Adductor brevis* (i.); *Vastus medialis* (o.)	Blondiaux, 1989; Miller & Reinhard, 1991; Pálfi, 1992; Molleson & Hodgson, 1993; Blondiaux, 1994; Molleson & Blondiaux, 1994; Courtaud & Rajev, 1998; Belcastro et al., 2001; Fornaciari et al., 2003; Garofalo, 2004; Charlier, 2006; Uerpmann et al., 2006; Üstündağ & Deveci, 2011; Anđelinović et al., 2015; Khudaverdyan et al., 2016; Panzarino & Sublimi Saponetti, 2017; Djukic et al., 2018
	Lateral lip of *linea aspera*	*Vastus lateralis* (o.); *Biceps femoris* (o., short head)	Miller & Reinhard, 1991; Pálfi, 1992; Fornaciari et al., 2003; Üstündağ & Deveci, 2011
	Linea aspera	Unspecified	Pap, 1985; Józsa et al., 1991; Simalcsik & Simalcsik, 2013; Pulcini, 2014; Anđelinović et al., 2015; Antikas & Wynn-Antikas, 2016
	Adductor tubercle (or medial supracondylar line)	*Adductor magnus* (i.)	Angel et al., 1987; Snow & Fitzpatrick, 1989; Pálfi, 1992; Molleson & Blondiaux, 1994; Charlier, 2006; Tichnell, 2012 (depending on the riding style); Bartsiokas et al., 2015; Djukic et al., 2018
	Medial and lateral popliteal surface	*Gastrocnemius* (o., medial and lateral heads)	Miller, 1992; Pálfi, 1992; Anđelinović et al., 2015
	Medial popliteal surface (only)	*Gastrocnemius* (o., medial head)	Molleson & Blondiaux, 1994; Üstündağ & Deveci, 2011
Patella	Anterior surface	*Quadriceps femoris* (i.): *vastus medialis*, *vastus intermedius*, *vastus lateralis*, *rectus femoris*	Pap, 1985; Józsa et al., 1991; Charlier, 2006
Tibia	Tibial tuberosity	*Quadriceps femoris* (i., via the patella ligament): *vastus medialis, vastus intermedius, vastus lateralis, rectus femoris*	Józsa et al., 1991; Bartsiokas et al., 2015
	Soleal line	*Soleus* (o.)	Belcastro et al., 2001; Fornaciari et al., 2003; Antikas & Wynn-Antikas, 2016; Panzarino & Sublimi Saponetti, 2017
Calcaneus	Calcaneal tuberosity	*Triceps surae* (i., via the Achilles tendon): *soleus*, *gastrocnemius*; *Plantaris* (i., via the Achilles tendon)	Belcastro et al., 2001; Charlier, 2006; Bartsiokas et al., 2015 (unilateral); Khudaverdyan et al., 2016 (unilateral)

In his early contribution, Angel (1982) describes "adductor exostoses ('rider's bone')" on the skeletons of two modern cowboys, without, unfortunately, explaining their precise localization (e.g., *linea aspera* or adductor tubercle).

It should also be noted that Uerpmann et al. (2006) describe skeletal changes that are usually attributed to horse riding and associate them to the possible practice of riding camels. This is supported by the context of Post-Neolithic Arabia and, especially, by the discovery of a camel skeleton in a grave, probably associated with a human burial.

Fornaciari et al. (2007) cite a hypertrophy of the femoral *rectus* muscle, femoral biceps, great adductor, small *gluteus*, lateral *vastus,* and *gastrocnemius* without specifying which origin or insertion sites are concerned. We assume the mention of the *pectineus* and *soleus* muscles refers to the pectineal line and soleal line, respectively. Similarly, Fornaciari et al. (2014) mention a strong hypertrophy of the femoral *rectus* muscle, femoral biceps, great adductor, small, and great *gluteus* without any further precision.

Serna et al. (2015) describe in the remains of a late 19th-century individual from Argentina buried in a rich double grave the important development of the insertion zones of the adductors on both femurs — without any further detail — and put it in relation with the practice of horse riding considering the socio-historical context of the site.

Anđelinović et al. (2015) also mention the presence of "intertrochanteric enthesophytes" on the femur as being induced by horse riding, without more precision. It might refer to enthesophytes on the quadrate tubercle that is located on the intertrochanteric crest and is the insertion site of the *quadratus femoris*, which is not commonly related to horse riding in the anthropological or sports medicine literature.

Antikas and Wynn-Antikas (2016) note on the remains of an adult male from a royal Macedonian tomb that "enthesophytes and riding markers exist on the iliac crest, the neck, major trochanter and *linea aspera* of the *femori* as well as on the popliteal line of the *tibiae*" (p. 686). It is unclear what the markers or enthesophytes on the iliac crest and the neck refer to.

An observation made by Panzarino and Sublimi Saponetti (2017) is atypical. They consider that some entheseal changes on the hand phalanges could be related to guiding the horse by holding the reins, and that a superficial inflammation on a proximal phalanx could be due to the way of holding the bridles between the fingers.

Finally, Fuka (2018) analyses the association of entheseal changes on the skeletal remains of Mongolian individuals, dated from the Bronze Age, the Iron Age, and the Xiongnu period.

The entheses are analyzed by muscle groups (shoulder, elbow, wrist, hip, and knee). Even though the detail regarding which muscles are taken into account, it is not specified which enthesis related to each muscle in particular (that is to say which origin or insertion site of which bone) is included in each composite muscle group and is affected by changes. In the end, entheseal changes related to muscle groups from the shoulder, elbow, and hip, seem to be positively associated with horse riding, with patterns of asymmetry related to the riding style: "the positive associations of the muscle groups of the left shoulder, left elbow, and both hips suggest an activity pattern that is indicative of left-handed riding, the style of riding observed among present-day Mongolian riders" (p. 66).

Table 4. Summary of the morphological variants associated with horse riding in the anthropological literature

Bone	Morphological variants observed	References
Os coxal	Ovalization, vertical elongation of the acetabulum, expanded anterior-superior rim	Miller & Reinhard, 1991; Pálfi, 1992; Courtaud & Rajev, 1998; Erickson et al., 2000; Garofalo, 2004; Uerpmann et al., 2006; Fornaciari et al., 2007; Üstündağ & Deveci, 2011; Baillif-Ducros et al., 2012; Baillif-Ducros & McGlynn, 2013; Fornaciari et al., 2014; Ciurletti, 2017; Baillif-Ducros, 2018
	Rounded notch in the acetabulum (caused by hitting of the femoral head)	Anđelinović et al., 2015
	Longitudinal cuts between the sacrum and iliac bone	Anđelinović et al., 2015
Femur	Variations of the anterior aspect of the femoral head-neck junction: Poirier's facet, expansion of the femoral head onto the neck, iliac imprint, *Reiterfacette*; Plaque, iliac imprint; Allen's fossa, anterior cervical imprint, cervical fossa	Miller & Reinhard, 1991; Blänkle, 1992; Pálfi, 1992; Molleson & Hodgson, 1993; Molleson & Blondiaux, 1994; Willey, 1997; Belcastro et al., 2001; Garofalo, 2004; Langlois & Gallien, 2006; Lösch, 2009; Üstündağ & Deveci, 2011; Dutour & Buzhilova, 2014; Fornaciari et al., 2014; Novotny et al., 2014; Pulcini, 2014; Anđelinović et al., 2015; Bartsiokas et al., 2015; Khudaverdyan et al., 2016; Sarry et al., 2016; Ciurletti, 2017; Pany-Kucera & Wiltschke-Schrotta, 2017; Panzarino & Sublimi Saponetti, 2017; Baillif-Ducros, 2018
	Curved greater trochanter	Anđelinović et al., 2015
	Rotation of the lesser trochanter	Fornaciari et al., 2007 (and flattening); Pulcini, 2014 (medial); Bartsiokas et al., 2015 (medial)
	Third trochanter	Simalcsik & Simalcsik, 2013; Bartsiokas et al., 2015
Tibia	Development of the interosseous crest of the tibia (bilateral asymmetry)	Wentz & de Grummond, 2009
Tibia/Talus	Squatting facets	Willey, 1997; Sarry et al., 2016
Metatarsals	Kneeling facets	Sarry et al., 2016
Humerus	Humeral torsion (related to holding the reins or the mane of horses)	Medaglini, 2016
Other	Ossification of the sternocostal cartilage; ossification of chest and neck cartilage	Miller, 1992

It should be noted that the variations of the anterior aspect of the femoral head-neck junction include several changes that are named differently in the literature, or that are not even differentiated by some scholars, hence our choice to group them in Table 4 (Villotte & Knüsel, 2009; Radi et al., 2013). Belcastro et al. (2001) are the only ones to distinguish the presence of Allen's fossa (in addition to the "anterior iliac imprint") and to suggest that it could be related to horse riding. Anđelinović et al. (2015) mention it too, but it is unclear whether it was actually observed in their skeletal series.

Simalcsik and Simalcsik (2013) observe in several skeletons from early Bronze Age Romanian tumuli the presence of what they consider as markers of equestrian activities on the femurs: "the subtrochanterian relief (…) represented by the crest, fossa and additional femoral trochanter" (p. 10). Although it would be reasonable to think that this last trait refers to the third trochanter, a morphological variant that can be observed on the gluteal tuberosity, it is not commonly associated with horse riding, unlike they claim it. Moreover, it is also unclear what represents the "subtrochanterian fossa": the hypotrochanteric fossa, another variation that was never associated with horse riding either, or the trochanteric fossa, in which the presence of spicules was actually often associated with riding? The "crest" seems to refer to the *linea aspera*. Considering the lack of clarity, we only added this reference concerning the enthesophytes of the *linea aspera* (Table 3), which are explicitly mentioned later, but not the other features.

Ciurletti (2017) attributes, based on a study by Anđelinović et al. (2015), the presence of female traits on the pelvis to the practice of horse riding, i.e., a wide sciatic notch and marked subpubic concavity. She observes a higher frequency of these traits in male coxal bones than in females' ones, which confirms, according to her, the stress related to horse riding. These skeletal changes seem very questionable, especially as the association between female features on the pelvis and horse riding by Anđelinović et al. (2015) is only explicitly stated in the abstract of the paper, and those precise characteristics are considered as "induced by frequent riding" without any explanation. Furthermore, unlike the authors' claim, those changes had not previously been found in horse riders in the study by Wentz and de Grummond (2009). Indeed, in this study, some pelvic indices (greater sciatic notch, subpubic concavity among others) are ambiguous regarding the sex diagnosis, which is probably due to the immaturity of the skeleton according to the authors.

Table 5. Summary of extraspinal traumatic lesions associated with horse riding in the anthropological literature

Anatomical region	Traumas observed	References
Head	Nasal bone, frontal bone fracture	Khudaverdyan et al., 2016; Karstens et al., 2018 (nasal)
	Mastoid process (unilateral thickening and volume increase due to a trauma)	Panzarino & Sublimi Saponetti, 2017
	Unspecified skull fracture	Anđelinović et al., 2015
Trunk	Ribs fracture	Pálfi, 1992; Willey, 1997; Aguayo, 2012; Khudaverdyan et al., 2016; Karstens et al., 2018
Upper limb	Clavicle fracture	Pálfi, 1992; Willey, 1997; Wentz & de Grummond, 2009; Khudaverdyan et al., 2016
	Humerus fracture	Wentz & de Grummond, 2009; Dutour & Buzhilova, 2014
	Shoulder fracture/dislocation	Panzarino & Sublimi Saponetti, 2017
	Forearm fracture (radius, ulna)	Pálfi, 1992; Willey, 1997 (radius); Karstens et al., 2018 (ulna)
	Wrist fracture	Pálfi, 1992 (bilateral distal radiuses)
	Finger bones	Willey, 1997 (2nd); Dutour & Buzhilova, 2014 (5th)
	Unspecified upper extremities fractures	Reinhard & Wall, 2002 (from abstract only)
Lower limb	Avulsion of lesser trochanter of femur	Pulcini, 2014
	Cutting wound on femur inflicted with an upward movement (i.e., by an opponent on foot)	Pulcini, 2014
	Knee sprain	Langlois & Gallien, 2006
	Tibia fracture	Pálfi, 1992; Langlois & Gallien, 2006; Karstens et al., 2018
	Stress fractures (via radiographic assessment)	Reinhard & Wall, 2002
	Oblique fracture tibia-fibula	Pap, 1985
	Proximal tibiofibular synostosis	Khudaverdyan et al., 2016
	Fibula fracture	Pálfi, 1992; Langlois & Gallien, 2006; Bagagli et al., 2012; Karstens et al., 2018
	Ankle sprain (calcification of the interosseous ligament tibia-fibula)	Pálfi, 1992; Langlois & Gallien, 2006
	Calcaneal fracture	Angel, 1982
	Other tarsal bones fracture	Willey, 1997 (lateral cuneiform)
	Metatarsal fracture	Willey, 1997 (5th); Aguayo, 2012
	Foot phalange fracture	Aguayo, 2012
	Foot fractures	Pálfi, 1992

It should be noted that for most of scholars who associate the presence of traumas with the practice of horse riding, a fall from the horse is one of the main possible explanations. Regarding foot traumas, another possible direct consequence of the contact with horses is the crushed foot, when being stepped on by horses (Willey, 1997) but also very likely if the horse falls directly on the rider's foot.

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 (lower in a higher frequency), the trunk, and head, in this order.

The description made by Willey (1997) on the remains of an individual who died at the Battle of the Little Bighorn (25 June 1876) is atypical. He noted the presence of "an exostosis near the proximal articular surface of the proximal end of the right proximal row hand phalanx II, most likely a healed dislocation or torn ligament" (p. 91). Willey comments the similarity of this lesion to a "cowboy thumb", which results from the fractures related to hanging onto or gripping a saddle horn while being thrown off a horse or a mechanical bull in rodeos (Kennedy, 1989). Similarly, the paleopathological investigation performed by Dutour and Buzhilova (2014) on skeletal remains of Napoleonic soldiers of the Grande Armée (Russian Campaign of 1812), discovered in Kaliningrad, lead to suggest that the presence of healed fractures of the fifth fingers could be "due to the bridle being yanked out when curbing a horse" (p. 522). This army notably included soldiers from cavalry regiments.

We should also mention that Langlois and Gallien (2006) attribute the presence of subperiosteal hematomas on femurs and tibias as being part of the "diagnostic" for horse riding.

Finally, some authors only mention an increased frequency of traumas in their sample of presumed riders, without being more specific (Miller, 1992). Others refer to the presence of polytraumatism, an association of several fractures (clavicle, humerus, wrist, ribs, femur, tibia, fibula) as a possible consequence of horse riding (Langlois & Gallien, 2006).

In addition to the five groups of skeletal changes that we reviewed here, another type of lesions was occasionally mentioned by some scholars as being related to the stress of horse riding: periostitis on the lower limbs and, in particular, the legs. Indeed, Reinhard and Wall (2002) present periostitis of the tibiae, assessed via radiography, as a skeletal indicator of equestrian life in Omaha skeletons dating between 1780 and 1820. Langlois and Gallien (2006) note the presence of periostitis on the anterior or internal side of the femurs and tibias as part of the lesions that can be associated with horse riding. Pulcini (2014) describes, in skeletons from a Bronze Age necropolis in Verona, Italy, the presence of tibial periostitis as being due to the repetitive microtraumas that occur in horse riding. Similarly, she describes in three cases (old adults) the presence of ischial bursitis that could be attributed to horse riding for the same reason. Anđelinović et al. (2015) also attribute periostitis on the lower extremities (tibia and fibula) of medieval skeletons from Croatia to frequent horse riding. Finally, Panzarino and Sublimi Saponetti (2017) presume that the presence of periostitis on the tibia and fibula can also be associated with the frequent and repetitive microtraumas during riding.

II.D.2. Main limitations for the identification of reliable horse riding-related skeletal changes

We presented here, in the form of synthetic tables (see II.D.1 above), a quasi-exhaustive review of the anthropological literature on horse riding-related skeletal changes (HRSC). The first conclusion that can be made from this review is that even though some changes are more often cited than others, there is no consensus on a set of skeletal changes that would allow to reliably identify this activity. While the mention of the same specific marker by numerous authors can give some credibility to it, it does not demonstrate its link with horse riding when authors simply make an observation and relate it to the activity based solely on previous research (Baillif-Ducros, 2018). Besides the early studies from the beginning of the 1990s (Miller & Reinhard, 1991; Pálfi, 1992), there are, in the end, only a few that really bring a contribution to the identification of HRSC, and even less are systematic studies (e.g., Erickson et al., 2000; Garofalo, 2004; Eng, 2007; Tichnell, 2012; Baillif-Ducros, 2018; Djukic et al., 2018; Fuka, 2018).

II.D.2.a. Limitations related to the link between horse riding and the materials

The selection of a pertinent skeletal series is one of the most determinant methodological criteria for the reconstruction of activities in past populations (see I.C above). Unfortunately, there is no historical or modern reference collection of skeletons of horse riders and the selection of a pertinent sample represents, therefore, a major difficulty.

In some studies, the hypothesis of the presence of riders among the individuals relies only on the presence of skeletal changes previously discussed as being related to horse riding and is not supported by any evidence (e.g., Fornaciari et al., 2003; Langlois & Gallien, 2006; Robin, 2011; Bagagli et al., 2012; Simalcsik & Simalcsik, 2013). In others, the archaeological, historical, or ethnological context suggests that the population investigated used to practice horse riding (e.g., Bradtmiller, 1983; Snow & Fitzpatrick, 1989; Józsa et al., 1991; Miller & Reinhard, 1991; Sandness & Reinhard, 1992; Molleson & Hodgson, 1993; Blondiaux, 1994; Molleson & Blondiaux, 1994; Courtaud & Rajev, 1998; Reinhard & Wall, 2002; Garofalo, 2004; Fornaciari et al., 2007; Wentz & de Grummond, 2009; Tichnell, 2012; Dutour & Buzhilova, 2014; Serna et al., 2015; Panzarino & Sublimi Saponetti, 2017; Djukic et al., 2018; Fuka, 2018; Karstens et al., 2018). Depending on the quality of these contextual data, this may represent valuable information as the group as a whole can be considered as a riding population, which should logically lead to a higher prevalence of some HRSC compared to other presumed non-riding populations. However, such population-level contextual information still does not allow identifying which individuals, in particular, were riders and which were not, and, in that case, the influence of HRSC in the data may likely be diluted.

As discussed by Baillif-Ducros (2018), the practice of horse riding must be attested by strong evidence, such as the presence of grave goods related to riding, in order to assure the reliability of the association between the skeletal changes and the activity. A possible exception to this point concerns rare cases of well-documented historical events that can lead to a reasonable interpretation of some skeletal changes in terms of activity. For instance, the presence of healed fractures, Schmorl's nodes, squatting facets, and Poirier's facets was assumed to be related to horse riding on the remains of individuals who arguably were soldiers from the Seventh Cavalry, who fought and died at the Battle of Little Bighorn on 25, June 1876, along with Lieutenant Colonel George A. Custer, during the American Civil and Indian Wars (Willey, 1997). In the same way, the presence of modifications on the femoral neck and acetabula, and healed fractures of the long bones, were considered as a possible consequence of the practice of horse riding on skeletal remains of Napoleonic soldiers of the Grande Armée (Russian Campaign of 1812), discovered in Kaliningrad, Russia (Dutour & Buzhilova, 2014). In a rather similar way, this exception may concern well-known historical figures such as King Philip II of Macedonia, father of Alexander the Great and renowned rider, whose remains have been presumably identified and show signs of horse riding according to the authors (Bartsiokas et al., 2015). The identification of the remains of historical figures is, however, always strongly debated, and this case is no exception.

While it must not be considered as absolute evidence, only the presence of archaeological items related to equestrian activity in the grave can, therefore, represent a robust indicator that one particular individual may have been a rider. Unfortunately, only a few studies explicitly mention the existence of a direct evidence associating the individuals and the riding practice in the funerary context (Pap, 1985; Pálfi et al., 1992b; Belcastro & Facchini, 2001; Belcastro et al., 2001; Uerpmann et al., 2006; Belcastro et al., 2007; Üstündağ & Deveci, 2011; Aguayo, 2012; Baillif-Ducros et al., 2012; Baillif-Ducros & McGlynn, 2013; Khudaverdyan et al., 2016;

Sarry et al., 2016; Baillif-Ducros, 2018). Among them, even fewer concern a sample of more than just one or a handful of presumed riders based on direct evidence (Pálfi, 1992; Belcastro & Facchini, 2001; Belcastro et al., 2001; Belcastro et al., 2007; Sarry et al., 2016; Baillif-Ducros, 2018). Studies with a sample size that do not allow the observation of a repetition of skeletal changes in several individuals and to perform a statistical analysis to test their significance can still provide valuable information, but these can be considered anecdotal in nature. In that case, indeed, we must acknowledge the possibility that the presence of certain changes on presumed riders' skeletons could be a mere coincidence. In that regard, the studies led by Belcastro and collaborators particularly stand out with a sample size of 13 presumed horsemen, with riding-related deposit in their graves, thus allowing a repetition of the observations and measurements (Belcastro & Facchini, 2001; Belcastro et al., 2001; Belcastro et al., 2007). They notably identified different entheseal changes and morphological variants that could be related to this practice, with the support of the archaeological context, functional aspects, and the anthropological literature (Belcastro et al., 2001).

II.D.2.b. The lack of a comparison group

Only the analysis of comparative samples of known riders and non-riders, from the same group or similar populations, can lead to the identification of reliable skeletal changes associated with horse riding, as the most significant differences observed between them should, in that case, reflect the consequences of this specific activity (Tichnell, 2012). Ideally, the main sample and the comparison group should indeed belong to the same population and the same period (i.e., genetically and culturally similar), in order to limit the introduction of external factors that could explain the possible differences observed (e.g., inter-population variability, differences in climate and geography, differences in lifestyles). This condition is, however, difficult or even impossible to respect in practice as a collection of clearly identified riders and non-riders from the same chrono-cultural context does not seem to exist in the archaeological record. Furthermore, the absence of riding-related archaeological elements is not enough to undoubtedly confirm that a population was not practicing this activity. The only certain cases of non-riding populations are prehistoric ones who lived before the domestication of the horse and later populations from territories where the horse was absent, such as Pre-Contact Native Americans, who lived before its reintroduction on the American continent by Europeans from the end of the 15th century.

In the end, despite this, a few scholars make a valuable effort to include a comparison group of presumed non-riders in their studies. The selection of the groups compared this way can rely on differences of lifestyles: nomadic pastoralists versus agricultural populations from Mongolia and China (Eng, 2007), Pre- versus Post-Contact Arikara populations and Post-medieval British city- versus country-dwelling populations (Tichnell, 2012), or also a medieval Avar population versus a medieval agricultural population from Serbia (Djukic et al., 2018). It should be noted that Miller and collaborators (Miller & Reinhard, 1991; Miller, 1992; Reinhard et al., 1994) also perform a comparison between a group of riders and non-riders in Post-Contact Native American Omaha and Ponca populations from Nebraska, but these two activity groups are identified only on the basis of the presence or absence of skeletal changes already considered as characteristic of horse riding. The authors are not, therefore, questioning the reliability of those changes as riding indicators.

As a group of presumed non-riders, some also decide to use modern reference collections of documented skeletons, with recorded information such as the sex, age, cause of death, or occupation of each individual. Thus, Eng and collaborators (2012) compared different groups of Mongolian nomadic pastoralists dating from the Bronze Age to the Mongol period with 20th-century European-American individuals from the Hamann-Todd Osteological Collection, while Garofalo (2004) compared two British medieval series, from the 1461 Battle of Towton mass grave and a cemetery of Dominican friars and wealthy parishioners, with 19th- and 20th-century European-American and African-American individuals from the Robert J. Terry Anatomical Skeletal Collection.

Some studies rely otherwise on the distinction between females and males within the same group (e.g., Tichnell, 2012; Ciurletti, 2017), assuming that riding was mostly an activity restricted to males. Historical sources tend in fact to attest that women who were riding horses generally belonged to a certain elite, such as during the Merovingian period, as described by Gregory of Tours, and that it mostly concerned parade riding, as attested by the generalized practice of riding sidesaddle for women since the 12th century (see Baillif-Ducros, 2018). Nevertheless, in archaeological populations, the assumption that women were not riding, or less than males, often lacks arguments.

Finally, another relevant option is to compare, within the same population, individuals who are presumed riders on the basis of their grave goods (horse bones, riding equipment) with the individuals who lack such direct evidence. Although the latter ones are not necessarily considered as non-riders, the possible differences in observed skeletal changes may reflect the differences in grave deposits between the two subgroups, and thus, hypothetically reflect differences in the practice of horse riding. Even though their purpose is not precisely to identify horse riding-related skeletal changes, Belcastro & Facchini (2001) are the first to compare in an early medieval Italian series, a group of horsemen, whose identification is based on the presence of archaeological deposit in the graves of the individuals, with the group of males who did not have such riding-related deposit. This way, they compared the stature as well as several other cranial and post-cranial morphometric characteristics to discuss populational aspects. Belcastro and collaborators (2007), following a similar procedure, compared these horsemen again with the individuals from the same necropolis without riding-related deposit, and also with a Roman Imperial period series. This time, the focus was on the diet, health, and behavior of these populations. Later on, Baillif-Ducros (2018) studied five Merovingian series from northeastern Gaul, each of them including at least one individual with riding-related grave goods. Her statistical analyses of various skeletal changes notably included a comparison between the individuals with and without riding elements in the graves, although, depending on the feature and the state of preservation of the bones, the sample size for the individuals with riding equipment could be very reduced. Therefore, most of the criteria considered as promising indicators for riding (such as Poirier's facet, the ovalization of the acetabulum, joint changes at the hip, or some entheseal changes at the ischiopubic ramus) were identified from observations on all individuals from the Merovingian series of that study, and not only on the individuals with riding deposit (Baillif-Ducros, 2018).

II.D.2.c. Other methodological limitations

One of the main limitations in the study of HRSC is the lack of methodological considerations in the approach adopted by scholars. As mentioned previously, there are only a few studies with a pre-established methodology and the adoption of a systematic recording of quantitative or qualitative variables (such as presence/absence/not observable), which are determinant to allow performing statistical analyses and identifying reliable activity-related skeletal changes (e.g., Erickson et al., 2000; Garofalo, 2004; Eng, 2007; Tichnell, 2012; Baillif-Ducros, 2018; Djukic et al., 2018; Fuka, 2018). However, the variety of scoring methods and skeletal features investigated makes it difficult to compare the studies. We also noted that, in some cases, studies lack details regarding the nature and the localization of the skeletal changes mentioned (e.g., Fornaciari et al., 2007; Simalcsik & Simalcsik, 2013; Anđelinović et al., 2015; Serna et al., 2015; Antikas & Wynn-Antikas, 2016). Some authors also present a list of changes assumed to be related to horse riding without explicitly mentioning which among them they actually observed in their samples (Bagagli et al., 2012).

Other limitations that we observed in the literature concern methodological aspects that have already been mentioned regarding the field of activity reconstruction (see I.C above). While the comparison between female and male individuals from the same group can provide very valuable information related to societal organization and the sexual division of labor, sexual dimorphism can also affect different types of skeletal changes (e.g., Jurmain et al., 2012; Weiss et al., 2012; Schrader, 2019). If both females and males are included in a sample, one cannot put aside the possibility that the differences observed between them do not necessarily reflect behavioral differences. Unfortunately, some studies are not cautious enough and fail to discuss this aspect before providing any interpretation in terms of activity (e.g., Miller & Reinhard, 1991). Similarly, while it is acknowledged that older individuals are affected by higher frequencies of degenerative changes that can bias the analysis of activity-related markers (e.g., Weiss, 2003, 2004; Alves Cardoso & Henderson, 2010; Milella et al., 2012), they are almost always present in the materials. Their inclusion in study samples is often inevitable and can sometimes be seen as a necessary "evil", in order to overcome problems related to age estimation or limited sample size, but the scholars must also, in that case, take this methodological bias into account in their discussion. Moreover, as discussed previously, pathological conditions responsible for entheseal changes, like DISH and spondyloarthropathies, can interfere when interpreting skeletal changes as being activity-related (e.g., Dutour, 1992; Jurmain et al., 2012; Villotte & Knüsel, 2013). Only a small minority of studies address this matter (e.g., Pálfi, 1992), while most fail to mention how the data were handled in such situations (i.e., inclusion, partial or total exclusion). This issue also concerns, for instance, the presence of traumas that can affect the study of entheseal and joint changes, as well as metric analyses, in an individual.

Furthermore, as previously discussed, even though there are problems of transposition between the modern data from sports medicine and the activities performed in past populations, those data can still provide useful indicators of the possible lesions and changes resulting from an activity and give more credibility to, if not confirm, the association between a skeletal change and an activity (Dutour, 1992, 2000). In this aspect, only a few studies refer to clinical and sports medicine literature to support the riding hypothesis (e.g., Blondiaux, 1994; Pálfi & Dutour, 1996; Baillif-Ducros et al., 2012; Djukic, 2016; Baillif-Ducros, 2018). In our review, we observed that if some of the skeletal changes mentioned by the authors can be viewed in relation to what sports medicine describes (such as spinal changes, extraspinal traumas, entheseal changes at the attachment sites of the muscles involved in riding), it is not the case for several of them, such as the hand phalanx inflammation considered to be related to holding the reins by Panzarino and Sublimi Saponetti (2017).

Finally, another limitation that impedes the ability to reach a reliable definition of a *horse riding syndrome* is the existence of various riding styles and equipment through cultures and eras, resulting in the possibility that there may not be any universal set of skeletal changes related to horse riding. Only a very few studies mention the potential impact of the riding style on the development of skeletal changes (Eng et al., 2012; Tichnell, 2012; Eng, 2016; Baillif-Ducros, 2018), and Tichnell (2012), only, includes this question in her study: she tests the hypothesis that different riding styles use different muscles by comparing bareback, British and Mongolian styles. Her results did not allow identifying any universal set and suggest, therefore, that "culturally-specific suites of features are needed to identify activity performers in different societies (p. 137). Baillif-Ducros (2018) also suggests that one should be looking for horse riding indicators specific to a chronological period in order to identify the presence of riders in a collection.

II.D.2.d.Implications for the identification of horse riding-related skeletal changes

Those numerous limitations result in a blurred vision regarding which skeletal changes should be considered as reliable and repeatable indicators of horse riding practice. On this basis, a study with the objective of identifying reliable HRSC should therefore at least

- rely on a pertinent population with a well-documented archaeological, historical, or ethnological context that confirms the practice of horse riding;
- include an adequate-size sample of individuals from this population, ideally young and mature adults of the same sex, with direct archaeological evidence for the practice of horse riding (such as grave goods) in order to allow a repetition of the observations and comparisons, and to avoid methodological biases;
- use a precise methodology with a systematic recording of a large scale of qualitative and quantitative features for statistical analyses;
- discuss the validity of the observed skeletal changes in light of functional morphology (i.e., by referring to the riding position characteristics) and sports medicine data;
- cautiously deal with the data in case of pathological conditions that can affect the analysis of some activity-related changes (e.g., metabolic or inflammatory disorders for entheseal changes, traumatic lesions for entheseal and joint changes, and measurements); and
- include a comparison sample of known non-riders.

III. Research objectives

Our main objectives can be divided into two major aspects.

III.A. A bioanthropological contribution

Our first and major objective is to bring a methodological contribution to the field of activity-related skeletal markers by improving the identification, in anthropological collections, of one of the major activities in the past that was horse riding. Taking into consideration the limitations noted in previous studies, we performed an extensive macromorphological analysis of various types of bones changes as well as osteometric analyses using pertinent skeletal samples. We selected these skeletal changes and indicators taking into account anatomical and functional aspects, and the bioanthropological and sports medicine literature on horse riding.

We relied on a population from the Hungarian Conquest period. Historical and archaeological sources attest that powerful armies of archers mounted on horses conquered the Carpathian Basin at the end of the 9th century and the beginning of the 10th century (Engel, 2001). In many cemeteries from that period, we can frequently uncover pieces of archery and horse riding equipment, as well as horse bones, that were intentionally deposited in the graves (Révész, 2003). 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. In that respect, this population is one of the most relevant for methodological investigations of activity-related skeletal changes, especially those regarding horse riding, which have been already identified in skeletal remains of medieval Hungarians (Pap, 1985; Józsa et al., 1991; Pálfi, 1992; Pálfi & Dutour, 1996).

We followed an approach previously applied in studies about skeletal changes related to archery and horse riding in particular (Belcastro & Facchini, 2001; Belcastro et al., 2007; Thomas, 2014; Tihanyi et al., 2015), which provided promising results in an exploratory and preliminary investigation (Berthon et al., 2016b). The objective is to analyze the prevalence of the skeletal changes of various types and values of metric data according to the presence or absence of archaeological deposits related to the activity of interest in the graves. Specifically, through a comparison between two subgroups from a Hungarian Conquest period cemetery, those with and without a horse-related deposit, as well as with an out-sample group of non-riders, we test the hypothesis that the individuals associated with a funeral deposit practiced horse riding during their life and should, therefore, display skeletal changes associated with this practice.

In the end, we expect to distinguish a set of bone changes that could reliably be associated with the practice of riding a horse, thus allowing the identification of this practice in an archaeological population, even though the universality of those markers will have to be questioned.

On another note, we previously mentioned that the multifactorial etiology of the skeletal changes, and especially the entheseal changes, represents one of the main difficulties for their interpretation in terms of activity (see I.C above). As an exploratory project, we investigated the three-dimensional microarchitecture at the level of an enthesis. Using micro-CT acquisitions and 3D reconstructions of the canals of the cortical bone, we aimed to observe if microstructural variations could allow distinguishing entheseal changes related to activity and those related to other factors such as metabolic disorders. Such a distinction could contribute to improving the reconstruction of activities of past populations.

III.B. An ethnoarchaeological contribution

As a second main objective, we are also interested in ethnoarchaeological aspects, for a better understanding of the societies from the Hungarian Conquest period. The analysis of the link between the archaeological deposits in the graves and the skeletal changes may provide clarification on the significance of the funerary practices, and, in particular, on the extent of the symbolic value of the horse-related deposits. In fact, if the presence of such deposit in the grave does not represent indisputable evidence — but a sufficient one — for the practice of riding during life, its absence does not necessarily mean either that an individual was not a rider.

Finally, this doctoral research will be expanded to other collections from the Hungarian Conquest period, and the data acquired in this doctoral research will pave the way for further studies focusing, in particular, on females and adolescents, always taking into consideration the archaeological deposits. The information that will be provided by such research on the individuals will give an opportunity to shed light upon the organization of the societies from the Hungarian Conquest period.

IV. The Hungarian Conquest period: historical and archaeological context

IV.A. Historical context

According to historical sources, the Hungarians, or Magyars, arrived in the Carpathian Basin as an alliance of seven tribes led by prince Árpád at the end of the 9th century (Róna-Tas, 1999; Engel, 2001). Under the pressure of other nomadic populations from the east, they arrived from the Pontic steppes, where they were previously settled. The question of their origin remains, however, a debated discussion (Türk, 2014; Neparáczki et al., 2018).

There is no contemporary Hungarian account of their arrival, so this event was mostly described by written sources produced by external cultures, or by Hungarian sources from later periods (13-14th centuries) (Tóth, 2015). It is believed that the Hungarians started to occupy some territories in the Carpathian Basin as early as 894 following military interventions that involved the Byzantines, Franks, Moravians, and Bulgarians. It would, however, be in 895 or 896 that attacks from the Pechenegs and Bulgarians led the Hungarians to definitely leave their lands between the Don and the Danube for the Carpathian Basin (Róna-Tas, 1999). In the very few years that followed, Hungarians progressively took control of the entire region, while conducting raids into Christian kingdoms in the north and the west, as well as against the Muslims in the Iberian Peninsula, and the Byzantines in the east (Engel, 2001). These raids led the Hungarians as far as Saxony and the city of Bremen, the Atlantic coasts of France and Spain through Reims, Burgundy, the Pyrenees, and Catalonia, the Southern tip of Italy through Rome, and the Byzantine city of Constantinople. The Hungarian conquerors were unanimously described by other cultures (e.g., Muslims, Byzantines, Western Christians) as nomadic horse riders, with warriors using notably a saber, spear, and bow from horseback (Róna-Tas, 1999; Engel, 2001) (Figure 3). Their use of long-distance shooting, surprise, and their incredible speed of action due to their nomadic fighting style represented a great advantage when facing heavier types of military forces, that were more common in Western territories, especially (Engel, 2001; Sandler, 2002) (Figure 4).

It is only the overwhelming defeat at the Battle of Lechfeld against the German forces of King Otto I in August 955 that marked the end of the campaigns of the Hungarians, although raids to the Byzantine Empire continued until 970 (Engel, 2001). In 972, prince Géza, a great-grandson of Árpád, was the leader of the Hungarians, and he tried to maintain peaceful relations with the neighbor powers, and especially with the Holy Roman Empire, paving the way to the substitution of the pagan beliefs of the Hungarian societies by the adoption of Christianity (Engel, 2001; Marcsik et al., 2002).

Finally, the Christian kingdom of Hungary was founded in the year 1000 or 1001, when Stephen I (later known as Saint Stephen), son of Géza, was crowned king. The kingdom of Hungary remained one of the greatest powers of Europe during at least the next 500 years, until the Ottoman conquest in the 16th century (Engel, 2001).

Figure 3. 3D model of an elite Hungarian mounted archer from the cemetery of Karos-Eperjesszög III (grave 11). Made by Pazirik Informatikai Kft for the exhibition „Elit alakulat" of the Herman Ottó Museum (Miskolc, Hungary). From http://elitalakulat.hu

Figure 4. Reconstruction of the fighting style of the mounted archers from the Hungarian Conquest period (László, 1982)

We should mention that the term "Conquest period" and "conquerors" literally describe the time and populations of the conquest of the Carpathian Basin itself, generally acknowledged to have started in 895, and have ended in 907, with the Battle of Pressburg (Langó, 2005). However, these terms are usually associated, in archaeology, to a 100-120 year-long period of time, starting with the conquest and ending with the consolidation of the Christian kingdom of Hungary, hence mostly covering the 10th century and its populations (Langó, 2005). This is the meaning that we will use in the rest of this dissertation. Similarly, we use the term "Hungarian" referring to the populations of the 10th-century Carpathian Basin, and not necessarily to the ethnic identity of the individuals in the cemeteries, which may include a mixture of conqueror and autochthonous populations (Langó, 2005).

IV.B. The cemeteries and populations from the Conquest period: archaeological context

Written sources mention that after settling in the Carpathian Basin in the years following the conquest, the tribal alliance formed an independent state that controlled the Basin and its surrounding areas through military force. The local populations were not eradicated but seem to have been integrated, resulting in the emergence of a new and coherent material culture, that differed from the preceding periods (Langó, 2005).

Even though the archaeological investigations of settlement sites are of great importance to provide information on the societies from the Conquest period (Visy, 2003), the main archaeological sources of the period are provided by the numerous cemeteries that were excavated across the Carpathian Basin (Révész, 2003). Around 30 000 burials have been excavated from cemeteries that were mostly in use from the time after the conquest until the 11th or even 12th century (Langó, 2005). The archaeological goods found in the graves in association with the individuals are still used to identify different levels of social status (Révész, 2014). The presence of elements of saber, axe, quiver, composite bow, and arrowheads may, for instance, be linked to warriors (Figure 5), while notable or distinguished individuals (males or females) may have been buried with rich costume and braid ornaments, jewelry, belt sets, or, in some cases, an ornated sabretache (Figure 6 and 7a). Weapons and riding elements (e.g., plates and mounts of saddle, bits, harnesses, stirrups) could also be richly ornamented (Engel, 2001; Révész, 2003) (Figure 8). Some are also buried with horses or with artifacts symbolizing the animal (Engel, 2001) (Figure 7b). Horses were killed and skinned in such a manner that the skull and leg bones were left in the hide, which was usually folded or spread out beside the deceased (Figure 5). This practice of partial horse burials was observed in several Conquest period cemeteries (Révész, 2003; Langó et al., 2011; Vörös, 2013). Examples of particularly rich cemeteries are notably provided by the three cemeteries of Karos, in northeastern Hungary, located between the Tisza and Bodrog rivers (Révész, 1996a, 2003) (Figure 5 and 6). The cemeteries from the Conquest period are also characterized by the presence of graves without warrior and horse riding attributes, or rich goods. This variety of archaeological material discovered in cemeteries is due to different social, regional, populational, and chronological factors (Révész, 2003; Langó, 2005; Révész, 2014).

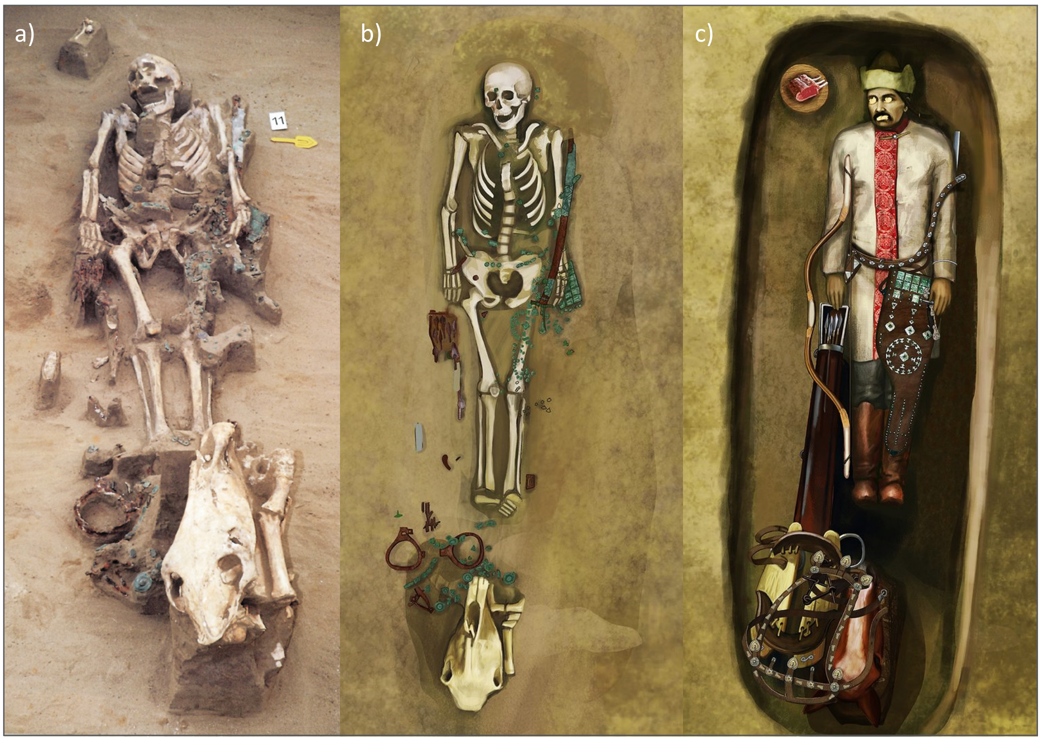

Figure 5. Example of the grave 11 from the Hungarian Conquest period cemetery of Karos-Eperjesszög: a) picture of the grave (Révész, 1999); and b, c) reconstruction of the burial made by Pazirik Informatikai Kft for the exhibition „Elit alakulat" of the Herman Ottó Museum (Miskolc, Hungary). From http://elitalakulat.hu

Figure 6. Example of the grave 47 from the Hungarian Conquest period cemetery of Karos-Eperjesszög II, with rich jewelry and cloth ornament set: a) reconstruction of the grave (Révész, 1999); b) set of jewelry and cloth ornaments (Révész, 1999); and c) gilded silver braid ornament with a mythical animal-like figure (Révész, 1996a)

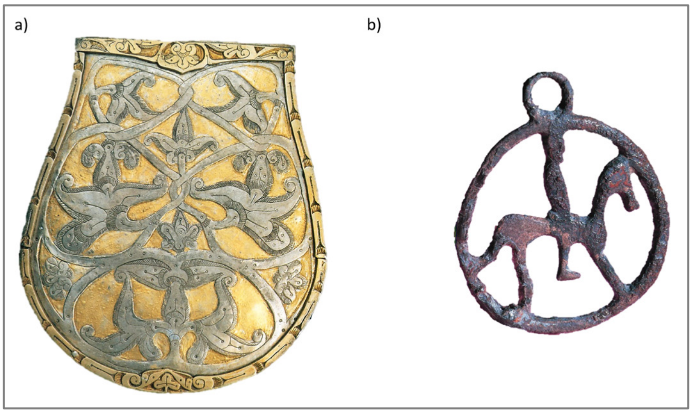

Figure 7. Examples of elements that are found as grave deposits in cemeteries from the Hungarian Conquest period: a) gilded silver sabretache from Karos-Eperjesszög II (Révész, 1996); and b) bronze pendant depicting a horse rider (Nepper, 1996)

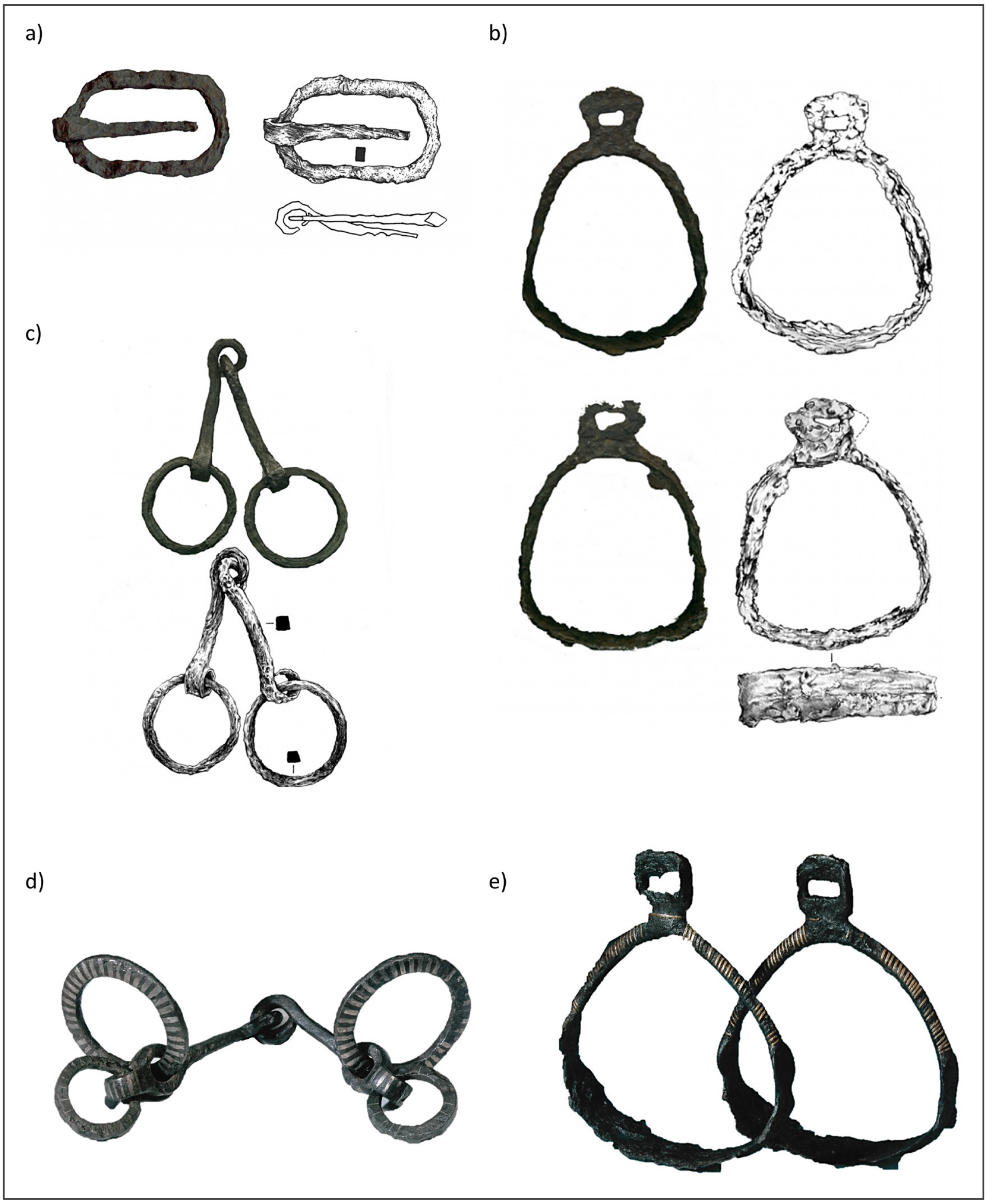

Figure 8. Examples of horse riding-related equipment found as grave deposits in cemeteries from the Hungarian Conquest period: a) picture and drawing of a girth buckle from Tiszabercel-Diófa-lapos, I. (http://corpus.josamuzeum.hu); b) pictures and drawings of the most common type of stirrups, from Ibrány-Esbóhalom, 199 (http://corpus.josamuzeum.hu); c) picture and drawing of the most common type of bit, from Ibrány-Esbóhalom (http://corpus.josamuzeum.hu); d) bit with silver ornaments from Muszka (Révész, 1999); and e) stirrups with silver ornaments from Muszka (Révész, 1999)

CHAPTER 2. MATERIALS & METHODS

I. Sárrétudvari-Hízóföld: A unique cemetery from the Hungarian Conquest period

I.A. Presentation of the cemetery and the collection

Figure 9. Location of the cemetery of Sárrétudvari-Hízóföld, in Hungary

Sárrétudvari is a village located in the Northern Great Plain region of eastern Hungary, about 50 km southwest of the city of Debrecen (Figure 9). The cemetery of Sárrétudvari-Hízóföld was excavated by Ibolya M. Nepper between 1983 and 1985. The graves delivered a large number of archaeological goods, such as jewels, elements of clothing or weapons (Nepper, 2002). These included, in particular, pieces of archery equipment (antler bow plates, quivers, arrowheads) and horse riding equipment (stirrups, bits, girth buckles, saddles; Figure 10). Several graves also contained horse bones (skull and extremities), that were, in some cases, folded inside the horsehide before being deposited in association with the individuals (Figure 11). Based on the grave goods, the period of use of the cemetery was estimated to be during the 10th century CE.

In Sárrétudvari-Hízóföld, 262 graves from that period provided a total of 265 individuals that were previously examined by Oláh (1990) and Pálfi (1992, 1997; Pálfi & Dutour, 1996). According to these studies, the population is composed of 101 subadults, under the age of 20 (including 3 fetuses), 162 adults and 2 indeterminate individuals. A comprehensive paleopathological analysis had been carried out on the entire series, providing valuable results regarding the infectious diseases and the activity-related skeletal markers in particular (Pálfi & Dutour, 1996; Pálfi, 1997).

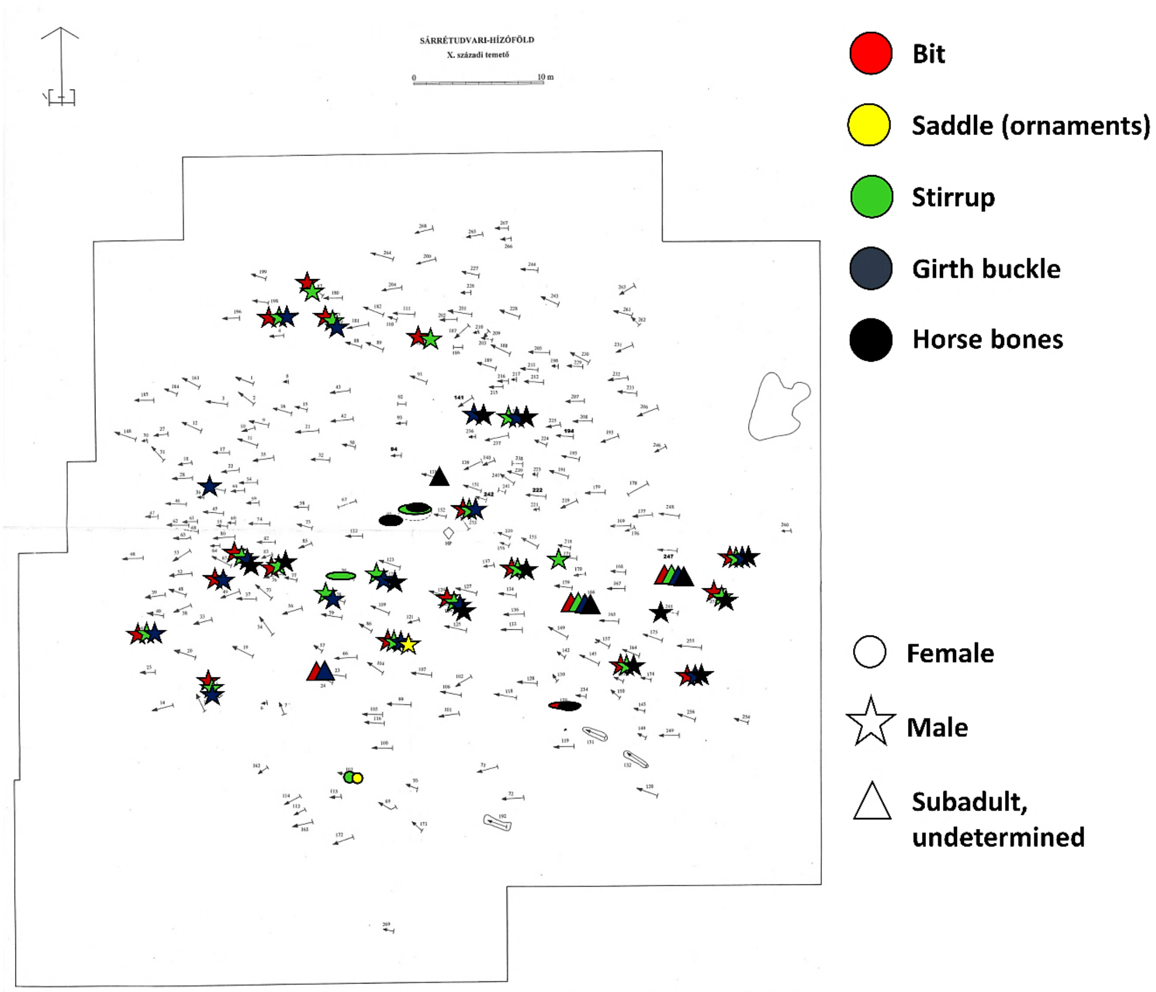

Figure 10. Map of the cemetery of Sárrétudvari-Hízóföld showing the distribution of graves with horse riding equipment or horse bones (Nepper, 2002, modified by Balázs Tihanyi)

Sárrétudvari-Hízóföld was selected as our main Hungarian collection among several other cases from the period for the following reasons: a) it was exhaustively excavated, well documented and published; b) it is one cemetery with the largest amount of archaeological remains that can be related to the practice of the mounted archers; c) the size of the population (see above); d) the state of preservation of the skeletons (between medium and good) was better than other samples from the 10th century; and, e) it is a series in which were originally identified the signs of a “Horse Riding Syndrome” in several individuals (Pálfi, 1992; Pálfi & Dutour, 1996; Pálfi, 1997). Furthermore, the human skeletons from Sárrétudvari-Hízóföld are readily available for research, hosted in the anthropological collection of the Department of Biological Anthropology of the University of Szeged, Hungary, one of the largest in Europe (Pap & Pálfi, 2011).

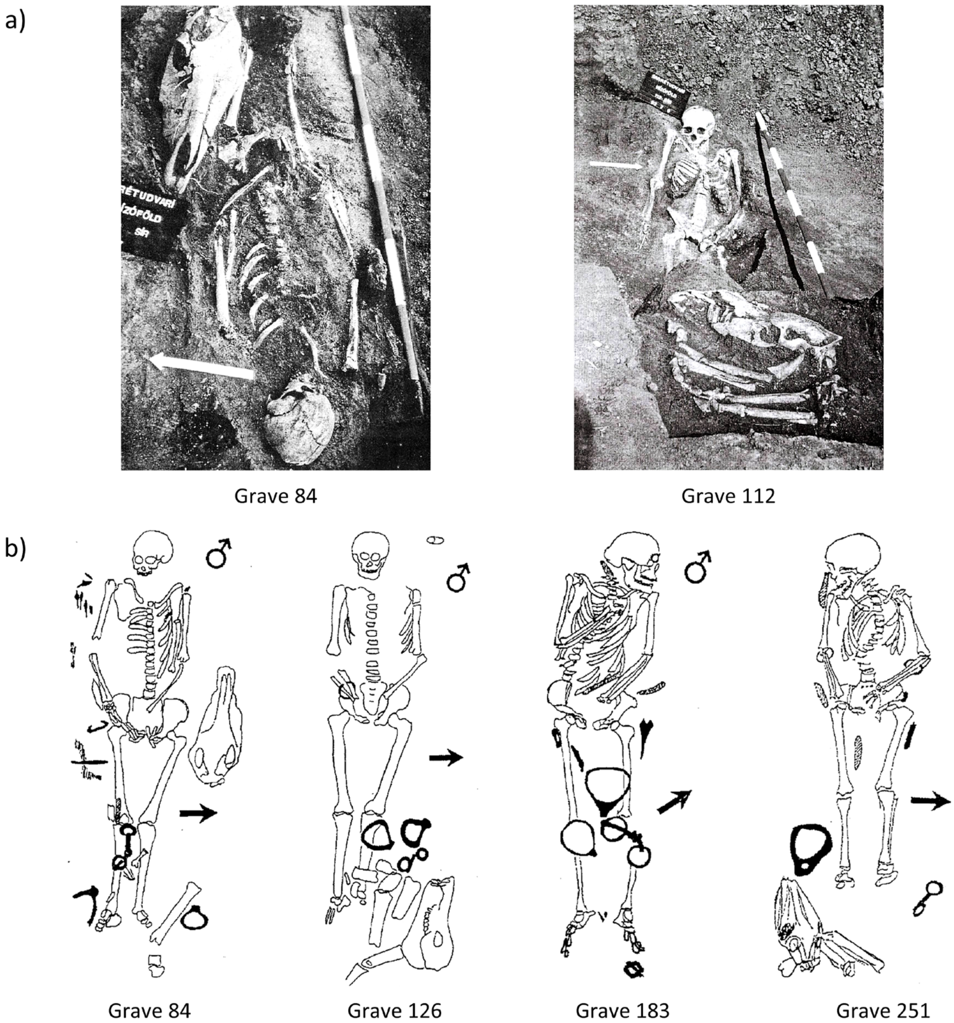

Figure 11. Examples of graves from the Hungarian Conquest period cemetery of Sárrétudvari-Hízóföld (10th century) with deposits of horse riding equipment (stirrups, girth buckles, and bits), sometimes associated with horse bones: a) field photographs (Nepper, 2002); and b) archaeological drawings of graves (Nepper, 2002)

I.B. Selection of the samples from the Hungarian Conquest period

I.B.1. Methodological considerations

Keeping in mind the numerous limitations mentioned by the scholars for the reconstruction of activities (e.g., Dutour, 1992; Jurmain et al., 2012), we included in this study only adult males. Sex is indeed an important factor that can influence how the bone adapts in response to activity. The differences observed between a group of females and a group of males might be due, for instance, to sexual dimorphism in body size and hormonal changes during puberty (Wilczak, 1998; Niinimäki, 2012a; Weiss et al., 2012). Furthermore, adolescents (even late ones) might present various traits related to developmental changes that could bias the comparisons. The decision of strictly focusing on adult males only results in samples of smaller sizes, but, in the frame of the methodological aspect of this research, it is a solution to limit the influence of non-mechanical factors in the results.

I.B.2. Reassessment of the sex of the individuals

We decided to reassess the sex that was previously determined, using more recent, reliable and accurate methodology. The coxal bone is the most relevant one for sex determination because of its marked sexual dimorphism resulting mainly from adaptive and functional constraints related to locomotion and childbearing. Furthermore, this sexual dimorphism is non-specific for populations, unlike other ones (Bruzek et al., 2005; Murail et al., 2005). We applied in a complementary way the Probabilistic Sex Diagnosis, or DSP, recently revalidated as DSP2 (Murail et al., 2005; Bruzek et al., 2017) and the macromorphological visual method developed by Bruzek (2002). Sex determination with these methods yields an accuracy rate close to 100 % and 98 %, respectively, in their reference samples. The first one, the DSP, is a metric method that relies on a combination of four to ten variables measured on the coxal bone, depending on its preservation. It has the great advantage of being based on a worldwide reference sample composed of more than 2000 individuals of known sex from 12 populations. The posterior probability of being female or male is calculated based on the linear discriminant analysis, and 0.95 is used as the threshold for sex classification, under which sex was not assigned (Bruzek et al., 2017). The second method involves the precise visual scoring on the coxal bone of five morphological features (with three subcriteria for three of them), possible even on fragmentary bones. The binary scoring (present/absent), along with an intermediate category, limits subjectivity compared to more classical ordinal scales of evaluation. Sex assessment follows the majority rule, with a reliability of 95 % (Bruzek, 2002).

Following these methods, we were able to reliably determine the sex of 121 individuals, including 7 subadults who were mature enough to perform a sex diagnosis. They included 52 females and 69 males.

The sex diagnosis that we performed, based on the complementary use of a macromorphological visual method and a metric probabilistic method, can be considered as strongly reliable (Bruzek, 2002; Murail et al., 2005; Bruzek et al. 2017), but several individuals remained indeterminate, mostly because of a poor preservation of the coxal bones. As an attempt to increase the number of adult male individuals in our sample, we had the opportunity to benefit from the results of a genetic analysis performed on several individuals from the cemetery of Sárrétudvari-Hízóföld by the members of the Department of Genetics of the University of Szeged, Dr. Tibor Török and Dr. Endre Neparáczki. This analysis notably aimed at a better understanding of the origins of the Hungarian Conquerors (e.g., Neparáczki et al., 2017; Neparáczki et al., 2018). Those data concerned 25 individuals from the cemetery, for which the sex diagnosis methods had been applied, as well as 10 subadults for which the sex could not be determined from a macroscopic analysis of the bones as they were too young. Regarding 22 individuals, we were able to determine the sex during our examination of the coxal bones and the genetic data confirmed our sex diagnosis in all cases (100%; 17 males and 5 females). The remaining three individuals had been considered as indeterminate adults as sex determination was not possible during our study due to a limited preservation or the absence of coxal bones. With the help of genetic data, these three individuals were proved to be females. Thus, we were not able to identify more male individuals to be included in our samples. However, the perfect correlation between the sex determined during our macroscopic analysis of the coxal bones and the sex identified via genetics confirms the reliability of the sex diagnosis methods that were used. This way, we can conclude that our selection of a male sample in the archaeological samples confidently excludes or strongly limits possible biases related to sex differences.

I.B.3. Reassessment of the age-at-death of the individuals

Age-at-death was also reassessed with more recent and reliable methodology. Bearing in mind the important variations regarding the maturation age of the skeleton (Scheuer & Black, 2004), the distinction between the adult individuals (considered to be 20 years of age or over) and the subadults was based on the following chosen criteria: the achieved maturation of the long bones (apart from the sternal extremity of the clavicle, as in the case of the iliac crest on the coxal bone), and the complete fusion of the epiphyseal rings of the vertebrae and the spheno-occipital synchondrosis (Bruzek et al., 2005). Following these criteria, two out of the 69 male individuals were considered as subadults (late adolescents) and were therefore excluded from the sample for the analyses.

We attempted then to split the adults into age categories, to distinguish, especially, the young and mature adult individuals (YMA), between 20 and 49 years of age, and the older adult ones, above 50 years of age. This distinction is determinant for the analysis of the entheseal changes and joint changes in particular, as they are strongly influenced by age (see Chapter 1, I.C).

As a first step, the absence of fusion or the incomplete fusion of either the iliac crest of the coxal bone or the medial extremity of the clavicle, or both, was used for the identification of young adults, who died between 20 and 29 years of age, specifically (Owings-Webb & Suchey, 1985; Kreitner et al., 1998; Coqueugniot & Weaver, 2007; Schaefer et al., 2009) (Appendix 8).

As a second step, we relied on the changes at the sacropelvic surface of the ilium following the method proposed by Schmitt (2005), which is different from the more classically used one proposed by Lovejoy et al. (1985). It is based on a simple scoring system of four independent features (transverse organization, modification of the articular surface, apical modification, and modification of iliac tuberosity) that aims to limit the intra- and interobservers error. It relies on a large reference sample ($N = 621$), and the probability of belonging to a chronological interval depends on the combination of the scores of the four features and is calculated through the Bayesian approach, with a minimum overall probability of 80%. When the two sides were fully observable and provided a different estimation, both chronological intervals were combined to obtain a reliable but larger estimation. When one of the four criteria was not observable, the chronological intervals obtained for each of the possible combinations of scores were also combined. When three features only could be observed on one side while the other side was fully observable (i.e., all four features), the results obtained from the latter one were preferred. This method results in reliable age estimation, although not very precise, with, in many cases, large chronological intervals (Schmitt, 2005; Baccino & Schmitt, 2006). Furthermore, poor preservation of the coxal bones may also greatly limit the results of the age estimation. It was thus common in our study that the resulting chronological intervals did not allow precisely categorizing the subjects. Instead, several individuals could only be identified as mature or old adults, above 30 years of age, while others could only be considered as indeterminate adults, who died above 20 years of age. In the end, 37 out of the 67 adult males could be categorized as young and mature adults (Appendix 8).

I.B.4. Composition of the samples of early Hungarians based on the archaeological deposits

In Sárrétudvari-Hízóföld, 32 graves presented an archaeological deposit that we can assume to be related to horse riding — either equipment or horse bones, or both. Based on the reassessed sex and age-at-death of the individuals, as explained above, there are at least 17 adult males within this group (RD = “Riding Deposit”) (Appendix 1, 2). The other individuals, which were not included in the study, are 1 female adult, 6 adults of indeterminate sex (one was not available during the study), 7 subadults and 1 unidentified individual (either a subadult or an adult).

In contrast, 50 individuals identified as adult males did not have any equipment related to horse riding or horse bones in their graves (NRD = "no Riding Deposit").

The results of the sex diagnosis performed on the 67 individuals from the RD and NRD groups are given in Appendix 5, 6, and 7.

The age estimation allowed categorizing the individuals in each group, as summarized in Table 6 (for details on the results, see Appendix 8). A separate analysis of the entheseal changes and joint changes will include only the young adults, and young or mature adults (see III.C.2 below).

Table 6. Summary of the results of the age estimation in the Hungarian archaeological groups with (RD) and without riding deposit (NRD), based on the changes at the sacropelvic surface of the ilium (Schmitt, 2005)

Categories based on the age estimation [age interval]	Number of individuals in the RD group	Number of individuals in the NRD group
Young Adults [20-29]	3	3
Young or Mature Adults [20-49]	4	27
Mature Adults [30-49]	0	0
Mature or Old Adults [≥ 30]	6	13
Old Adults [≥ 50]	0	2
Indeterminate Adults [≥ 20]	4	5
Total	17	50

II. Out-sample comparison: the documented collection of Lisbon

II.A. Why a comparative sample?

Even if the archaeological data are determinant for the association between the skeletal markers and the activities, some limitations must be kept in mind. In our case, the sample of individuals from the Conquest period is divided into two sub-samples based on the presence or absence of deposit related to horse in the graves of the individuals, the hypothesis being that the ones without deposit (NRD) may not have practiced horse riding, or maybe to a lesser extent than the others (RD). However, caution is recommended as we must consider the possibility that the funerary deposits might have only a symbolic function and not be related with the actual practice of riding during the life of individuals. Therefore, the distinction between the two groups might not reflect the reality of the presence or absence of horse riders. Furthermore, all elements originally deposited in the graves might not have been preserved (e.g., taphonomic processes, disappearance of organic materials, lootings). Thus, it must be acknowledged that some individuals who initially had a deposit in their grave may have finally been included in the NRD group. For these reasons, a third group, with a clear and reliable context, is determinant to allow multiple comparisons that could clarify our understanding concerning both the methodological and the ethnoarchaeological aspects.

II.B. Selection of a collection

We selected an extra-group for which the intensive and regular practice of horse riding was highly improbable. It allowed first to compare each group in the Hungarian collection with this extra-group of non-riders, to observe the similarities or the differences between them, and it also allowed, secondly, to compare the early Hungarians as one group with the extra-group non-riders. As explained previously, if the distinction between the two sub-groups of Hungarians would not reflect the reality of the presence and absence of riders among them, it is however logical to expect that the semi-nomadic population of Hungarians as a whole should present more skeletal changes related to horse riding than the extra-group of non-riders.

In order to limit biases related to interpopulational variations, the most appropriate population for this comparison study would certainly be a medieval Hungarian one with the evident absence of the practice of horse riding. However, such population might simply not exist as the use of horses was very widespread in medieval Hungary. One viable option would have been to study prehistoric samples, preceding the domestication of the horse. This choice would have required to select samples from various collections in order to reach a satisfying number of individuals and would have, therefore, resulted in a non-homogenous sample. Furthermore, the preservation of such prehistoric skeletal remains, usually being rather poor, would have strongly limited the observations.

Among the limited possibilities remaining available for our purpose, we chose to use a European documented skeletal collection, with a known socio-cultural context. Due to the valuable data associated with the individuals, such documented or identified skeletal collections have been used for numerous methodological studies regarding especially the estimation of the age at death, sex determination, diseases, and the activities (e.g., Coqueugniot & Weaver, 2007; Perréard Lopreno, 2007; Alves Cardoso, 2008; Coqueugniot et al., 2010b; Villotte et al., 2010; Niinimäki, 2011; Alves Cardoso & Henderson, 2013; Milella et al., 2015; Bruzek et al., 2017). Bearing in mind the potential limits that this involves concerning inter-populational variability, in particular, we believed it still represents a valid alternative that can provide input to the discussion on the link between bone changes and horse riding.

II.C. The documented collection of Lisbon

II.C.1. Presentation of the collection

We used the Luís Lopes Skeletal Collection, curated in the National Museum of Natural History and Science (MUHNAC), in Lisbon. It is composed of 1692 skeletons with information regarding, among others, the sex, age at death, cause of death, and the occupation of the individuals (Cardoso, 2006; Alves Cardoso & Henderson, 2013). They were mostly Portuguese people who lived in Lisbon and who were born and had died between 1805 and 1975. The majority of the individuals in our sample mainly lived during the first half of the 20th century (average year of birth = 1900; average year of death = 1940), in an important urban area, with electricity and modern means of transport. This fact makes it very unlikely that they were practicing horse riding in an intensive way and on a daily basis, as was the case for our semi-nomadic Hungarians. They are therefore assumed to be a non-riding population.

II.C.2. Selection of the sample

To be consistent with the selection performed in the Hungarian collection, we included in this study only skeletons with a completed bone maturation, apart from the iliac crest and the sternal extremity of the clavicle, which still might be in a state of incomplete fusion. These are, indeed, usually among the last epiphyses to fully achieve their maturation, which can occur until the age of about 25 for the iliac crest and 29 or more for the medial clavicle (e.g., Bruzek et al., 2005; Coqueugniot & Weaver, 2007; Schaefer et al., 2009).

Among the available adult males, we selected only individuals whose occupation was known, and we attempted to select among them mostly individuals who can be considered as having been generally physically "active" and to exclude those who presumably had a rather limited level of physical activity during their life (e.g., office worker, student, etc.) (Appendix 3). A comparison between the semi-nomadic Hungarians, known to have participated in many conflicts during the Conquest period, and a modern sample of individuals with a minimum of physical activity would probably result in very weak information regarding the influence of horse riding on the bones. Indeed, the presence of various non-specific changes might simply reveal that the Hungarians had more physical activity than the individuals from the modern sample.

While the occupation title is not an absolute evidence of what precise gestures the individuals performed on a daily basis, it still represents a rather good indicator of the fact that people had more or fewer chances to have had a rather high or low level of physical activity during their life. However, we stress that we did not attend to perform a precise categorization of the occupations, based, for instance, on criteria such as the preferential use of the muscles of the upper or lower limbs, the intensity, the repeatability of the gestures, or the specialization. One reason was that the comparison sample needed to be used not only in the frame of this study concerning horse riding but also for a parallel investigation of archery-related markers, which focuses mostly on the upper limb and raises different questions. Furthermore, a distinction between the occupations following such criteria as mentioned above would have resulted in too little sample sizes. Finally, the information that is available is the occupation at the time of death, but we ignore, in most cases, the conditions in which the individuals were living as children, for how long they had that occupation, or if they changed it during their life. It has been demonstrated that the categorization of occupation can represent a source of bias for the study of activities (Alves Cardoso & Henderson, 2013; Perréard Lopreno et al., 2013).

Following those methodological considerations, we selected in the collection a sample composed of 47 adult males, aged 20 and older. The state of preservation of the bones was between good and excellent.

Again, to be consistent with the selection performed in the Hungarian collection, the age estimation method (see I.B.3 above) was also performed on the individuals from the documented collection of Lisbon (Table 7), and the results were compared with the known age-at-death (Table 8). It has to be noted that for the age estimation in the documented collection, we used the table of distribution of the posterior probabilities computed from a reference population whose age distribution is uniform, while we used the table of distribution of the posterior probabilities computed from a reference population whose age distribution corresponds to a life expectancy at birth of 30 years in the case of the archaeological samples (Schmitt, 2005). This was because the selection of the sample from the documented collection was based on specific criteria (sex, age, occupation), and is, therefore, not supposed to represent a natural population. In particular, there was no individual above 56 years of age in our selected sample.

Table 7. Summary of the results of the age estimation in the comparison group from Lisbon (LIS), based on the changes at the sacropelvic surface of the ilium (Schmitt, 2005)

Categories based on the age estimation [age interval]	Number of individuals in the LIS group
Young Adults [20-29]	4
Young or Mature Adults [20-49]	10
Mature Adults [30-49]	0
Mature or Old Adults [≥ 30]	28
Old Adults [≥ 50]	2
Indeterminate Adults [≥ 20]	3
Total	47

Table 8. Comparison between the estimated age based on the changes at the sacropelvic surface of the ilium (Schmitt, 2005) and the known age in the documented collection of Lisbon

Estimated age	Known age	Estimated age	Known age
20-29	20	30-59	46
20-49	20	30-59	47
20-29	21	30-59	47
20-29	27	30-59	47
20-39	28	30-59	47
20-29*	30	20-59	48
20-49	30	>40	48
20-49	31	30-59	49
20-39	31	>50	50
20-39	32	>40	50
30-59	33	30-59	50
>40*	35	20-49*	50
20-49	37	20-59	51
30-59	37	30-59	51
30-59	38	30-59	52
20-59	38	30-59	52
30-59	39	>40	53
20-49	39	30-59	53
20-49	40	30-59	53
30-59	40	30-59	53
30-59	43	>50	54
>40	43	30-59	54
30-59	45	30-59	56
30-59	45		

* indicates that the known age is not included within the estimated age interval

Out of a total of 47 individuals, the known age was included within the estimated age interval for 44 of them (93,6%). It can furthermore be noted that, regarding the remaining three, one was estimated to be more than 40 years of age while the known age was 35, while the age of the two others was just one year above the limit of the estimated interval (30 instead of 20-29 years, and 50 instead of 20-49 years of age). We can, therefore, consider that the age estimation based on the changes at the sacropelvic surface of the ilium (Schmitt, 2005) was reliable in the documented sample.

Based on that observation, we decided not to use the estimated age but the known age in the documented collection for the selection of a group of young and mature adults to be compared with the young and mature adults identified in the archaeological groups. The sample size of the comparative group was, this way, larger for the analysis of entheseal and joint changes (i.e., 32 young and mature adults, identified with the known age, instead of 13 young and young or mature adults identified on the basis of the age estimation).

III. Methods for the study of horse riding-related skeletal changes

III.A. Macromorphological analyses

III.A.1. Entheseal changes

Many entheseal changes (EC) of the lower limb were associated with the practice of horse riding in anthropological literature (see Chapter 1, II.D.1). We previously discussed how EC are used as activity-related skeletal changes and their limitations, including the heterogeneity of the scoring methods (see Chapter 1, I.B and I.C). Considering that recent studies revealed that the correlation between EC and activity was not straightforward, and especially, that currently proposed scoring methods seem to be not efficient enough to reflect activity (e.g., Niinimäki & Baiges Sotos, 2013; Djukic et al., 2015; Michopoulou et al., 2015; Michopoulou et al., 2017), we applied a simple binary scoring method. We relied on the widely used method proposed by Villotte (2006, 2008), which was later simplified from a three-grade scale to a binary scoring method, with minor and major changes combined into a "present" score (Villotte et al., 2010). This simplification has also been recommended and applied by others (Alves Cardoso & Henderson, 2010; Ponce, 2010; Niinimäki & Baiges Sotos, 2013). It notably contributes to decrease subjectivity and thus to increase inter- and intraobserver agreement and facilitate comparisons. More detailed scoring methods, such as the new Coimbra method (Henderson et al., 2017b) propose a precise scoring of different features with the division of the enthesis into two zones, the margin, and surface. This distinction requires, however, precise knowledge regarding the anatomy of the entheses and the authors provide, so far, description for only a few of them. In addition, this method focuses only on fibrocartilaginous entheses, while a simple binary scoring can allow using fibrocartilaginous and fibrous entheses in the same analysis (Niinimäki & Baiges Sotos, 2013).

As mentioned previously (see Chapter 1, I.C), it was suggested that EC at fibrocartilaginous entheses provide more reliable results as they are more correlated with activity than those at fibrous entheses, for which the normal aspect and limits are less well understood (e.g., Villotte & Knüsel, 2013). Our investigation of horse riding-related skeletal changes notably aims to confirm if the skeletal changes mentioned in literature for several decades can be considered as reliable indicators for the practice of horse riding. It appears that several entheses that are referred to be part of the "horse riding syndrome" are fibrous entheses located on the diaphysis of the femur and tibia, in particular (see Chapter 1, II.D.1). These entheses are origin and insertion sites of muscles that are important in the practice of horse riding (Willson, 2013), and they were also used in recent studies focusing on horse riders (Djukic et al., 2018). Besides, a study by Niinimäki and Baiges Sotos (2013) provides an example where both types of entheses were included, and this factor did not have any influence on the results. In that regard, we included both fibrocartilaginous and fibrous entheses in our analysis of EC.

The function of the muscles attached to the entheses was the first criterion for their selection. We included indeed only entheses related to muscles that cover a wide range of movements involved in the position of the rider, contributing to control, coordination, and stabilization (Willson, 2013; McGrath, 2015). The second criterion for the selection of entheses was, as mentioned above, their repeated mention in the anthropological literature as markers related to horse riding, in order to confirm or invalidate their pertinence in this respect. In addition, for more reliability, we mainly focused on entheses that were frequently mentioned, described, and scored in the literature on EC, and especially in methodological studies. This led, for instance, to the exclusion of several entheses located on the coxal bone. Entheses for which scoring appeared to problematic (due to a difficulty to distinguish normal and changed aspects, for instance), were also avoided. It was the case of the origin sites of the medial and lateral heads of the gastrocnemius muscle.

In the end, we selected 13 entheses, including nine fibrocartilaginous and four fibrous ones (Table 9). Twelve of them were repeatedly mentioned in the "horse riding syndrome" literature, and most of those were frequently used and described in the literature on EC. The origin site of the straight head of the *rectus femoris* at the anterior inferior iliac spine (COX E1) was also included considering the function played by this muscle (hip flexion, knee extension), and the fact that there is no other muscle attached to this site, allowing to discuss more precisely the relation between the EC and the movements allowed by the muscle related to the enthesis. In addition, it is a fibrocartilaginous enthesis (Dragoni & Bernetti, 2016). The changes at the insertion site of the *obturator externus* and *obturator internus*, in the trochanteric fossa, are rarely scored as EC (Belcastro et al., 2001; Lieverse et al., 2013), but more often as a morphological variant (or nonmetric trait), under the appellation "spicules" or "exostosis" in the trochanteric fossa (Finnegan, 1978). This insertion site is also considered as a fibrocartilaginous enthesis (Tichnell, 2012; Lieverse et al., 2013). Finally, the adductor tubercle, insertion site of the *adductor magnus*, is also rarely scored as a common enthesis, but it was included here considering that is it the attachment site of a single determinant muscle for horse riding. It is considered as a fibrous enthesis (Tichnell, 2012; Djukic et al., 2015).

Table 9. Entheses investigated in the analysis of entheseal changes

Bone	Enthesis study code	Site of the observed changes	Muscles attached to the site (o. = origin site; i. = insertion site)	Type of enthesis (F = fibrous; FC = fibrocartilaginous)
Coxal bone	COX E1	Anterior inferior iliac spine	*Rectus femoris* (o., straight head)	FC
	COX E2	Ischial tuberosity	*Semimembranosus* (o.); *Semitendinosus* (o.); *Biceps femoris* (o., long head)	FC
Femur	FEM E1	Anterior surface of greater trochanter	*Gluteus minimus* (i.)	FC
	FEM E2	Superior lateral surface of greater trochanter	*Gluteus medius* (i.)	FC
	FEM E3	Trochanteric fossa	*Obturator externus* (i.); *Obturator internus* (i.)	FC
	FEM E4	Lesser trochanter	*Iliopsoas* (i.): *iliacus, psoas major, psoas minor*	FC
	FEM E5	Gluteal tuberosity	*Gluteus maximus* (i.)	F
	FEM E6	*Linea aspera* (middle medial and lateral lips)	Medial lip: *Adductor magnus* (i.); *Adductor longus* (i.); *Adductor brevis* (i.); *Vastus medialis* (o.) Lateral lip: *Vastus lateralis* (o.); *Biceps femoris* (o., short head)	F
	FEM E7	Adductor tubercle	*Adductor magnus* (i.)	F
Patella	PAT E1	Anterior surface	*Quadriceps femoris* (i.): *vastus medialis, vastus intermedius, vastus lateralis, rectus femoris*	FC
Tibia	TIB E1	Tibial tuberosity	*Quadriceps femoris* (i., via the patella ligament): *vastus medialis, vastus intermedius, vastus lateralis, rectus femoris*	FC
	TIB E2	Soleal line	*Soleus* (o.)	F
Calcaneus	CAL E1	Calcaneal tuberosity	*Triceps surae* (i., via the Achilles tendon*): soleus, gastrocnemius*; *Plantaris* (i., via the Achilles tendon)	FC

Most of these entheses and their type were reviewed by Villotte (2008); see Appendix 4 for muscles functions

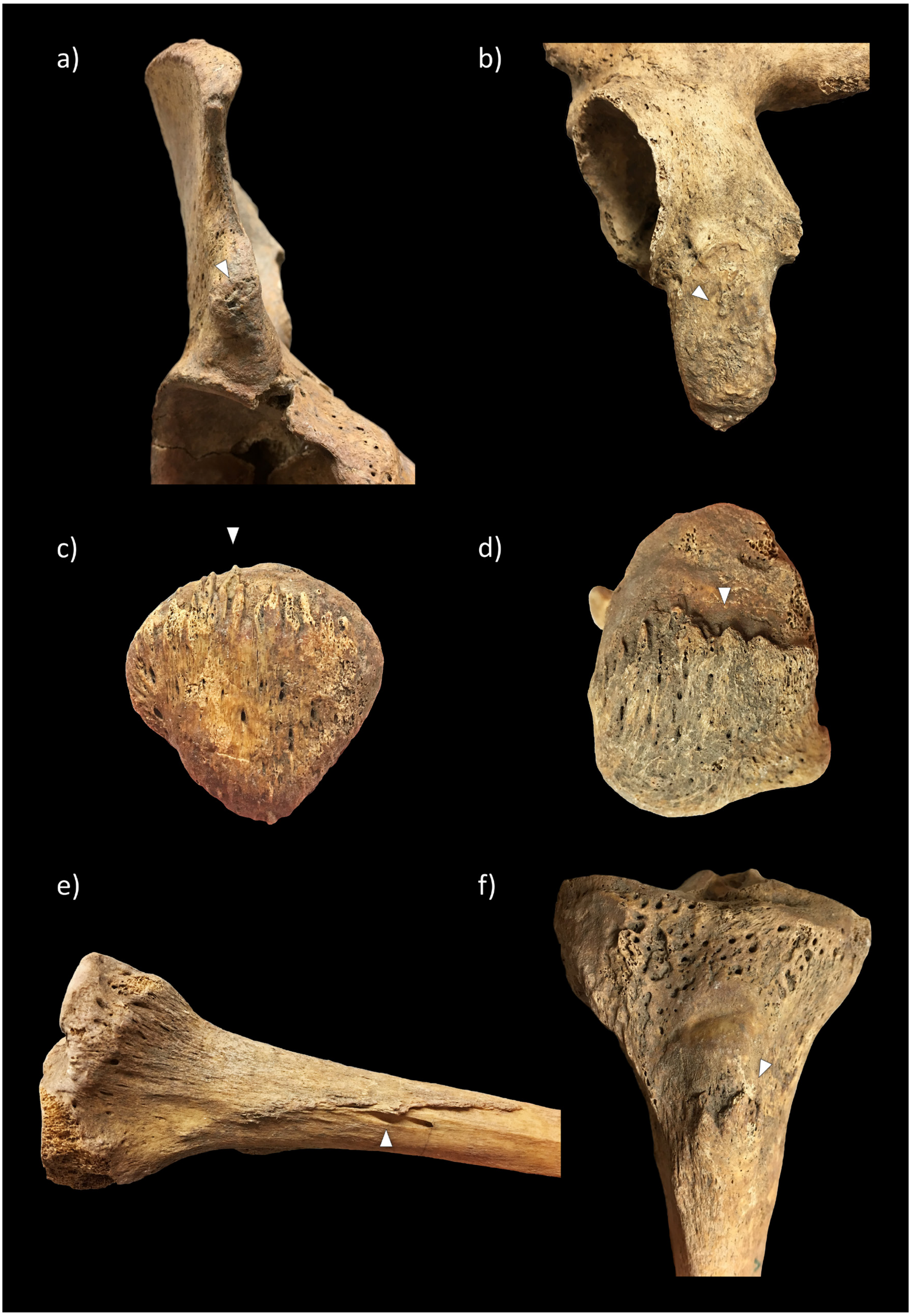

Figure 12. Examples of entheseal changes that were analyzed on the coxal bone, patella, and tibia: a) anterior inferior iliac spine (COX E1); b) ischial tuberosity (COX E2); c) anterior surface of the patella (PAT E1); d) calcaneal tuberosity (CAL E1); e) soleal line (TIB E2); and f) tibial tuberosity (TIB E1). Collection of Sárrétudvari-Hízóföld (10th century)

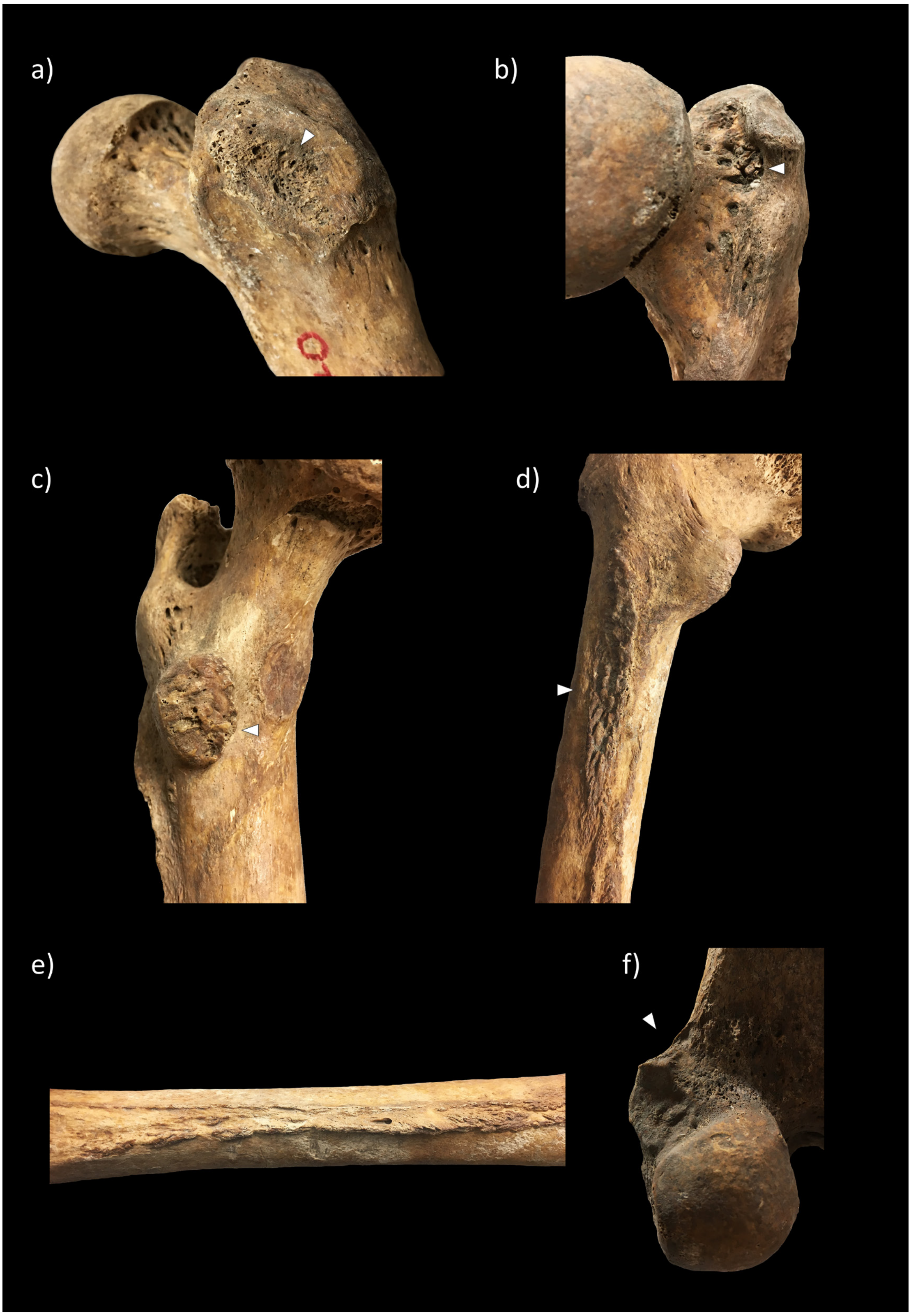

Figure 13. Examples of entheseal changes that were analyzed on the femur: a) anterior surface of greater trochanter (FEM E1); b) trochanteric fossa (FEM E3); c) lesser trochanter (FEM E4); d) gluteal tuberosity (FEM E5); e) *linea aspera*, medial and lateral lips (FEM E6); and f) adductor tubercle (FEM E7). Collection of Sárrétudvari-Hízóföld (10th century)

The origin sites of the *semimembranosus*, the *semitendinosus*, and the long head of the *biceps femoris* were combined and scored as one enthesis, as well as the middle medial and lateral lips of the *linea aspera* on the femur, where are attached multiple muscles. These entheses may indeed be difficult to distinguish precisely, and this distinction is rarely mentioned in the literature on horse riding. Their combination allows improving the reliability of the scoring and the possibility to make comparisons.

Some notable examples of the EC that were scored are presented in Figure 12 and Figure 13.

Two series of analyses of EC were performed: one with only young and mature adult individuals, and the other with individuals in all adult age categories (see III.C.2 below).

III.A.2. Joint changes

We discussed how joint changes can be used as activity-related skeletal changes and their limitations (see Chapter 1, I.B and I.C). Various methods using a multiple-grade scale have been used for scoring joint changes (Crubézy, 1988; Buikstra & Ubelaker, 1994; Rogers & Waldron, 1995). However, bone preservation often represents a limit in archaeological materials, leading to very limited sample sizes for each grade. Furthermore, the use of a multiple-grade scale greatly depends on the experience of the observer and can lead to low repeatability of the scoring method. In this regard, degrees of severity are often clustered into two categories: absence (or barely discernible presence) of changes, and presence of (obvious) changes, notably when joint surfaces are combined into major articulations (e.g., Alves Cardoso, 2008; Ponce, 2010; Zampetti et al., 2016). In our study, a score of 1 (present) was given to a joint when there was clearly discernible osteophyte formation on the surface or the rim of an articular surface, joint contour deformation, eburnation, or loss of morphology of the joint. The presence of porosity alone was not enough to receive a score of 1, as it is sometimes difficult to differentiate from taphonomic processes and its cause is not fully understood (Rothschild, 1997; Groves, 2006; Schrader, 2019). We must stress that the aim was not here to propose a reliable diagnostic of osteoarthritis as a condition, but, rather in a descriptive approach, to evaluate differences in the presence of bone changes at the joints between groups, to determine if the practice of horse riding could have an influence on their development.

The articular surfaces composing each joint from the acetabulum to the trochlea of the talus (except the proximal tibiofibular joint) were systematically and precisely scored (Figure 14 and 15). The articular surfaces were then combined into the major joints of the lower limb to identify which may be affected more by changes related to the practice of horse riding (Table 10). The patellofemoral and tibiofemoral joints, both components of the knee, were analyzed independently, as they involve different articular surfaces. In addition, joint changes at the patella were specifically observed in riding populations and assumed to be related to the use of stirrups, also used by the populations from the Hungarian Conquest period (Baillif-Ducros & McGlynn, 2013; Baillif-Ducros, 2018).

Table 10. Joints included in the analysis of joint changes

Joint region	Joint	Bone involved in the joint	Articular surface scored
Hip	Acetabulofemoral	Coxal bone	Acetabulum
		Femur	Femoral head
Knee	Patellofemoral	Femur	Patellar surface
		Patella	Medial and lateral articular facets
	Tibiofemoral	Femur	Medial and lateral condyles
		Tibia	Medial and lateral condyles
Ankle	Talocrural	Tibia	Inferior and malleolar articular surfaces
		Fibula	Malleolar articular surface
		Talus	Superior, medial and lateral articular surfaces

Osteophytes of the *fovea capitis* of the femur were also mentioned in the anthropological literature on horse riding (see Chapter 1, II.D.1), even if it is rather considered that they affect high-level athletes, in general, and not specifically horse riders (Auvinet, 1980a; Baillif-Ducros, 2018). The presence of perifoveal osteophytes was investigated in our study, independently from the joint changes of the coxofemoral joint (Figure 16). The presence of perifoveal osteophytes only and no other changes at the femoral head was not considered for attributing a score 1 to the coxofemoral joint (Baillif-Ducros, 2018, following Demarais & Lequesne, 1979).

Although vertebral joint changes (at the vertebral bodies and articular facets) were repeatedly mentioned in the anthropological literature on horse riding, we did not include them in the present study. Their use as activity-related markers has indeed been discussed, due notably to the structure and function of the spine and the strong correlation of vertebral joint changes with age and other factors (Bridges, 1994; Knüsel et al., 1997; Weiss & Jurmain, 2007; Novak & Šlaus, 2011).

As for the analysis of entheseal changes, two series of analyses were performed: one with only young and mature adult individuals, and the other with individuals in all adult age categories (see III.C.2 below).

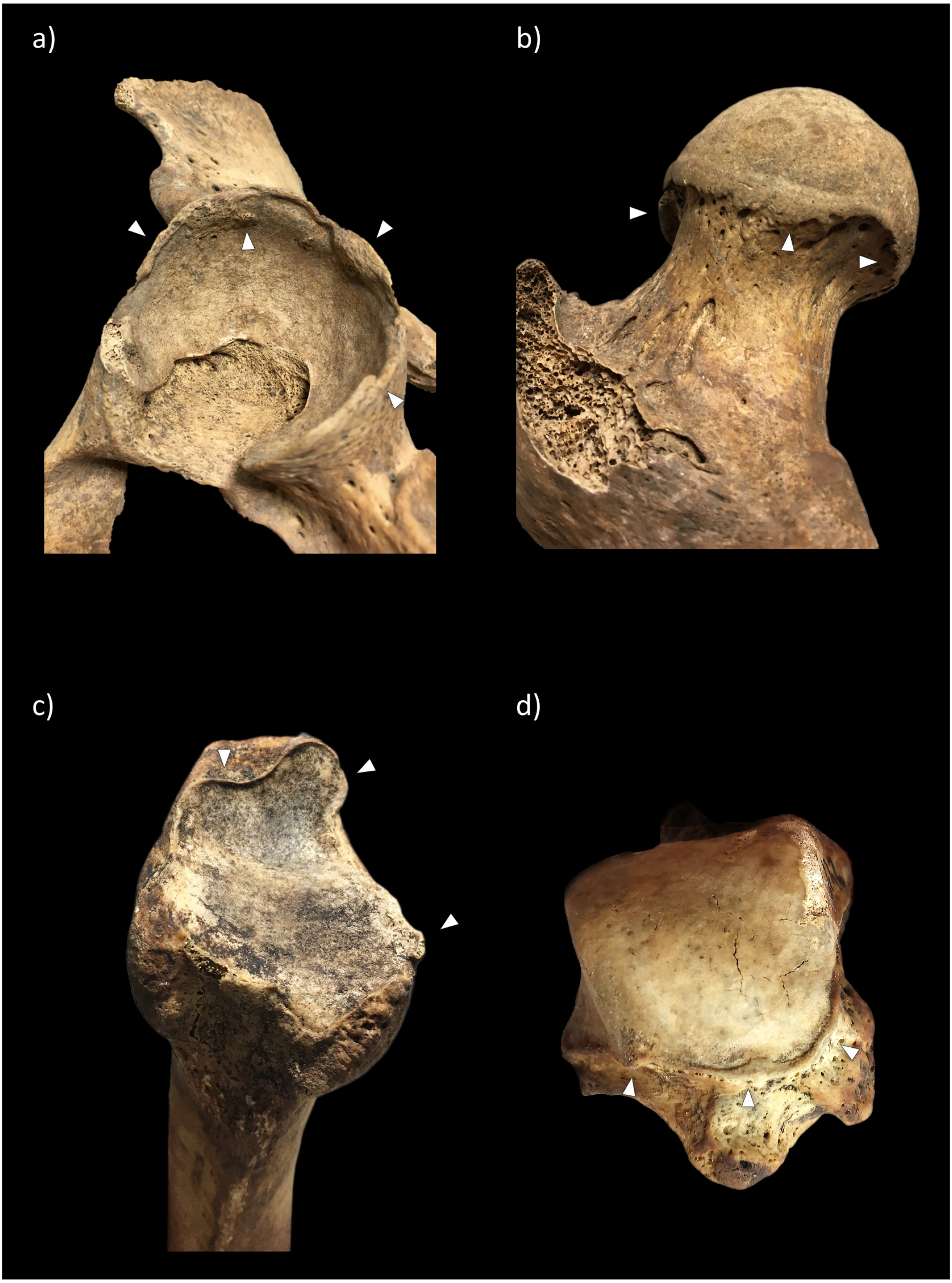

Figure 14. Examples of changes scored at the a) acetabular surface of the coxofemoral joint; b) femoral head of the coxofemoral joint; c) inferior and malleolar surfaces of the tibia for the ankle joint; and d) superior articular surface of the talus for the ankle joint. Collection of Sárrétudvari-Hízóföld (10th century) and documented collection of Lisbon

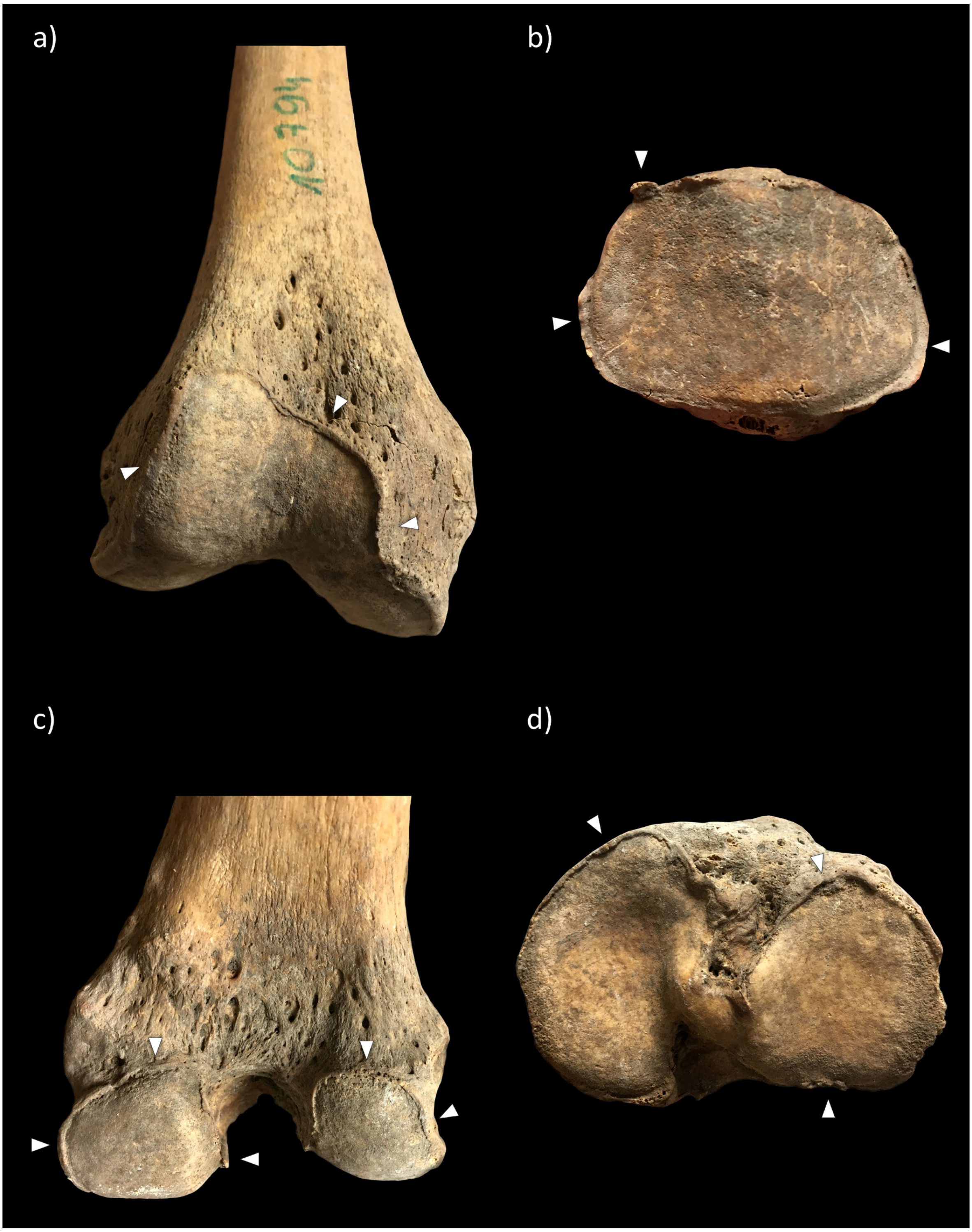

Figure 15. Examples of changes scored at the a) patellar surface of the patellofemoral joint; b) medial and lateral articular facets of the patella for the patellofemoral joint; c) medial and lateral condyles of the femur for the tibiofemoral joint; and d) medial and lateral condyles of the tibia for the tibiofemoral joint. Collection of Sárrétudvari-Hízóföld (10th century)

Figure 16. Examples of coxofemoral joint changes: a) erosion of the superior part of the acetabulum; b) perifoveal osteophytosis on the femoral head, which were analyzed independently. Collection of Sárrétudvari-Hízóföld (10th century)

III.A.3. Morphological variants of the femur

Morphological variants, nonmetric or discrete traits, include various skeletal changes that are usually considered as nonpathological and can result from multiple internal and external causes. If these causes are not fully understood, it is often assumed that there is an underlying genetic component that plays an important part in the development of most variants. They are thus widely used in biological distance studies for analyzing population affinity. It is however acknowledged that sex, age, or activity can also be determining factors for these traits (Berry, 1975; Finnegan, 1978; Hauser & De Stefano, 1989; Capasso et al., 1999; Saunders & Rainey, 2008; Mann & Hunt, 2013).

As discussed previously, various morphological variants have been used and interpreted as horse riding-related skeletal changes (see Chapter 1, II.D.1). Most of them concern the femur, and the most frequently cited ones are the variations of the anterior aspect of the femoral head-neck junction. These include different changes that are often not differentiated, leading to confusion regarding their presumed link with the practice of horse riding.

We selected six morphological variants, focusing especially on the proximal part of the femur, and including the most commonly cited variants in the literature that are assumed to be related to horse riding (Table 11). The aim was to evaluate the reliability of these indicators.

We also included, in an exploratory approach, the posterior cervical imprint and the hypotrochanteric fossa, as they are well-defined traits that could appear to be interesting considering their location.

Table 11. Morphological variants of the femur investigated in the study

Morphological variant code	Morphological variant	Location on the femur
FEM V1	Poirier's facet	Anterior femoral head-neck junction
FEM V2	Anteroiliac plaque	Anterior femoral head-neck junction
FEM V3	Allen's fossa	Anterior femoral head-neck junction
FEM V4	Posterior cervical imprint	Posterior femoral head-neck junction
FEM V5	Third trochanter	Gluteal tuberosity
FEM V6	Hypotrochanteric fossa	Lateral to gluteal tuberosity

The distinction between Poirier's facet, anteroiliac plaque, and Allen's fossa relied on the redefinition by Radi et al. (2013). All selected morphological variants were scored as a dichotomous variable (presence/absence) following these definitions:

Poirier's facet: lateral expansion of the articular surface of the femoral head articular surface onto the anterior aspect of the femoral neck, smooth, on the same plane and in continuity with the articular surface of the head (Kostick, 1963; Finnegan, 1978; Capasso et al., 1999; Villotte & Knüsel, 2009; Mann & Hunt, 2013; Radi et al., 2013) (Figure 17a).

Anteroiliac plaque: imprint located on the anterior margin of the femoral neck close to the head. It is a bony overgrowth that may be on the same plane as the femoral head, lower than the femoral neck plane, or on an intermediate level, and may be delimitated by a bony rim. Unlike the articular surface of the head or Poirier's facet, it has an entirely rough surface. It can be present in addition to Poirier's facet and Allen's fossa (Finnegan, 1978; Villotte & Knüsel, 2009; Mann & Hunt, 2013; Radi et al., 2013) (Figure 17b).

Allen's fossa: circumscribed area on the anterior portion of the femoral neck, close to the border of the head, characterized by a cortical erosion with exposition of the trabecular bone (Kostick, 1963; Finnegan, 1978; Capasso et al., 1999; Villotte & Knüsel, 2009; Mann & Hunt, 2013; Radi et al., 2013). The presence of an area with clustered pores of 1mm or more of diameter on the cortical surface, categorized as a score 1 cribra by Radi et al. (2013), was also included in the scoring of this variant for this study as this feature was probably also referred to as Allen's fossa (or cervical fossa) in previous studies, without distinction (Figure 17c).

Posterior cervical imprint: facet located on the posterior aspect of the neck that may be laterally delimitated by a tubercle (Kostick, 1963; Capasso et al., 1999). Kostick (1963) defines it as “a facet resembling Poirier’s”. The figure provided by the author to illustrate this imprint shows, however, a circumscribed area for which appearance looks closer to the anteroiliac plaque, being on a lower plane as the articular surface of the head. In that regard, we recorded as a posterior cervical imprint any facet, continuous or discontinuous with the head surface, smooth or rough, delimitated or not by a rim, as long as it was observed on the posterior femoral neck and close to the head (Figure 17d).

Third trochanter: rounded or oval tubercle found at the superior end of the gluteal tuberosity (line, crest, or ridge). It develops instead of, or above it, and often resembles the lesser trochanter in form (Hrdlička, 1937; Finnegan, 1978; Lozanoff et al., 1985; Mann et al., 2016) (Figure 17e).

Hypotrochanteric fossa: fossa located in the superior posterior part of the femoral diaphysis between the gluteal tuberosity and the lateral margin. It can be associated with the third trochanter (Hrdlička, 1934; Finnegan, 1978; Mann et al., 2016) (Figure 17f).

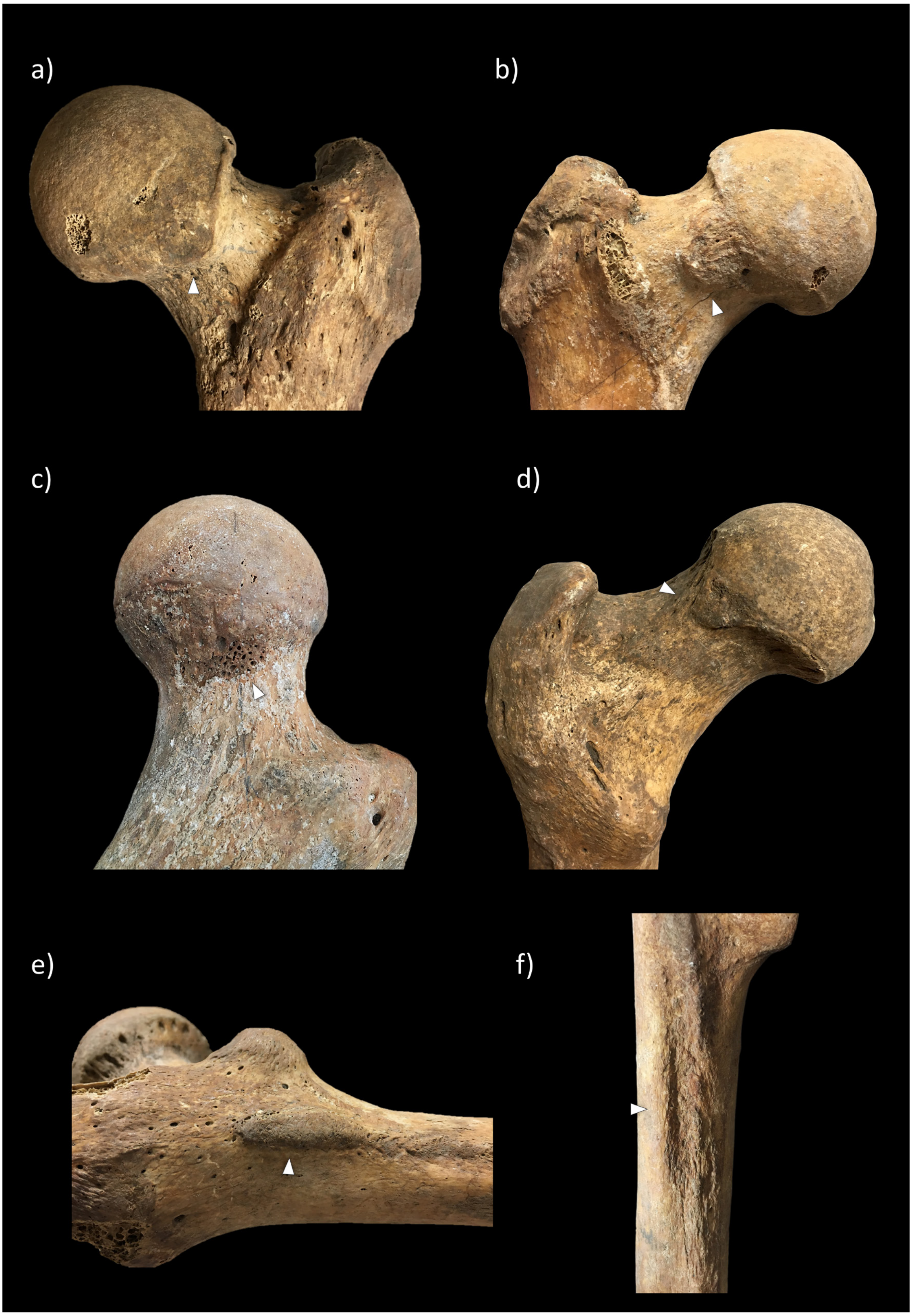

Figure 17. Morphological variants of the femur analyzed in this study: a) Poirier's facet; b) anteroiliac plaque; c) Allen's fossa; d) posterior cervical imprint; e) third trochanter; and f) hypotrochanteric fossa. Collection of Sárrétudvari-Hízóföld (10th century)

III.A.4. Vertebral changes

III.A.4.a. Schmorl's nodes

Schmorl's nodes (SN) are vertical herniations of intervertebral disc tissue (nucleus pulposus) that appear in bone in the form of a well-defined and smooth-walled lesion on the superior or inferior surface of the vertebral body. They are frequent in past and modern populations, and especially in young people who practice a physical activity at a high level, with a predominance in males. Their etiology is still unclear, but trauma, long-term mechanical loading, and congenital weakening are among the most debated factors. In bioarchaeology, SN are often used as indicators of stress to discuss activities and behaviors in past populations (Capasso et al., 1999; Groves, 2006; Alves Cardoso, 2008; Faccia & Williams, 2008; Üstündağ, 2009; Waldron, 2009; Novak & Šlaus, 2011). They are among the most cited skeletal changes assumed to be related to the practice of horse riding (see Chapter 1, II.D.1).

SN were scored according to their severity, following the precise description proposed by Knüsel et al. (1997), and used by Üstündağ (2009) in their methodological study of SN (Table 12; Figure 18). As SN usually have a high prevalence in populations, this scoring procedure may be better suited to reveal differences between groups related to a different level of activity, and more specifically, to the practice of horse riding, compared to using a simple binary recording procedure.

Table 12. Scoring criteria for Schmorl's nodes, from Üstündağ (2009), after Knüsel et al. (1997)

Score	Description of the lesions
Small Schmorl's nodes (1)	Less than 2mm deep covering an area equivalent to less than half the anteroposterior length of the vertebral body
Large Schmorl's nodes (2)	More than 2mm deep covering an area of more than half the anteroposterior length of the vertebral body

SN were scored on each vertebra that could precisely be identified in the column. Both superior and inferior endplates were scored separately, and a vertebra was considered as affected if at least one of these surfaces showed the presence of a node. If SN were observable on both surfaces of a vertebra, the highest score was attributed to the whole vertebra. A vertebra was considered as observable if more than half of the surface of at least one endplate was observable.

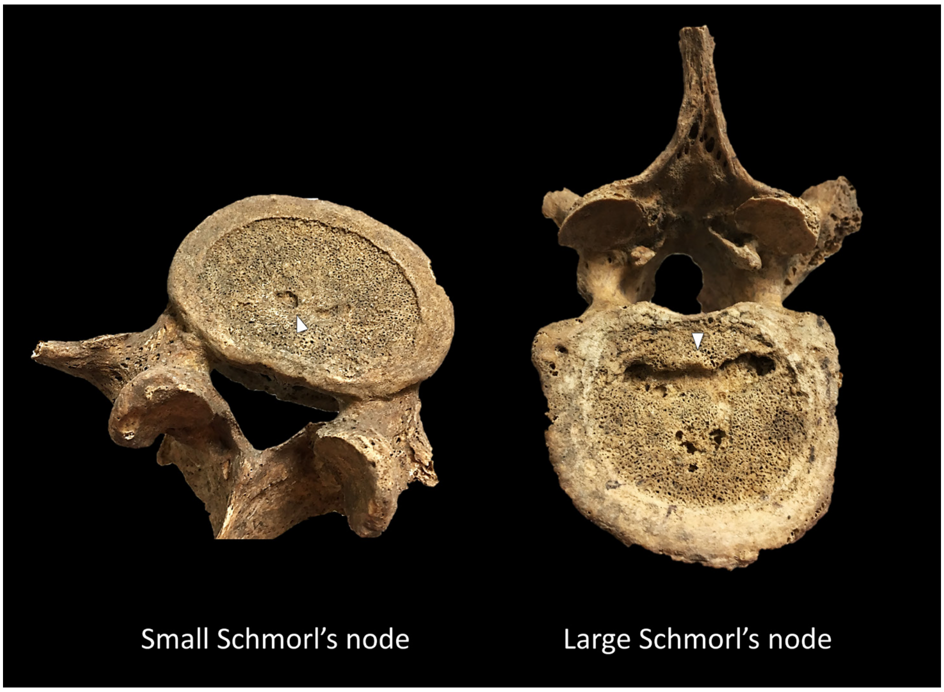

Figure 18. Examples of small and large Schmorl's nodes. Collection of Sárrétudvari-Hízóföld (10th century)

We analyzed the results for each vertebra from the first thoracic to the first sacral vertebra taken separately in order to precisely identify which vertebrae were more affected by SN in each group. Vertebrae were also combined by segment, to be able to observe more differences depending on the general level of the lesions. The upper (from the first to the sixth thoracic vertebra) and lower thoracic levels (from the seventh to the twelfth vertebra) were distinguished and also combined together to be compared with the lumbar level (from the first lumbar to the first sacral vertebra).

We must acknowledge, for the scoring of SN on vertebrae, the major contribution of our colleague from the Department of Biological Anthropology of the University of Szeged, Balázs Tihanyi, whose doctoral research relied on the same materials. Considering the simplicity and precision of the scoring method used for recording SN, and the fact that we trained together for the scoring of all skeletal changes, an interobserver agreement evaluation was not deemed necessary.

III.A.4.b. Spondylolysis

Spondylolysis is a defect in the neural arches at the *pars interarticularis* of the vertebrae. It results in the separation between the anterior part (body, pedicles, transverse processes, superior articular facets) and the posterior part of the vertebra (inferior articular facets, laminae, spinous process). It can occur bilaterally or unilaterally. Its prevalence is higher in athletic populations, and it seems to appear in childhood or early adulthood, and more frequently in males. Spondylolysis does not seem to increase with aging. Its etiology is debated, and genetic factors and stress fracture are among the most cited possible causes. This trait is often used in bioarchaeology for investigating stress level in past populations (Merbs, 1983; Bridges, 1989; Merbs, 1989; Capasso et al., 1999; Fibiger & Knüsel, 2005; Molnar, 2006; Waldron, 2009; Ponce, 2010). Spondylolysis was occasionally cited among the skeletal changes assumed to be related to the practice of horse riding (see Chapter 1, II.D.1).

Figure 19. Example of unilateral spondylolysis (or partially healed spondylolysis) on a 5th lumbar vertebra. Collection of Sárrétudvari-Hízóföld (10th century)

Spondylolysis was scored as present or absent. When present, we also noted when it was unilateral or bilateral (Figure 19). Although spondylolysis is more commonly associated with the lumbar vertebrae, all vertebrae from the third cervical to the first sacral vertebra were examined. As for Schmorl's nodes, we acknowledge, for the scoring of spondylolysis, the valuable contribution of our colleague from the Department of Biological Anthropology of the University of Szeged, Balázs Tihanyi, whose doctoral research relied on the same materials.

III.A.5. Traumatic lesions

Traumatic lesions can be of particular interest in the study of past populations as they can result from conflicts or natural accidents, thus providing insights of the environment in which evolved the individuals or their activities and behaviors (Pálfi, 1992; Larsen, 1997; Jurmain, 1999; Buzon & Richman, 2007; Paine et al., 2007; Tung, 2007; Henderson, 2009; de la Cova, 2012). Traumatic lesions at various locations on the skeleton have been described as being possibly related to the practice of horse riding, and especially the fall from a horse, while fractures are very common in modern horse riders (Ki et al., 2018; see Chapter 1, II.B and II.D.1).

The presence of signs of fractures was systematically recorded. The results were analyzed according to grouped bones and anatomical regions as presented in Table 13. 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 (Figure 20). Microtraumatic lesions or cases of *myositis ossificans*, i.e., ossification of injured muscles, were not considered here. A case of surgical trepanation at the occipital bone in the Hungarian series was not included in this analysis. 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. Groups of bones or regions were considered as observable when at least half of the elements composing them were observable.

Table 13. Bones and anatomical regions examined for fractures

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

Figure 20. Examples of healed fractures on the lower limb, at the: a) tibia, and b) comparison with the healthy bone on the right; and at the: c) fibula, and d) comparison with the healthy bone on the right. Collection of Sárrétudvari-Hízóföld (10th century)

We acknowledge the fact that the scoring of traumatic lesions on the upper part of the skeleton was performed by our colleague from the Department of Biological Anthropology of the University of Szeged, Balázs Tihanyi, whose doctoral research relied on the same materials. They were included in this study with the fractures of the lower limbs considering that anthropological literature and sports medicine, especially, refer to acute traumas at the upper part of the body as being a very common consequence of horse riding.

III.B. Osteometric analyses

III.B.1. The index of ovalization of the acetabulum

The practice of horse riding is suspected of altering the shape of the acetabulum due to the pressure of the femoral head on the acetabulum related to the position of the rider (Baillif-Ducros et al., 2012). Changes that are mentioned in the literature are described as an ovalization of the acetabulum or an expansion/elongation of the rim, which can be anterior-superior or superior (e.g., Miller & Reinhard, 1991; Pálfi, 1992; Courtaud & Rajev, 1998; Erickson et al., 2000; Garofalo, 2004; Üstündağ & Deveci, 2011; Baillif-Ducros et al., 2012; Eng et al., 2012; Baillif-Ducros & McGlynn, 2013; Fornaciari et al., 2014; Ciurletti, 2017; Larentis, 2017; Baillif-Ducros, 2018). The results of a visual examination greatly depend on the experience of the observer, thereby limiting the reliability and reproducibility of the observations. Therefore, different methodologies have been experimented to identify precise, reliable, and repeatable criteria to describe the acetabular shape changes. Although the Fourier analysis used by Erickson et al. (2000) on acetabula from two Native American Arikara populations seems particularly relevant to capture the changes of the shape of the entire acetabular rim, several portions of the acetabular rim are frequently not preserved in ancient materials. Instead, we used direct measurements of the acetabulum to calculate a vertical/horizontal diameter index and analyze the shape of the acetabulum (Baillif-Ducros et al., 2012; Berthon et al., 2016b; Sarry et al., 2016; Baillif-Ducros, 2018; Berthon et al., 2019). The vertical and horizontal diameters are relevant to assess the anterior-superior rim expansion previously described (Erickson et al., 2000; Baillif-Ducros et al., 2012).

The metrics are well-defined measurements that can be easily taken: VEAC (M22) corresponds to the maximum vertical diameter of the acetabulum, measured as a prolongation of the longitudinal axis of the ischium, and HOAC (M22) is the maximum horizontal diameter, measured perpendicularly to VEAC (Baillif-Ducros et al., 2012; Bräuer, 1988; Bruzek et al., 2017; Murail et al., 2005). The measurements are neither external nor internal but taken precisely on the rim of the acetabulum (Figure 21a). They were used to calculate a vertical/horizontal diameter index (VEAC/HOAC) that allows comparing the acetabular shape between individuals, groups, and studies. This index of ovalization of the acetabulum (IOA) indicates a vertical ovalization when it is higher than 1 (VEAC > HOAC), whereas an IOA close to 1 corresponds to circular acetabula, and an IOA inferior to 1 indicates acetabula wider than their height (HOAC > VEAC; Figure 21b,c). The metrics were recorded with a digital sliding caliper with a precision of 0.1 mm. Both left and right acetabula were measured to address asymmetry questions. We excluded suspected cases of hip dysplasia, subluxation or dislocation, and acetabula showing strong osteophytosis at the rim.

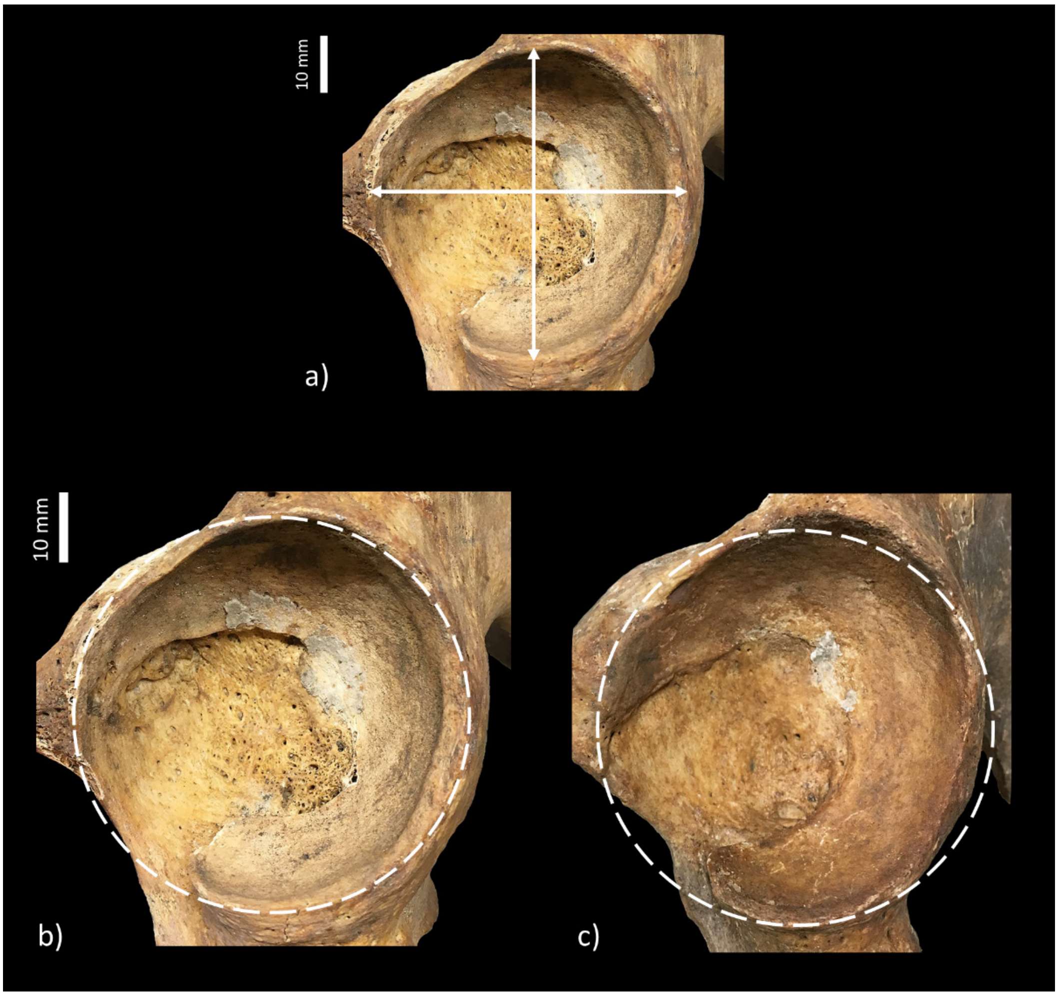

Figure 21. a) Measurements of the maximum vertical and horizontal diameters of the acetabulum, and examples of b) an acetabulum with a shape intermediate between circular and a horizontal ovalization (index = 0.971), and c) an acetabulum exhibiting a strong vertical ovalization (index = 1.082). The discontinuous lines represent exact circles for reference

Considering the particular interest of this index for the analysis of horse riding-related skeletal changes, and the fact that the measurements of the acetabula, although well defined, are not very commonly used in anthropological studies, we performed an interobserver and intraobserver agreement evaluation to assure the reproducibility of the measurements. The measurements were taken by one observer (A) in the Hungarian archaeological series, without knowledge of the presence or absence of horse riding deposit in the graves of the individuals. Additionally, a set of measurements was taken by a second observer (B), independently. Observer A had more practical experience than Observer B in metrics of the coxal bone, but both observers are experienced in osteometry. The definitions and techniques of measurements were clarified before the test. Observer A also performed a second round of measurements (A2), with an interval of several months, to assess the intraobserver agreement. Observer B's measurements were compared with the A2 set. Thirty coxae from 15 individuals were measured for comparing the vertical and the horizontal diameters, respectively. The individuals were selected randomly among the adults, provided that the acetabular rim was well preserved. The concordance between the series of measurements was evaluated using the concordance correlation coefficient that allows quantifying the agreement between two measures of the same variable (Lin, 1989). Values are ranged between -1 and 1, with ±1 denoting a perfect concordance or discordance and 0 denoting an absence of correlation.

III.B.2. Other indices of shape and robusticity

External dimensions of bones can, like cross-sectional geometry (CSG), contribute to identifying differences in activity patterns between and within populations (Buikstra & Ubelaker, 1994; Larsen, 1997; Knüsel, 2000b; Stock, 2006; Perréard Lopreno, 2007; Shaw & Stock, 2009b, 2009a; Niinimäki, 2012a). This relies on the ability of bones to adapt to mechanical loading (see Chapter 1, I.B). If CSG provides more detailed information regarding the architectural properties of long bones, external bone dimensions have also proved to be informative, reliable, and accurate when compared to CSG results (Stock & Shaw, 2007; Ponce, 2010). Large databases on external bone dimensions also allow to record in a more complete way variations of the human skeleton, and this approach can furthermore be preferred for practical, time, and cost reasons (Ponce, 2010).

External measurements can be used to calculate various indices of shape and robusticity. In humans, lower limbs are part of the locomotor system and are therefore more likely to reflect the effect of mobility, while upper limbs, used to perform manual activities, are more likely to provide information on specific activities and asymmetry (Ponce, 2010). The index of ovalization of the acetabulum is a particular case: it was indeed specifically selected for being a potential reliable indicator of the practice of horse riding and because the changes of the shape of the acetabulum have been repeatedly mentioned in the anthropological literature on horse riding (see III.B.1 above). In an exploratory approach, we selected various other indices calculated from direct measurements on the lower limb bones. Unlike the index of ovalization of the acetabulum, suspected to be influenced specifically by the practice of horse riding, these other indices are rather general descriptors of the overall shape and robusticity of the main bones of the lower limb, and we thus assume that they can allow identifying differences in the level of activity and mobility between groups. Specifically, the comparison between both Hungarian archaeological groups, with (RD) and without riding deposit (NRD), is of particular interest as they are considered as coming from the same population. In that regard, possible differences between these two groups are less likely to be related to interpopulation variability and, more likely, to external factors. The distinction between both groups relying only on the presence or absence of horse-related deposit (riding equipment and horse bones) in the graves, differences in the practice of horse riding would represent a logical explanation for possible variations of those indices observed between those groups.

A selection of measurements was taken on the femur, patella, tibia, fibula, talus, and calcaneus. These metrics mostly include the maximum or physiological length, anteroposterior and mediolateral diameters at midshaft, or the minimum circumference of the diaphysis in case of long bones, as well as the maximum or articular length, breadth, and height, in the case of the tarsal bones. The measurements are all well defined by R. Martin (in the reedition by G. Bräuer, 1988), and are commonly used in anthropology. In that respect, no inter- or intraobserver agreement evaluation was performed. The metrics were recorded using a digital sliding caliper with a precision of 0.1 mm, as well as an osteometric board, a spreading caliper, and a measuring tape, with a precision of 1 mm. Both left and right bones were measured.

The measurements were used to calculate the indices of shape and robusticity (Table 14). The selected indices are also defined by Martin (in the reedition by Bräuer, 1988) and are used in anthropology to characterize individuals and populations (Janssens & Perrot, 2006-2007). Unlike raw measurements, indices do not require to control for the size factor, and they easily allow comparisons between individuals or groups. We must stress that our intergroup comparisons relied only on the direct result of the index calculation, and not on the classical categorization of bones shape traditionally used by anthropologists to describe populations.

Table 14. Indices of shape and robusticity calculated from direct measurements on the lower limb bones and used for intergroup comparisons

Bone	Index code	Index name	Formula and definition (x 100; in mm) Measurement codes from Martin (re-edited by Bräuer, 1988)	
Femur	FEM I1	Length-thickness (robusticity) index	M8/M2	Circumference of midshaft/ Physiological (bicondylar) length
	FEM I2	Pilastric index	M6/M7	Anteroposterior diameter of midshaft/ Mediolateral diameter of midshaft
	FEM I3	Platymeric index	M10/M9	Subtrochanteric anteroposterior diameter/ Subtrochanteric mediolateral diameter
	FEM I4	Epicondylar width—transverse shaft diameter index	M7/M21	Mediolateral diameter of midshaft/ Epicondylar width
	FEM I5	Head robusticity index	(M18+M19)/M2	(Vertical head diameter+Transverse head diameter)/ Physiological length
Patella	PAT I1	Height-width index	M1/M2	Maximum height/Maximum width
Tibia	TIB I1	Length-thickness (robusticity) index	M10b/M2	Minimum circumference of shaft/ Physiological length
	TIB I2	Platycnemic index	M9a/M8a	Mediolateral diameter at nutrient foramen/ Anteroposterior diameter at nutrient foramen
Fibula	FIB I1	Length-thickness (robusticity) index	M4a/M1	Minimum circumference of midshaft/ Maximum length
Talus	TAL I1	Length-width index	M2/M1	Talar width/Talar length
	TAL I2	Length-height index	M3/M1	Talar height/Talar length
	TAL I3	Trochlear index	M5/M4	Transverse trochlear breadth/Trochlear length
Calcaneus	CAL I1	Length-width index	M2/M1	Breadth across the sustentaculum/Maximum length
	CAL I2	Length-height index	M4/M1a	Height of body/Total length

III.C. Limiting bias

III.C.1. The influence of pathological conditions

For both qualitative and quantitative analyses, the data were excluded — considered as not observable — for the concerned bone or bone part in case of presence of possible or probable signs of a pathological condition. The data were, however, excluded for the whole lower limb from the concerned side or both sides in the most severe cases, which would have likely caused such discomfort for the individual that it could have altered lower limb movements. Even if this potential discomfort was only temporary and the pathology could have been well treated, there is a risk it resulted in the irregular development or the absence of development of some skeletal changes. When only one side presented signs of a severe condition, the data regarding the "healthy side" were not excluded (except in case of a strong asymmetry of values), even if we acknowledge the fact that irregular skeletal changes may also indirectly result from the pathological condition on the other side, due to a compensation mechanism for example. This decision was taken as a compromise for avoiding too little sample size in the case of the archaeological groups where bone preservation was already a limiting factor. Severe cases included conditions such as fractures of the femur or tibia, polytraumas, or osteomyelitis. Probable cases of hip dysplasia also led to data exclusion on the concerned side or both sides (Figure 22). Suspected cases were verified with the measurements of the femoral neck-shaft angle, the tönnis angle, and the lateral center-edge angle (Serra-Tosio, 2011). However, such measurements are mainly adapted for radiographical examination; thus, cases that remained doubtful afterward were also excluded from the statistical analyses.

Figure 22. Case of slipped capital femoral epiphysis in an individual from Sárrétudvari-Hízóföld

For the analysis of entheseal changes, in particular, possible cases of diffuse idiopathic skeletal hyperostosis (DISH, or Forestier's disease) were excluded from the data set, as this metabolic disorder is particularly characterized by the calcification and ossification of soft tissues, including ligaments and tendons (Resnick & Niwayama, 1976; Waldron, 2009; Holgate & Steyn, 2016). The main diagnostic criteria considered to identify a probable or possible DISH were: the ossification of the right side anterior longitudinal ligament on the vertebrae, with a "candle wax" appearance, on at least 3-4 contiguous vertebrae; normal intervertebral disc spaces and apophyseal joints; absence of sacroiliac joint changes; and symmetric entheseal changes at locations such as the ulnar olecranon, superior patella, posterior calcaneus, or the iliac crest of the coxal bone (Resnick & Niwayama, 1976; Rogers & Waldron, 2001; Paja et al., 2010; Paja, 2013; Faccia et al., 2016). Based on these criteria, three individuals from the comparison group from Lisbon (LIS) were excluded from the analysis of entheseal changes (Figure 23). Suspicious cases from the Hungarian series of Sárrétudvari-Hízóföld did not meet these criteria, and the observed changes were attributed to degenerative joint disease instead.

Similarly, the individual SH182 from Sárrétudvari-Hízóföld was excluded from the analysis of entheseal and joint changes because of signs of a probable inflammatory polyarthropathy (Resnick, 2002). The skeleton displayed in fact generalized, bilateral and symmetric erosive alterations of the joints (intervertebral discs and apophyseal joints, acromioclavicular and sternoclavicular joints, sacroiliac joint, acetabulum, as well as carpal, metacarpal, tarsal, and metatarsal bones, hand and foot phalanges, etc.), with ankylosis of several vertebrae and phalanges, and entheseal changes at multiple sites.

Figure 23. Case of DISH, with ossification of the right side anterior longitudinal ligament on vertebrae from an individual from the collection of Lisbon

III.C.2. The influence of age

Although it was demonstrated that the influence of activity on entheseal and joint changes is not straightforward, it is the conclusion of a majority of studies that their development is closely related to age (see Chapter 1, I.C). The presence of older adults in a sample for analyzing those changes as potential activity-related markers represents, therefore, a bias, and the analysis of those changes should thus include only young and mature adults to limit the influence of age on the results.

The number of entheses and joints that could be observed was dependent on bone preservation, which was a limiting factor in the archaeological materials, especially. The strict methodological criteria that we used (see III.C.1 above) also narrowed down the sample sizes, and the age estimation let several individuals uncategorized (see I.B.3 above). In the end, the number of possible observations was particularly limited, especially if we focused only on the young and mature adults, as recommended.

In order to be able to conduct reliable statistical analyses and identify differences between groups, we performed two series of comparisons: one with only the young and mature adults, and another one, of a less limited size, including individuals in all adult age categories, i.e., young, mature, and old adults as well as adults of indeterminate age. Even if the development of entheseal and joint changes is closely related to age, the presence of old adults in each of the three groups should allow making intergroup comparisons. In details, on a total of 17 individuals in the Hungarian group with riding deposit (RD), six were estimated to be either mature or old adults, and four were indeterminate (Table 6); thus there could be a maximum of 10 old adults in this group (59%). Among the 50 individuals from the Hungarian group without riding deposit (NRD), 13 were considered as either mature or old adults, two were old adults, and five were indeterminate (Table 6); thus, there could be a maximum of 20 old adults in this group (40%). In comparison, based on the documentation, there were 15 individuals aged 50 or more in the group from the Lisbon collection (LIS) on a total of 47 (32%). However, the age estimation performed using the same method as for the archaeological groups (see II.C.2 above) led to categorize 33 individuals as either mature or old adults, or indeterminate (Table 7), which means 70% of possible old adults instead of the known 32%. It is therefore very unlikely that all of the individuals who were not precisely categorized as young and mature adults in the archaeological groups were actually old adults, and the real proportion of old individuals in the RD and NRD groups is probably less than the maximum estimations mentioned above, like in the case of the LIS group. Thus, we can reasonably consider that the proportion of old adults in the archaeological samples must not be disproportionate compared to the known old adults in the LIS group (32%), and, therefore, that the influence of age on the results should concern the three groups in a similar way, allowing for comparisons. Another argument for performing in a complementary way the analysis on individuals in all age categories is that older adults had more time to develop activity-related skeletal changes than those who died younger. In any case, we acknowledged the possible influence of age in the analyses including adults in all age categories. The results of these analyses were used to bring complementary results for comparison with the results obtained with young and mature adult individuals and will be discussed with caution.

As for the entheseal and joint changes, age can also represent a bias factor in the analysis of external bone measurements (and cross-sectional geometry) due to bone loss, which increases with age under the influence of multiple factors, including mechanical ones (Frost, 2003; Kirchengast, 2015). Age-related bone loss is however less in weight-bearing bones, such as the femur and tibia, in particular, compared to other bones, as they receive larger loads and larger muscle forces due to locomotion (Peck & Stout, 2007). In that regard, and in order to perform reliable statistical analyses with satisfactory sample sizes, we included individuals in all adult age categories in the analyses of indices of shape and robusticity of the lower limb bones.

Finally, concerning Schmorl's nodes, a methodological study revealed that they seem to occur more in young individuals and that their frequency does not increase with age. In addition, there was no association observed between Schmorl's nodes and degenerative vertebral joint diseases (Üstündağ, 2009). As Schmorl's nodes appear not to be related to the process of aging, their analysis also included individuals in all adult age categories in our study. In the same way, we also used all individuals in our samples for the analysis of the morphological variants of the femur, spondylolysis, and traumatic lesions.

III.C.3. Other aspects

The protocol for the analysis of the activity-related skeletal changes was elaborated specifically for this study and it includes multiple types of skeletal changes for which scoring required practical training. For most of them, both qualitative and quantitative data, we felt a progression in our way of scoring over time, which was very likely related to the experience acquired after analyzing several dozens of skeletons. In order to limit the risk of having important differences between the first analyzed skeletons and the ones that were examined later with a "trained eye", the skeletons that were studied during the first weeks were reexamined again and all data were rescored. We used the second set of data for these skeletons in all analyses.

Furthermore, we must emphasize that the recording of all data from the different types of analyses was performed without knowledge of the presence or absence of horse-related deposit associated with the individuals in the graves, in the case of the Hungarian series.

III.D. Statistical analyses

III.D.1. General considerations

Our bioarchaeological analysis consists in identifying possible differences between the three groups selected in the sample: the Hungarian archaeological groups with (RD) and without riding deposit (NRD) and the comparison group from the documented collection of Lisbon (LIS). As a first step, we compared the three groups together. When a significant difference was observed, we had to perform pairwise comparisons to identify between which groups was found this significant difference. In our case, three pairs of groups were tested: RD versus NRD, RD versus LIS, and NRD versus LIS. We, therefore, had to take into account the multiple comparison problem.

In hypothesis testing, the significance level that is selected (α = .05, in most of the cases) corresponds to the accepted risk of falsely concluding that a difference that is observed is a reality while there is, in fact, no difference. When multiplying comparisons, we increase the risk of obtaining false-positive results, i.e., of falsely rejecting the null hypothesis in one of the tests. To address this problem, we must either lower the significance level α or correct the *p* values obtained from the multiple comparisons. We used the Holm-Bonferroni correction method, which sequentially increases the *p* values in order to decrease the risk of error: the smallest obtained *p* value is multiplied by the number of comparisons (N), the second smallest one is multiplied by N-1, the next one by N-2, etc. The application of a correction method results in adjusted *p* values. See Nikita (2017) for further details regarding the multiple comparison problem and the application of the Holm-Bonferroni method.

The sample sizes are not large: 17 individuals in the RD group, 50 in the NRD group, and 47 in the LIS group. The strict methodological criteria that we applied led to the exclusion of data concerning several of these individuals, depending on the type of analysis. Bone preservation was also a limiting factor in the archaeological groups, in particular. Furthermore, when attempting to include only the young and mature adult individuals for the analysis of entheseal and joint changes, observations were made on a lower number of individuals. For these reasons, the conditions to perform parametric tests were frequently not met. In order to have homogenous results, we used non-parametric tests only, in all analyses.

The analyses were performed using SPSS Statistics 25. For all statistical tests, the set significance level was $\alpha = .05$. We used exact *p* values, which provide a reliable result, regardless of the size or distribution of the data, whenever it was possible. When exact *p* values could not be computed, we applied the Monte Carlo method, a repeated sampling method that provides an unbiased estimate of the exact *p* value. Where applicable, two-tailed tests were systematically used.

III.D.2. Qualitative analyses

For the analysis of entheseal changes, joint changes, morphological variants, vertebral changes, and traumatic lesions, scoring each feature as "absent", "present" (small and large in the case of Schmorl's nodes), or "not observable" (usually when more than half of the element surface was altered or missing), allowed to calculate true prevalence rates: n/N, with n, the number of affected elements, and N, the number of observable elements for each analysis. In addition, we calculated the ratio of individuals affected by a condition (or presenting a feature), divided by the number of individuals who had enough observable elements for each type of analysis. Individuals were considered observable if half or more of the bone elements that were scored for each analysis were present.

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 III.D.1 above). The intergroup comparisons were performed using data from both sides, combined and taken independently. For the analysis of entheseal changes, joint changes, and morphological variants, bilateral asymmetry was also assessed, using paired bones or elements only. Bilateral asymmetry was calculated by subtracting the left side score from the right side for each individual (i.e., right score minus left score). This could result in three possible outcomes: "0" (equal scores, either for absence or presence on both sides), "1" (presence on the right side and absence on the left side), and "-1" (presence on the left side and absence on the right side). Frequencies of each outcome were calculated per feature and per group. The pattern of bilateral asymmetry was also compared between groups using Fisher's exact test.

III.D.3. Quantitative analyses

Descriptive statistics (minimum, maximum, mean, standard deviation) were calculated for each index, on both sides. Considering its particular interest for horse riding, boxplots were constructed to visually represent the distribution of the index of ovalization of the acetabulum (IOA) in each group. For all indices, including the IOA, the non-parametric Kruskal-Wallis H test was used to assess differences between the three groups. When a statistically significant difference was found, we used the non-parametric Mann-Whitney U test to perform pairwise comparisons between the groups. In that case, the obtained *p* values were corrected following the Holm-Bonferroni method (see III.D.1). Those tests were applied to the indices of both sides, combined and taken independently. We also used the non-parametric Wilcoxon signed-rank test, applied on the paired indices in each group, to evaluate the bilateral asymmetry. The difference between both sides' indices was also calculated (right minus left index value), and the resulting values were compared between the groups using the Mann-Whitney U test to evaluate differences in the pattern of asymmetry.

CHAPTER 3. RESULTS

I. Macromorphoscopic analyses

The results of the sex diagnosis and the age estimation are presented in Chapter 2.

I.A. Results of the analysis of entheseal changes

I.A.1. Intergroup comparisons

I.A.1.a. Young and mature adult individuals

A total of 1357 entheses could be observed in all young and mature adults, and 196 (14%) were affected by changes. There was no difference between sides. There were more entheseal changes observed in the RD and NRD groups than in the LIS group (14%, 19%, and 11%, respectively, when left and right were combined; Table 15). The difference between the three groups was statistically significant, and pairwise comparisons revealed that this significant difference concerned the NRD and LIS group, in particular (*p* adjusted < .001).

Table 15. Frequency of all entheseal changes observed in the young and mature adult individuals (YMA) from the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

	RD YMA			NRD YMA			LIS YMA			*p*	*p* exact adjusted		
	N	*n*	*n/N*	*N*	*n*	*n/N*	*N*	*n*	*n/N*	exact	RD-NRD	RD-LIS	NRD-LIS
Left	70	10	14%	249	52	21%	336	38	11%	**.007**	.474	.541	**.005**
Right	64	9	14%	288	51	18%	350	36	10%	**.025**	.766	.766	**.023**
Left+Right	134	19	14%	537	103	19%	686	74	11%	**< .001**	1	1	**< .001**

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*, observable entheses; *n*, affected entheses

Those EC concerned a total of 45 young and mature adult individuals (75%) among the entire sample of 60 who were considered as observable (i.e., when at least half of the entheses were observable on each side). There was no significant difference between sides. A higher proportion of individuals was affected by at least one EC in the RD (86%) and NRD (84%) groups compared to the LIS group (64%; Table 16). This difference was not statistically significant (*p* = .211), nor was it when individuals were considered separately depending on if they were affected on their left or right side (*p* = .053 and *p* = .141, respectively).

Table 16. Frequency of young and mature adult individuals (YMA) with at least one enthesis affected by changes in the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

	RD YMA			NRD YMA			LIS YMA			*p*
	N	*n*	*n/N*	*N*	*n*	*n/N*	N	n	n/N	exact
Left	7	5	71%	23	19	83%	29	15	52%	.053
Right	7	6	86%	27	18	67%	29	14	48%	.141
Left+Right	7	6	86%	25	21	84%	28	18	64%	.211

Fisher's exact test, two-tailed; *N*, number of observable individuals; *n*, number of individuals with at least one enthesis affected by changes

The frequencies of EC observed in each group and the results of the statistical comparisons between groups are shown in Table 17 and Figure 24.

The number of observations for each enthesis was rather limited due to the small sample size of YMA individuals and bone preservation in the archaeological materials and the RD group, in particular. The EC that were the most frequently observed in the entire sample concerned the calcaneal tuberosity (CAL E1, 39%), while the least frequently observed EC were those of the anterior surface of the greater trochanter of the femur (FEM E1, 3%). There was no significant difference between sides, even if 8 out of 13 entheses were slightly more affected on the left side. The NRD group showed the highest frequencies for a majority of EC (10/13). There was a statistically significant difference between groups for 3 entheses: the adductor tubercle of the femur (FEM E7), the tibial tuberosity (TIB E1), and the calcaneal tuberosity (CAL E1). The pairwise comparisons with corrected *p* values did not reveal a significant difference between any groups for FEM E7, even if we observed that the largest difference was between the RD group (38%) and the LIS group (5%), in particular. Concerning TIB E1, it was significantly more affected in the LIS group than in the NRD group (*p* adjusted = .018). This enthesis was not affected at all in the NRD and RD groups. As for CAL E1, EC were significantly more frequent in the RD and NRD groups compared to the LIS group (*p* adjusted = .012 and *p* adjusted < .001, respectively).

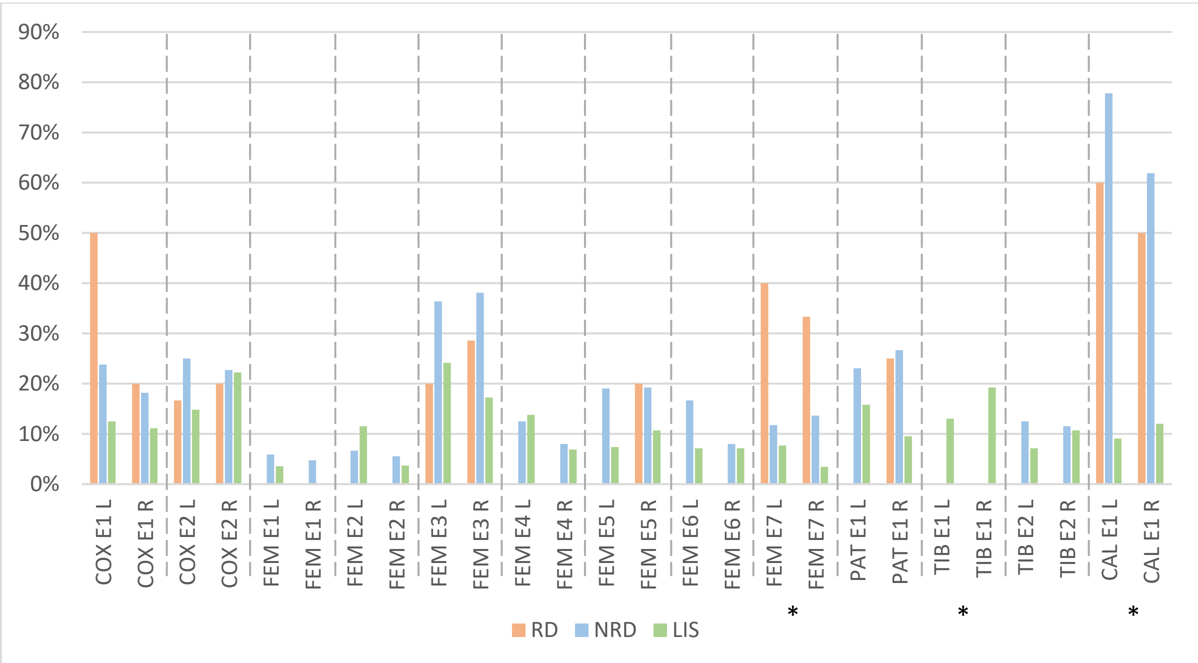

Figure 24. Frequency of entheseal changes observed for young and mature adult individuals (YMA) from the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS). See Table 9 for the entheses' codes; * indicates statistically significant differences between groups (see Table 17)

Table 17. Frequency of entheseal changes observed in young and mature adult individuals (YMA) from the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

Enthesis	RD YMA			NRD YMA			LIS YMA			*p* exact	*p* exact adjusted		
	N	*n*	*n/N*	*N*	*n*	*n/N*	*N*	*n*	*n/N*		RD-NRD	RD-LIS	NRD-LIS
COX E1 L	6	3	50%	21	5	24%	24	3	13%	.101	-	-	-
COX E1 R	5	1	20%	22	4	18%	27	3	11%	.627	-	-	-
COX E1 L+R	11	4	36%	43	9	21%	51	6	12%	.125	-	-	-
COX E2 L	6	1	17%	20	5	25%	27	4	15%	.776	-	-	-
COX E2 R	5	1	20%	22	5	23%	27	6	22%	1	-	-	-
COX E2 L+R	11	2	18%	42	10	24%	54	10	19%	.882	-	-	-
FEM E1 L	4	0	0%	17	1	6%	28	1	4%	1	-	-	-
FEM E1 R	4	0	0%	21	1	5%	26	0	0%	.490	-	-	-
FEM E1 L+R	8	0	0%	38	2	5%	54	1	2%	.664	-	-	-
FEM E2 L	4	0	0%	15	1	7%	26	3	12%	1	-	-	-
FEM E2 R	4	0	0%	18	1	6%	27	1	4%	1	-	-	-
FEM E2 L+R	8	0	0%	33	2	6%	53	4	8%	1	-	-	-
FEM E3 L	5	1	20%	22	8	36%	29	7	24%	.555	-	-	-
FEM E3 R	7	2	29%	21	8	38%	29	5	17%	.280	-	-	-
FEM E3 L+R	12	3	25%	43	16	37%	58	12	21%	.166	-	-	-
FEM E4 L	5	0	0%	16	2	13%	29	4	14%	1	-	-	-
FEM E4 R	6	0	0%	25	2	8%	29	2	7%	1	-	-	-
FEM E4 L+R	11	0	0%	41	4	10%	58	6	10%	.790	-	-	-
FEM E5 L	5	0	0%	21	4	19%	27	2	7%	.435	-	-	-
FEM E5 R	5	1	20%	26	5	19%	28	3	11%	.552	-	-	-
FEM E5 L+R	10	1	10%	47	9	19%	55	5	9%	.317	-	-	-
FEM E6 L	6	0	0%	24	4	17%	28	2	7%	.449	-	-	-
FEM E6 R	5	0	0%	25	2	8%	28	2	7%	1	-	-	-
FEM E6 L+R	11	0	0%	49	6	12%	56	4	7%	.542	-	-	-
FEM E7 L	5	2	40%	17	2	12%	26	2	8%	.198	-	-	-
FEM E7 R	3	1	33%	22	3	14%	29	1	3%	.138	-	-	-
FEM E7 L+R	8	3	38%	39	5	13%	55	3	5%	**.027**	.245	.070	.269
PAT E1 L	5	0	0%	13	3	23%	19	3	16%	.707	-	-	-
PAT E1 R	4	1	25%	15	4	27%	21	2	10%	.312	-	-	-
PAT E1 L+R	9	1	11%	28	7	25%	40	5	13%	.392	-	-	-
TIB E1 L	7	0	0%	21	0	0%	23	3	13%	.351	-	-	-
TIB E1 R	6	0	0%	24	0	0%	26	5	19%	.070	-	-	-
TIB E1 L+R	13	0	0%	45	0	0%	49	8	16%	**.004**	1	.372	**.018**
TIB E2 L	7	0	0%	24	3	13%	28	2	7%	.819	-	-	-
TIB E2 R	6	0	0%	26	3	12%	28	3	11%	1	-	-	-
TIB E2 L+R	13	0	0%	50	6	12%	56	5	9%	.606	-	-	-
CAL E1 L	5	3	60%	18	14	78%	22	2	9%	**< .001**	.576	.060	**< .001**
CAL E1 R	4	2	50%	21	13	62%	25	3	12%	**.001**	1	.253	**.002**
CAL E1 L+R	9	5	56%	39	27	69%	47	5	11%	**< .001**	.457	**.012**	**< .001**

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 entheses; *n*, number of affected entheses; see Table 9 for the entheses' codes

I.A.1.b. Individuals in all adult age categories

When we included all the individuals from our sample, regardless of the estimated age categories in the archaeological series and the known age in the documented collection, we could observe a total of 2241 entheses, of which 579 (26%) were affected by changes. The frequencies of EC were higher than when focusing only on YMA, and there were still more EC observed in the RD and NRD groups than in the LIS group (28%, 34%, and 17%, respectively, when left and right were combined; Table 18). On both sides, the difference between the three groups was statistically significant, and pairwise comparisons revealed that this difference was significant between the NRD and LIS groups, in particular (*p* adjusted < .001), as well as between the RD and LIS groups (*p* adjusted < .001). There was also a significantly higher frequency of EC in the RD group compared to the NRD group, but only when data from both sides were combined (*p* adjusted = .034).

Table 18. Frequency of all entheseal changes observed in individuals in all adult age categories from the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

	RD all			NRD all			LIS all			*p* exact	*p* exact adjusted		
	N	***n***	***n/N***	***N***	***n***	***n/N***	***N***	***n***	***n/N***		**RD-NRD**	**RD-LIS**	**NRD-LIS**
Left	168	48	29%	449	165	37%	489	91	19%	**< .001**	.058	**.017**	**< .001**
Right	158	43	27%	490	158	32%	487	74	15%	**< .001**	.277	**.002**	**< .001**
Left+Right	326	91	28%	939	323	34%	976	165	17%	**< .001**	**.034**	**< .001**	**< .001**

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 entheses; *n*, number of entheses affected

Those EC concerned a total of 86 individuals (84%) among the entire sample of 102 who were considered as observable (i.e., when at least half of the entheses were observable on each side). A higher proportion of individuals were affected by at least one EC in the RD (94%) and NRD (91%) groups compared to the LIS group (73%; Table 19). This difference was statistically significant (*p* = .043).

Table 19. Frequency of individuals in all adult age categories with at least one enthesis affected by changes in the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

	RD all			NRD all			LIS all			*p* exact	*p* exact adjusted		
	N	***n***	***n/N***	***N***	***n***	***n/N***	***N***	***n***	***n/N***		**RD-NRD**	**RD-LIS**	**NRD-LIS**
Left	17	14	82%	41	37	90%	42	27	64%	**.012**	.444	.444	**.024**
Right	17	16	94%	45	36	80%	40	24	60%	**.016**	.260	**.034**	.115
Left+Right	17	16	94%	44	40	91%	41	30	73%	**.043**	1	.177	.137

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; *n*, number of individuals with at least one enthesis affected by changes

Pairwise comparisons with corrected *p* values revealed that there were significantly more individuals affected by EC in the NRD group (90%) compared to the LIS group (64%) considering only EC on the left side (*p* adjusted = .024), and more in the RD group (94%) compared to the LIS group (60%) on the right side (*p* adjusted = .034). There was, however, no significant difference between sides.

The frequencies of EC observed in each group and the results of the statistical comparisons between groups are shown in Table 20 and Figure 25.

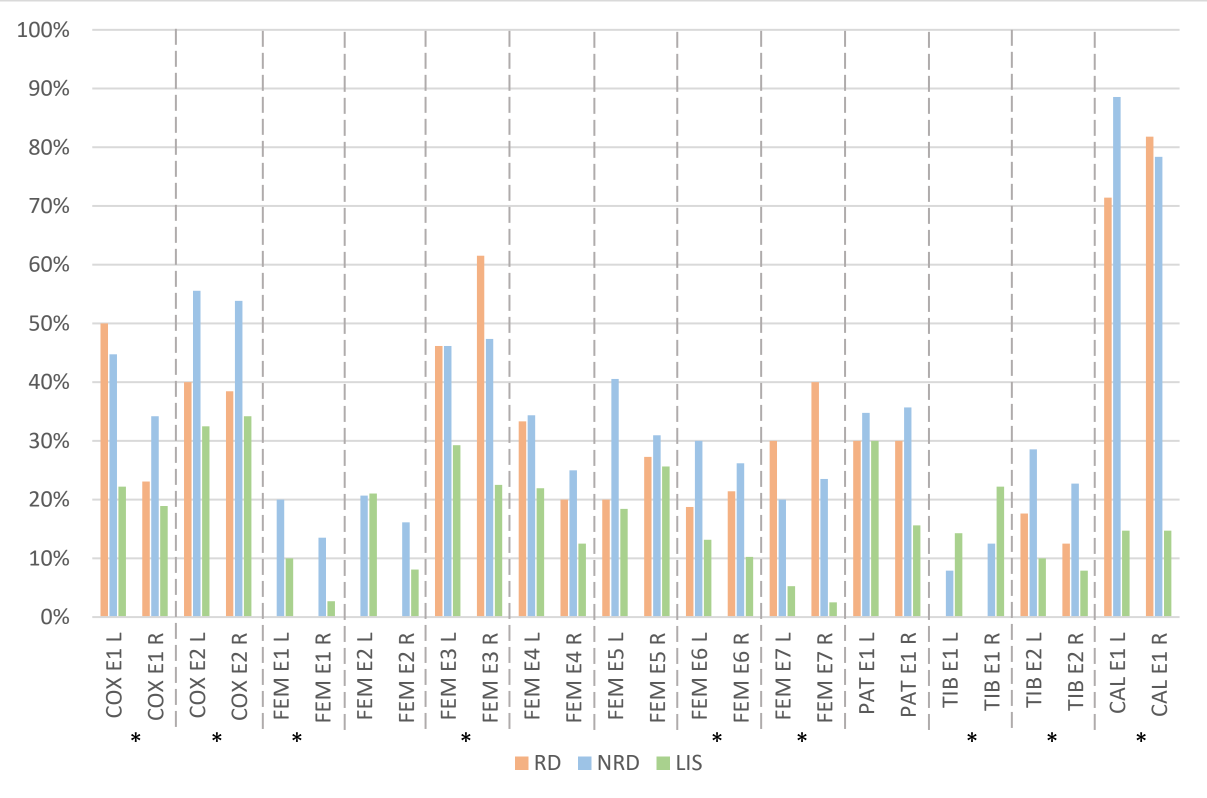

Figure 25. Frequency of entheseal changes observed in individuals in all adult age categories from the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS). See Table 9 for the entheses' codes; * indicates statistically significant differences between groups (see Table 20)

The number of observations for each enthesis was less limited than when selecting only YMA individuals. The EC that were the most frequently observed in the entire sample still concerned the calcaneal tuberosity (CAL E1, 54%), while the least frequently observed EC were also still those of the anterior surface of the greater trochanter of the femur (FEM E1, 10%). There was no significant difference between sides, even if 11 out of 13 entheses were slightly more affected on the left side. The NRD group showed the highest frequencies for a majority of EC (10/13).

Table 20. Frequency of entheseal changes observed in individuals in all adult age categories from the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

Enthesis	RD all			NRD all			LIS all			*p*	*p* exact adjusted		
	N	*n*	*n/N*	*N*	*n*	*n/N*	*N*	*n*	*n/N*	exact	RD-NRD	RD-LIS	NRD-LIS
COX E1 L	14	7	50%	38	17	45%	36	8	22%	.062	-	-	-
COX E1 R	13	3	23%	38	13	34%	37	7	19%	.345	-	-	-
COX E1 L+R	27	10	37%	76	30	39%	73	15	21%	**.033**	1	.238	**.039**
COX E2 L	15	6	40%	36	20	56%	40	13	33%	.131	-	-	-
COX E2 R	13	5	38%	39	21	54%	38	13	34%	.208	-	-	-
COX E2 L+R	28	11	39%	75	41	55%	78	26	33%	**.025**	.378	.646	**.028**
FEM E1 L	11	0	0%	30	6	20%	40	4	10%	.225	-	-	-
FEM E1 R	10	0	0%	37	5	14%	37	1	3%	.211	-	-	-
FEM E1 L+R	21	0	0%	67	11	16%	77	5	6%	**.047**	.179	.582	.179
FEM E2 L	6	0	0%	29	6	21%	38	8	21%	.739	-	-	-
FEM E2 R	8	0	0%	31	5	16%	37	3	8%	.470	-	-	-
FEM E2 L+R	14	0	0%	60	11	18%	75	11	15%	.233	-	-	-
FEM E3 L	13	6	46%	39	18	46%	41	12	29%	.263	-	-	-
FEM E3 R	13	8	62%	38	18	47%	40	9	23%	**.014**	.523	**.047**	.063
FEM E3 L+R	26	14	54%	77	36	47%	81	21	26%	**.006**	.651	**.030**	**.024**
FEM E4 L	12	4	33%	32	11	34%	41	9	22%	.428	-	-	-
FEM E4 R	15	3	20%	40	10	25%	40	5	13%	.411	-	-	-
FEM E4 L+R	27	7	26%	72	21	29%	81	14	17%	.201	-	-	-
FEM E5 L	15	3	20%	37	15	41%	38	7	18%	.094	-	-	-
FEM E5 R	11	3	27%	42	13	31%	39	10	26%	.897	-	-	-
FEM E5 L+R	26	6	23%	79	28	35%	77	17	22%	.150	-	-	-
FEM E6 L	16	3	19%	40	12	30%	38	5	13%	.197	-	-	-
FEM E6 R	14	3	21%	42	11	26%	39	4	10%	.179	-	-	-
FEM E6 L+R	30	6	20%	82	23	28%	77	9	12%	**.034**	.704	.704	**.032**
FEM E7 L	10	3	30%	30	6	20%	38	2	5%	.061	-	-	-
FEM E7 R	10	4	40%	34	8	24%	40	1	3%	**.002**	.422	**.012**	**.019**
FEM E7 L+R	20	7	35%	64	14	22%	78	3	4%	**< .001**	.250	**.001**	**.003**
PAT E1 L	10	3	30%	23	8	35%	30	9	30%	.934	-	-	-
PAT E1 R	10	3	30%	28	10	36%	32	5	16%	.216	-	-	-
PAT E1 L+R	20	6	30%	51	18	35%	62	14	23%	.312	-	-	-
TIB E1 L	15	0	0%	38	3	8%	35	5	14%	.328	-	-	-
TIB E1 R	14	0	0%	40	5	13%	36	8	22%	.137	-	-	-
TIB E1 L+R	29	0	0%	78	8	10%	71	13	18%	**.021**	.209	.053	.238
TIB E2 L	17	3	18%	42	12	29%	40	4	10%	.105	-	-	-
TIB E2 R	16	2	13%	44	10	23%	38	3	8%	.187	-	-	-
TIB E2 L+R	33	5	15%	86	22	26%	78	7	9%	**.018**	.656	.656	**.021**
CAL E1 L	14	10	71%	35	31	89%	34	5	15%	**< .001**	.202	**.001**	**< .001**
CAL E1 R	11	9	82%	37	29	78%	34	5	15%	**< .001**	1	**< .001**	**< .001**
CAL E1 L+R	25	19	76%	72	60	83%	68	10	15%	**< .001**	.551	**< .001**	**< .001**

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 entheses; *n*, number of affected entheses; see Table 9 for the entheses' codes

There was a statistically significant difference between groups for 9 entheses: the anterior inferior iliac spine (COX E1), the ischial tuberosity (COX E2), the anterior surface of the greater trochanter (FEM E1), the trochanteric fossa (FEM E3), the *linea aspera* (FEM E6), the adductor tubercle (FEM E7), the tibial tuberosity (TIB E1), the soleal line (TIB E2), and the calcaneal tuberosity (CAL E1). Except for FEM E1 and TIB E1, pairwise comparisons showed for each enthesis a significant difference between the NRD group and the LIS group, in which EC were less frequent. For FEM E3, FEM E7, and FEM E7, there was also a significantly higher frequency of EC in the RD group compared to the LIS group. The largest differences observed concerned CAL E1 and were between the NRD (89%) and LIS (15%) groups on the left side (p adjusted < .001), and the RD (82%) and LIS (15%) groups on the right side. There was no significant difference between both Hungarian archaeological groups for any enthesis.

I.A.2. Bilateral asymmetry

Side dominance was analyzed using pairs of bones, which leads to smaller sample sizes. Considering the limited amount of entheses that were already observable in the sample of young and mature adults, we used paired bones from individuals in all adult age categories for this analysis.

The results are shown in Table 21. In general, the left and right sides were equivalent, either in absence or presence of EC. The differences observed between sides tended to show more often a left-side dominance (presence on the left side and absence on the right side) for all groups, but these differences were light. The enthesis concerned the most by asymmetry was the trochanteric fossa (FEM E3), with 20% of unequal scores in the RD group, 27% in the NRD group, and 18% in the LIS group. Specifically, there was 20%, 15%, and 8% of right-side dominance in the RD, NRD, and LIS groups, respectively, while there was 0%, 12%, and 11% of left-side dominance. There was no statistically significant difference in the pattern of asymmetry between groups.

Table 21. Bilateral asymmetry for the entheseal changes observed on paired bones in individuals in all adult age categories from the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

Enthesis	Asymmetry	RD		NRD		LIS		*p* exact
		n	*n/N*	*n*	*n/N*	*n*	*n/N*	
COX E1	R = L	9	90%	30	94%	29	91%	.634
	R > L	0	0%	0	0%	2	6%	
	L > R	1	10%	2	6%	1	3%	
	N pairs	10		32		32		
COX E2	R = L	11	92%	31	94%	27	77%	.349
	R > L	1	8%	1	3%	5	14%	
	L > R	0	0%	1	3%	3	9%	
	N pairs	12		33		35		
FEM E1	R = L	6	100%	26	93%	34	97%	.682
	R > L	0	0%	0	0%	0	0%	
	L > R	0	0%	2	7%	1	3%	
	N pairs	6		28		35		
FEM E2	R = L	3	100%	21	91%	32	94%	.305
	R > L	0	0%	2	9%	0	0%	
	L > R	0	0%	0	0%	2	6%	
	N pairs	3		23		34		
FEM E3	R = L	8	80%	24	73%	31	82%	.680
	R > L	2	20%	5	15%	3	8%	
	L > R	0	0%	4	12%	4	11%	
	N pairs	10		33		38		
FEM E4	R = L	10	91%	26	93%	33	87%	.824
	R > L	0	0%	1	4%	1	3%	
	L > R	1	9%	1	4%	4	11%	
	N pairs	11		28		38		
FEM E5	R = L	9	100%	33	97%	34	97%	1
	R > L	0	0%	0	0%	1	3%	
	L > R	0	0%	1	3%	0	0%	
	N pairs	9		34		35		
FEM E6	R = L	13	100%	37	97%	34	100%	1
	R > L	0	0%	0	0%	0	0%	
	L > R	0	0%	1	3%	0	0%	
	N pairs	13		38		34		
FEM E7	R = L	7	100%	25	100%	34	97%	1
	R > L	0	0%	0	0%	0	0%	
	L > R	0	0%	0	0%	1	3%	
	N pairs	7		25		35		
PAT E1	R = L	7	100%	14	88%	22	81%	.094
	R > L	0	0%	2	13%	0	0%	
	L > R	0	0%	0	0%	5	19%	
	N pairs	7		16		27		
TIB E1	R = L	13	100%	29	88%	29	91%	.775
	R > L	0	0%	3	9%	3	9%	
	L > R	0	0%	1	3%	0	0%	
	N pairs	13		33		32		
TIB E2	R = L	15	94%	34	85%	35	97%	.301
	R > L	0	0%	2	5%	1	3%	
	L > R	1	6%	4	10%	0	0%	
	N pairs	16		40		36		
CAL E1	R = L	10	100%	30	94%	28	93%	.892
	R > L	0	0%	0	0%	1	3%	
	L > R	0	0%	2	6%	1	3%	
	N pairs	10		32		30		

Fisher's exact test, two-sided; L, left side; R, right side; Asymmetry calculated as right side minus left side; R = L, equal scores; R > L, right score higher; L > R, left score higher

I.B. Results of the analysis of joint changes

I.B.1. Intergroup comparisons

I.B.1.a. Young and mature adult individuals

A total of 463 joints (as presented in Chapter 2, and apart from the *fovea capitis* case) could be observed in all young and mature adults, and 62 (13%) showed changes. There was no significant difference between sides. There were more joint changes observed in the LIS group than in the RD and the NRD groups (17%, 4%, and 11%, respectively, when left and right were combined; Table 22). The difference between the 3 groups was statistically significant (p = .044), even if pairwise comparisons with corrected p values did not reveal any significant difference between pairs of groups.

Table 22. Frequency of all joint changes observed in the young and mature adult individuals (YMA) from the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

	RD YMA			NRD YMA			LIS YMA			*p*	*p* exact adjusted		
	N	*n*	*n/N*	*N*	*n*	*n/N*	*N*	*n*	*n/N*	exact	RD-NRD	RD-LIS	NRD-LIS
Left	24	1	4%	87	11	13%	118	19	16%	.316	-	-	-
Right	21	1	5%	93	9	10%	120	21	18%	.165	-	-	-
Left+Right	45	2	4%	180	20	11%	238	40	17%	**.044**	.263	.113	.242

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 joints; *n*, number of affected joints

Those changes concerned a total of 26 young and mature adult individuals (43%) among the entire sample of 60 who were considered as observable (i.e., when at least half of the joints were observable on each side). There was no significant difference between sides. A higher proportion of individuals showed changes at a minimum of one joint in the LIS group (52%) compared to the NRD (38%) and RD (29%) groups (Table 23). This difference was not statistically significant (p = .493).

Table 23. Frequency of young and mature adult individuals (YMA) with at least one joint affected by changes in the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

	RD YMA			NRD YMA			LIS YMA			*p*
	N	*n*	*n/N*	*N*	*n*	*n/N*	N	n	n/N	exact
Left	7	1	14%	24	6	25%	30	11	37%	.447
Right	6	1	17%	26	6	23%	30	12	40%	.335
Left+Right	7	2	29%	24	9	38%	29	15	52%	.493

Fisher's exact test, two-tailed; *N*, number of observable individuals; *n*, number of individuals with at least one joint affected by changes

The frequencies of joint changes observed in each group and the results of the statistical comparisons between groups are shown in Table 24 and Figure 26.

Table 24. Frequency of joint changes observed in young and mature adult individuals (YMA) from the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

Joint	RD YMA			NRD YMA			LIS YMA			*p* exact
	N	*n*	*n/N*	*N*	*n*	*n/N*	*N*	*n*	*n/N*	
Acetabulofemoral L	7	1	14%	24	5	21%	30	7	23%	1
Acetabulofemoral R	6	1	17%	24	4	17%	31	8	26%	.807
Acetabulofemoral L+R	13	2	15%	48	9	19%	61	15	25%	.729
Patellofemoral L	5	0	0%	20	1	5%	30	5	17%	.528
Patellofemoral R	5	0	0%	19	1	5%	30	5	17%	.532
Patellofemoral L+R	10	0	0%	39	2	5%	60	10	17%	.151
Tibiofemoral L	5	0	0%	20	4	20%	30	4	13%	.627
Tibiofemoral R	4	0	0%	24	3	13%	30	5	17%	.848
Tibiofemoral L+R	9	0	0%	44	7	16%	60	9	15%	.603
Talocrural L	7	0	0%	23	1	4%	28	3	11%	.775
Talocrural R	6	0	0%	26	1	4%	29	3	10%	.747
Talocrural L+R	13	0	0%	49	2	4%	57	6	11%	.419

Fisher's exact test, two-tailed; *N*, number of observable joints; *n*, number of affected joints

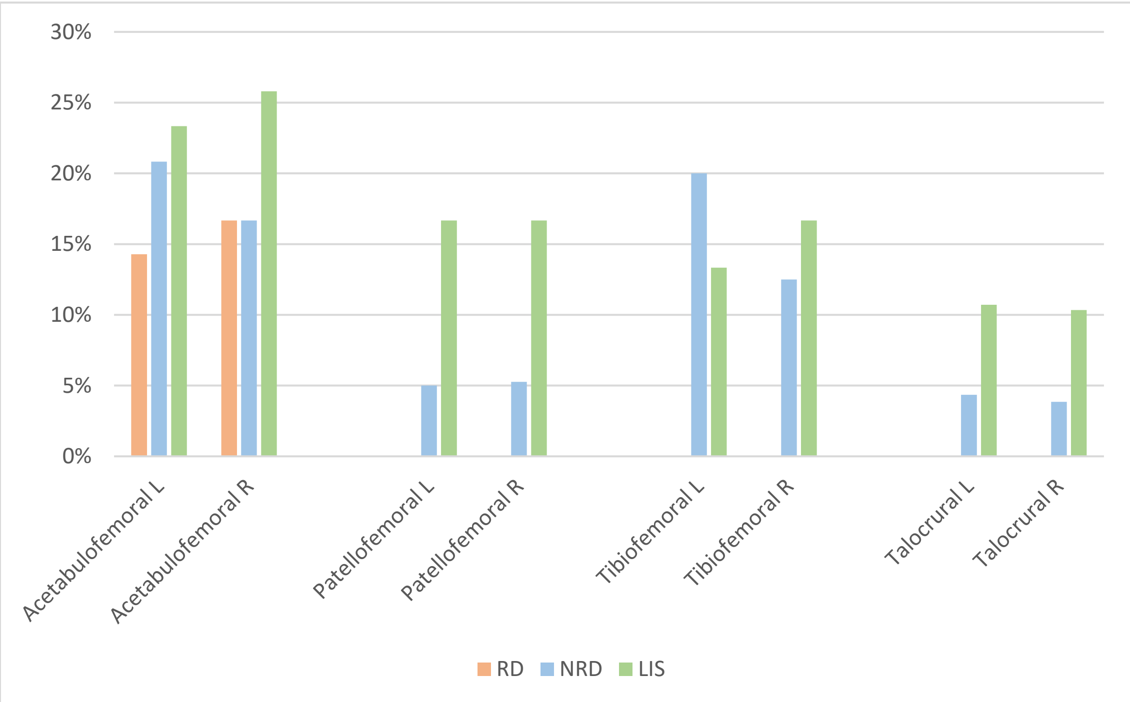

Figure 26. Frequency of joint changes observed for young and mature adult individuals (YMA) from the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS)

The number of observations for each joint was rather limited due to the small sample size of YMA individuals and bone preservation in the archaeological materials and in the RD group, in particular. The joint changes that were the most frequently observed in the entire sample concerned the acetabulofemoral joint (21%), while the least frequently observed joint changes were those of the talocrural joint (7%). There was no significant difference between sides. The

LIS group showed the highest frequencies for all joints, except for the tibiofemoral joint where the frequency was higher for the NRD group on the left side (20% versus 13%). There was no statistically significant difference between groups.

Regarding the perifoveal osteophytes on the femoral head, in particular, the frequency was higher in the NRD group (38%) compared to the LIS (25%) and RD (22%) groups (Table 25). There was no significant difference according to the side within each group, neither there was between groups.

Table 25. Frequency of perifoveal osteophytes (femoral head) observed in young and mature adult individuals (YMA) from the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

Site	RD YMA			NRD YMA			LIS YMA			*p*
	N	***n***	***n/N***	***N***	***n***	***n/N***	***N***	***n***	***n/N***	**exact**
***Fovea capitis* L**	6	1	17%	19	7	37%	30	8	27%	.687
***Fovea capitis* R**	3	1	33%	20	8	40%	30	7	23%	.438
***Fovea capitis* L+R**	9	2	22%	39	15	38%	60	15	25%	.322

Fisher's exact test, two-tailed; *N*, number of observable joints; *n*, number of affected joints

I.B.1.b.Individuals in all adult age categories

A total of 774 joints (as presented in Chapter 2, and apart from the *fovea capitis* case) could be observed in individuals in all adult age categories, and 193 (25%) showed changes. There was no significant difference between sides and the frequency of joint changes was approximately equivalent between groups (Table 26).

Table 26. Frequency of joint changes observed in individuals in all adult age categories from the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

	RD all			NRD all			LIS all			*p*
	N	***n***	***n/N***	***N***	***n***	***n/N***	***N***	***n***	***n/N***	**exact**
Left	57	14	25%	150	37	25%	178	44	25%	1
Right	58	15	26%	159	44	28%	172	39	23%	.576
Left+Right	115	29	25%	309	81	26%	350	83	24%	.760

Fisher's exact test, two-tailed; *N*, number of observable joints; *n*, number of affected joints

Those joint changes concerned a total of 65 individuals in all adult age categories (63%) among the entire sample of 103 who were considered as observable (i.e., when at least half of the joints were observable on each side). There was also no significant difference between sides and groups (Table 27).

Table 27. Frequency of individuals in all adult age categories with at least one joint affected by changes in the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

	RD all			NRD all			LIS all			*p* exact
	N	*n*	*n/N*	*N*	*n*	*n/N*	N	n	n/N	
Left	16	9	56%	42	21	50%	45	22	49%	.930
Right	16	8	50%	45	25	56%	43	22	51%	.897
Left+Right	16	10	63%	43	28	65%	44	27	61%	.961

Fisher's exact test, two-tailed; *N*, number of observable individuals; *n*, number of individuals with at least one joint affected by changes

The frequencies of joint changes observed in each group and the results of the statistical comparisons between groups are shown in Table 28 and Figure 27.

Table 28. Frequency of joint changes observed in individuals in all adult age categories from the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

Joint	RD all			NRD all			LIS all			*p* exact
	N	*n*	*n/N*	*N*	*n*	*n/N*	*N*	*n*	*n/N*	
Acetabulofemoral L	15	6	40%	42	18	43%	45	16	36%	.762
Acetabulofemoral R	15	5	33%	43	20	47%	44	13	30%	.245
Acetabulofemoral L+R	30	11	37%	85	38	45%	89	29	33%	.260
Patellofemoral L	13	2	15%	34	6	18%	45	12	27%	.574
Patellofemoral R	14	3	21%	34	7	21%	43	11	26%	.943
Patellofemoral L+R	27	5	19%	68	13	19%	88	23	26%	.529
Tibiofemoral L	12	5	42%	34	10	29%	45	9	20%	.241
Tibiofemoral R	14	6	43%	39	13	33%	43	10	23%	.290
Tibiofemoral L+R	26	11	42%	73	23	32%	88	19	22%	.088
Talocrural L	17	1	6%	40	3	8%	43	7	16%	.396
Talocrural R	15	1	7%	43	4	9%	42	5	12%	.907
Talocrural L+R	32	2	6%	83	7	8%	85	12	14%	.429

Fisher's exact test, two-tailed; *N*, number of observable joints; *n*, number of affected joints

The number of observations for each joint was less limited than on the YMA individuals. The joint changes that were the most frequently observed in the entire sample still concerned the acetabulofemoral joint (38%), while the least frequently observed joint changes were those of the talocrural joint (11%). There was no significant difference between sides. Unlike with YMA only, the LIS group showed the highest frequencies only in the case of the patellofemoral and talocrural joints, while joint changes were more frequent in the NRD group for the acetabulofemoral joint (45%), and in the RD group for the tibiofemoral joint (42%). This joint showed the largest difference, between the RD group and the LIS group (22%). There was, however, no statistically significant difference between groups. We also observed that the frequencies were closer between the RD and NRD groups than compared to the LIS group.

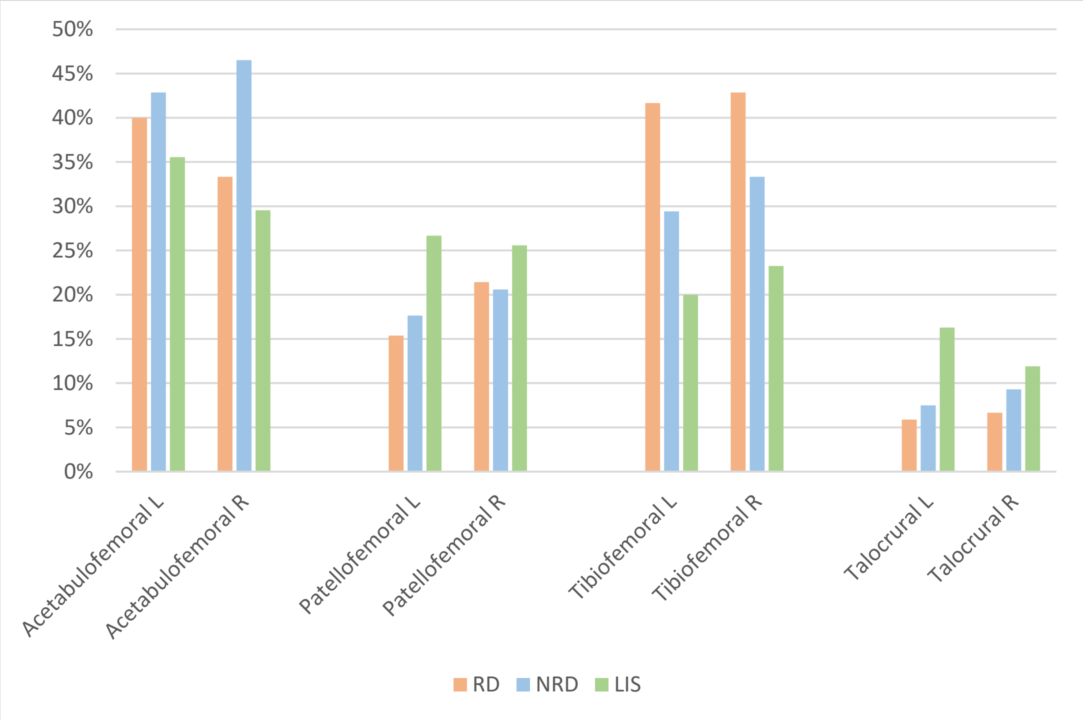

Figure 27. Frequency of joint changes observed in individuals in all adult age categories from the Hungarian groups with (RD) and without (NRD) riding deposit and the comparison group from Lisbon (LIS)

Regarding the perifoveal osteophytes on the femoral head, in particular, the frequency was higher in the RD (57%) and NRD groups (53%), compared to the LIS group (34%; Table 29). This difference was statistically significant (p = .032), even if the pairwise comparisons with corrected p values did not indicate any significant difference between pairs of groups. There was no significant difference between sides.

Table 29. Frequency of perifoveal osteophytes (femoral head) observed in individuals in all adult age categories from the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

Joint	RD all			NRD all			LIS all			*p* exact	*p* exact adjusted		
	N	*n*	*n/N*	*N*	*n*	*n/N*	*N*	*n*	*n/N*		RD-NRD	RD-LIS	NRD-LIS
Fovea L	12	6	50%	32	15	47%	44	15	34%	.418	-	-	-
Fovea R	9	6	67%	34	20	59%	43	15	35%	.056	-	-	-
Fovea L+R	21	12	57%	66	35	53%	87	30	34%	**.032**	.805	.160	.094

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, observable joints; n, affected joints

I.B.2. Bilateral asymmetry

As for the EC, we used paired bones from individuals in all adult age categories for the analysis of bilateral asymmetry.

The results are shown in Table 30. In general, there was no strong asymmetry within each group. The joint that was concerned the most by asymmetry was the acetabulofemoral joint

(RD, 21%; NRD, 15%; LIS, 16%), with a higher frequency of joint changes on the left side in the RD and LIS groups, and a higher frequency of joint changes on the right side in the NRD groups. These differences were, however, small, and based on a rather limited number of observations. There was no statistically significant difference in the pattern of asymmetry between groups.

Table 30. Bilateral asymmetry for the joint changes observed in individuals in all adult age categories from the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

Joint	Bilateral asymmetry	RD all		NRD all		LIS all		*p* exact
		n	*n/N*	*n*	*n/N*	*n*	*n/N*	
Acetabulofemoral	R = L	11	79%	34	85%	36	84%	.797
	R > L	1	7%	4	10%	3	7%	
	L > R	2	14%	2	5%	4	9%	
	N pairs	14		40		43		
Patellofemoral	R = L	11	92%	26	90%	37	88%	1
	R > L	1	8%	2	7%	3	7%	
	L > R	0	0%	1	3%	2	5%	
	N pairs	12		29		42		
Tibiofemoral	R = L	11	100%	26	84%	35	83%	.853
	R > L	0	0%	4	13%	5	12%	
	L > R	0	0%	1	3%	2	5%	
	N pairs	11		31		42		
Talocrural	R = L	15	100%	35	92%	37	93%	.949
	R > L	0	0%	2	5%	1	3%	
	L > R	0	0%	1	3%	2	5%	
	N pairs	15		38		40		

Fisher's exact test, two-sided; L, left side; R, right side; Asymmetry calculated as right side minus left side; R = L, equal scores; R > L, right score higher; L > R, left score higher

Regarding the perifoveal osteophytes on the femoral head, there was also no strong side dominance within each group, nor was there any statistically significant difference in the pattern of asymmetry between groups (Table 31).

Table 31. Bilateral asymmetry for the perifoveal osteophytes (femoral head) observed in individuals in all adult age categories from the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

Site	Bilateral asymmetry	RD all		NRD all		LIS all		*p* exact
		n	*n/N*	*n*	*n/N*	*n*	*n/N*	
Fovea capitis	R = L	8	89%	24	89%	36	88%	.782
	R > L	1	11%	3	11%	3	7%	
	L > R	0	0%	0	0%	2	5%	
	N pairs	9		27		41		

Fisher's exact test, two-sided; L, left side; R, right side; Asymmetry calculated as right side minus left side; R = L, equal scores; R > L, right score higher; L > R, left score higher

I.C. Results of the analysis of morphological variants of the femur

I.C.1. Intergroup comparisons

We could observe a total of 295 (27%) morphological variants of the femur out of 1075 observable sites. There was no significant difference between sides. There were more variants observed in the RD and NRD groups than in the LIS group (37%, 31%, and 22%, respectively, when left and right were combined; Table 32). The difference between the 3 groups was statistically significant, regardless of the side, and pairwise comparisons with corrected *p* values revealed that this significant difference concerned the RD and LIS groups (*p* adjusted = .002), and the NRD and LIS groups (*p* adjusted = .006).

Table 32. Frequency of all morphological variants of the femur in the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

	RD			NRD			LIS			*p* exact	*p* exact adjusted		
	N	***n***	***n/N***	***N***	***n***	***n/N***	***N***	***n***	***n/N***		**RD-NRD**	**RD-LIS**	**NRD-LIS**
Left	77	31	40%	203	59	29%	251	57	23%	**.010**	.172	**.010**	.172
Right	65	21	32%	238	76	32%	241	51	21%	**.017**	1	.140	**.029**
Left+Right	142	52	37%	441	135	31%	492	108	22%	**< .001**	.215	**.002**	**.006**

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 sites; *n*, number of bone sites with a morphological variant

Those morphological variants concerned a total of 101 individuals (94%) among the entire sample of 107 who were considered as observable (i.e., when at least half of the sites were observable on each side). There was no significant difference between sides. A higher proportion of individuals was affected by at least one morphological variant in the RD group (100%) compared to the NRD (93%) and LIS groups (93%; Table 33). This difference was not statistically significant (*p* = .739), nor was it when individuals were considered separately depending on if they were affected on their left or right side (*p* = .325 and *p* = .681, respectively).

Table 33. Frequency of individuals with at least one morphological variant on the femur in the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

	RD			NRD			LIS			*p* exact
	N	***n***	***n/N***	***N***	***n***	***n/N***	***N***	***n***	***n/N***	
Left	15	15	100%	39	34	87%	44	41	93%	.315
Right	13	11	85%	43	40	93%	42	39	93%	.681
Left+Right	15	15	100%	46	43	93%	46	43	93%	.739

Fisher's exact test, two-tailed; *N*, number of observable individuals; *n*, number of individuals with at least one morphological variant

The frequencies of morphological variants of the femur observed in each group and the results of the statistical comparisons between groups are shown in Table 34 and Figure 28.

Table 34. Frequency of morphological variants of the femur in the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

Morphological variant	RD			NRD			LIS			*p* exact	*p* exact adjusted		
	N	*n*	*n/N*	*N*	*n*	*n/N*	*N*	*n*	*n/N*		RD-NRD	RD-LIS	NRD-LIS
FEM V1 L	11	6	55%	34	5	15%	43	7	16%	**.022**	**.043**	**.043**	1
FEM V1 R	9	3	33%	39	11	28%	42	6	14%	.202	-	-	-
FEM V1 L+R	20	9	45%	73	16	22%	85	13	15%	**.018**	.309	**.019**	.099
FEM V2 L	13	7	54%	36	27	75%	43	36	84%	.098	-	-	-
FEM V2 R	9	8	89%	41	27	66%	42	33	79%	.266	-	-	-
FEM V2 L+R	22	15	68%	77	54	70%	85	69	81%	.203	-	-	-
FEM V3 L	13	2	15%	33	3	9%	34	3	9%	.777	-	-	-
FEM V3 R	9	0	0%	39	5	13%	31	2	6%	.527	-	-	-
FEM V3 L+R	22	2	9%	72	8	11%	65	5	8%	.869	-	-	-
FEM V4 L	10	2	20%	26	2	8%	44	4	9%	.510	-	-	-
FEM V4 R	13	1	8%	37	8	22%	43	3	7%	.162	-	-	-
FEM V4 L+R	23	3	13%	63	10	16%	87	7	8%	.315	-	-	-
FEM V5 L	15	10	67%	33	16	48%	44	5	11%	**< .001**	.351	**< .001**	**.001**
FEM V5 R	12	8	67%	39	19	49%	41	5	12%	**< .001**	.335	**.001**	**.001**
FEM V5 L+R	27	18	67%	72	35	49%	85	10	12%	**< .001**	.120	**< .001**	**< .001**
FEM V6 L	15	4	27%	41	6	15%	43	2	5%	.052	-	-	-
FEM V6 R	13	1	8%	43	6	14%	42	2	5%	.390	-	-	-
FEM V6 L+R	28	5	18%	84	12	14%	85	4	5%	**.034**	.762	.115	.115

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; see Table 11 for the variants' codes; *N*, number of observable sites; *n*, number of sites with a morphological variant

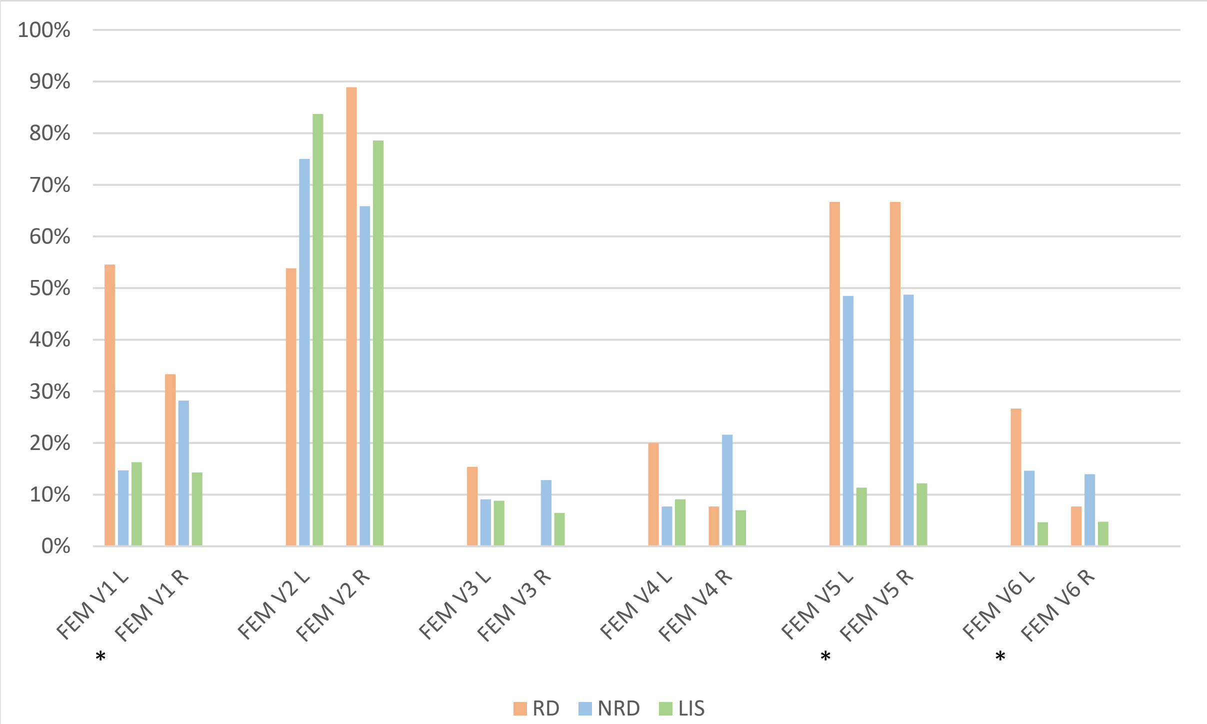

Figure 28. Frequency of morphological variants of the femur in the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS). * indicates statistically significant differences between groups (see Table 34)

The morphological variant that was the most frequently observed in the entire sample is the anteroiliac plaque (FEM V2, 75%), while the least frequently observed was Allen's fossa (FEM V3, 9%). There was no statistically significant difference between sides, even if we notably noted a higher frequency of FEM V2 on the right side (89% versus 54% on the left side) in the RD group. The highest frequencies were found in the RD group for three morphological variants: Poirier's facet (FEM V1), the third trochanter (FEM V5), and the hypotrochanteric fossa (FEM V6). The NRD group showed the highest frequencies for Allen's fossa and the posterior cervical imprint (FEM V4), while the LIS group showed the highest frequencies for the anteroiliac plaque. These differences were statistically significant only for FEM V1, FEM V5, and FEM V6. Pairwise comparisons with corrected p values revealed that FEM V1 was significantly more frequent in the RD group (55%) than in the NRD (15%) and LIS groups (16%) for the left side, in particular (p adjusted = .043 for each). The frequency of FEM V5 was significantly higher in the RD (67%) and NRD (49%) groups than in the LIS group (12%; p adjusted < .001). FEM V6 did not show any significant difference between pairs of groups, but the frequency was higher in the RD (18%) and NRD (14%) groups than in the LIS group (5%).

I.C.2. Bilateral asymmetry

Analyzing only paired femurs, we did not observe any strong asymmetry within each group (Table 35). The morphological variant that was concerned the most by asymmetry was the posterior cervical imprint (FEM V4), with 11% in the RD group (left-side dominance), 13% in the NRD group (right-side dominance), and 4% in the LIS group (2% of left-side dominance and 2% of right-side dominance). There was no statistically significant difference in the pattern of asymmetry between groups.

Table 35. Bilateral asymmetry for the morphological variants of the femur in the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

Morphological variant	Bilateral asymmetry	RD		NRD		LIS		*p* exact
		n	*n/N*	*n*	*n/N*	*n*	*n/N*	
FEM V1	R = L	7	100%	29	91%	38	97%	.272
	R > L	0	0%	3	9%	0	0%	
	L > R	0	0%	0	0%	1	3%	
	N pairs	7		32		39		
FEM V2	R = L	6	86%	31	94%	38	97%	.121
	R > L	1	14%	0	0%	0	0%	
	L > R	0	0%	2	6%	1	3%	
	N pairs	7		33		39		
FEM V3	R = L	8	100%	30	97%	28	97%	.796
	R > L	0	0%	1	3%	0	0%	
	L > R	0	0%	0	0%	1	3%	
	N pairs	8		31		29		
FEM V4	R = L	8	89%	20	87%	39	95%	.144
	R > L	0	0%	3	13%	1	2%	
	L > R	1	11%	0	0%	1	2%	
	N pairs	9		23		41		
FEM V5	R = L	10	91%	28	97%	38	97%	.344
	R > L	1	9%	0	0%	0	0%	
	L > R	0	0%	1	3%	1	3%	
	N pairs	11		29		39		
FEM V6	R = L	11	100%	36	97%	39	100%	.552
	R > L	0	0%	0	0%	0	0%	
	L > R	0	0%	1	3%	0	0%	
	N pairs	11		37		39		

Fisher's exact test, two-sided; L, left side; R, right side; asymmetry calculated as right side minus left side; R = L, equal scores; R > L, right score higher; L > R, left score higher

I.D. Results of the analysis of vertebral changes

I.D.1. Schmorl's nodes

A total of 95 individuals had observable and identifiable vertebrae from the first thoracic to the first sacral one, and 77 (81%) of them were affected by at least one Schmorl's node (SN) on the superior or inferior endplate of a vertebra. The frequency of individuals with SN was higher concerning the lower thoracic vertebrae (from the seventh to the twelfth) and it was lower regarding the upper thoracic vertebrae (Table 36). This difference was statistically significant for the NRD (Fisher's exact test, $p = .002$) and LIS groups ($p < .001$) but not for the RD group ($p = .286$). In details, in the NRD group, there were significantly more individuals with SN at the lower thoracic level compared to the upper thoracic one (*p* adjusted = .002), and at the lower thoracic level compared to the lumbar level (*p* adjusted = .047). It was the same situation in the LIS group (*p* adjusted < .001 in both cases). Still focusing on the frequency of individuals affected by SN (Table 36), we also observed higher frequencies of affected individuals in the RD group at all levels, while the lowest frequencies were found in the LIS group. There was no statistically significant difference between groups, but we noticed rather large differences between the RD group and the LIS group, in particular, at the upper thoracic and lumbar levels (50% versus 20% with *p* adjusted = .051, and 58% versus 30% with *p* adjusted = .055, respectively). The frequency of individuals with SN was more homogenous between groups at the lower thoracic level.

Table 36. Frequency of individuals with at least one vertebra affected by a Schmorl's node in the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

	RD			NRD			LIS			*p* exact
	N	***n***	***n/N***	***N***	***n***	***n/N***	***N***	***n***	***n/N***	
T1-T6	10	5	50%	37	15	41%	45	9	20%	.051
T7-T12	12	10	83%	36	29	81%	45	34	76%	.830
L1-L5+S1	12	7	58%	35	19	54%	46	14	30%	.055
All	12	11	92%	38	32	84%	45	34	76%	.469

Fisher's exact test, two-tailed; *N*, number of observable individuals; *n*, number of individuals with at least one Schmorl's node; T, thoracic vertebrae; L, lumbar vertebrae; S1, first sacral vertebra

The frequencies of vertebrae affected by SN in each group according to their size (small or large) and location, and the results of the statistical comparisons between groups are shown in Table 37, Figure 29, 30, and 31. A total of 1592 vertebrae from the first thoracic to the first sacral one could be observed and identified in the entire sample, among which 441 (28%) were affected by at least one SN. In the same way as for the analysis of frequencies of affected individuals, we observed more SN at the lower thoracic level, and less at the upper thoracic level (Figure 31). There were also more SN at the thoracic vertebrae pooled together than at the lumbar level. The NRD and RD groups showed the highest frequencies at all levels.

There were 350 cases of small SN (22%) and 91 cases of large SN (6%) in the entire sample. Small and large SN were both found in higher frequencies in the NRD and RD groups (Table 37; Figure 29, 30, and 31). Small SN were mostly found at the 8th and 9th thoracic vertebrae (53% and 47%, respectively), while large SN were mostly located at the 11th and

10th thoracic vertebrae (17% and 15%, respectively). Taking the size of SN into account (absence, presence of small SN, presence of large SN), we observed a statistically significant difference between groups at all levels (Table 37), and pairwise comparisons with corrected *p* values revealed that this difference concerned the NRD and LIS groups (as well as the RD and LIS groups when all vertebrae were taken together). Looking at each vertebra separately, only the 12th thoracic and 1st lumbar vertebrae showed significant differences between groups, and the main differences were found between the NRD and LIS groups (Table 37; Figure 30). More precisely, we observed the influence of the size of SN. At various levels, there was, indeed, a larger difference observed between groups, and especially between the NRD and LIS groups, considering large SN compared to small SN (Table 37; Figure 30 and 31). This was the case at the 12th thoracic vertebra (38% versus 33% for small SN, and 22% versus 2% for large SN), and at the 1st lumbar vertebra (31% versus 21% for small SN, and 19% versus 2% for large SN), as well as for the entire lower thoracic level, from the 7th to the 12th vertebra (41% versus 41% for small SN, and 20% versus 6% for large SN). Furthermore, when the presence of small SN only was considered (Table 37; Figure 30), we observed only a statistically significant difference between groups concerning the 1st lumbar vertebra ($p = .049$), while, with large SN only, we observed a significant difference between groups for the 11th ($p = .018$) and 12th ($p = .016$) thoracic vertebrae, as well as for the 1st lumbar vertebra ($p = .031$). With *p* values corrected for pairwise comparisons, those differences were significant between the NRD and LIS groups for large SN observed on the 11th (*p* adjusted = .034) and 12th (*p* adjusted = .023) thoracic vertebrae. In general, the distribution of SN by vertebra and according to size was more similar between the RD and NRD groups, compared to the LIS group (Table 37; Figure 29, 30, and 31).

Table 37. Frequency of Schmorl's nodes by size on the thoracic (T), lumbar (L), and the first sacral (S) vertebrae in the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison taking size into account

Vertebrae	*N*			Small nodes RD		Small nodes NRD		Small nodes LIS		Large nodes RD		Large nodes NRD		Large nodes LIS		All nodes RD		All nodes NRD		All nodes LIS		*p* exact	*p* exact adjusted		
	RD	NRD	LIS	*n*	*n/N*	*n*	*n/N*	*n*	*n/N*	*n*	*n/N*	*n*	*n/N*	*n*	*n/N*	*n*	*n/N*	*n*	*n/N*	*n*	*n/N*		RD-NRD	RD-LIS	NRD-LIS
T1	11	37	44	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	-	-	-	-
T2	10	36	45	0	0%	1	3%	0	0%	0	0%	0	0%	0	0%	0	0%	1	3%	0	0%	.505	-	-	-
T3	8	35	43	0	0%	1	3%	0	0%	0	0%	0	0%	0	0%	0	0%	1	3%	0	0%	.500	-	-	-
T4	8	34	44	0	0%	4	12%	1	2%	0	0%	1	3%	0	0%	0	0%	5	15%	1	2%	.250	-	-	-
T5	9	33	44	1	11%	8	24%	5	11%	0	0%	1	3%	0	0%	1	11%	9	27%	5	11%	.282	-	-	-
T6	10	34	44	3	30%	9	26%	6	14%	1	10%	4	12%	2	5%	4	40%	13	38%	8	18%	.234	-	-	-
T7	11	35	43	3	27%	11	31%	17	40%	1	9%	6	17%	2	5%	4	36%	17	49%	19	44%	.441	-	-	-
T8	11	33	45	6	55%	18	55%	23	51%	1	9%	5	15%	3	7%	7	64%	23	70%	26	58%	.701	-	-	-
T9	11	34	45	5	45%	16	47%	21	47%	1	9%	6	18%	3	7%	6	55%	22	65%	24	53%	.592	-	-	-
T10	11	35	45	4	36%	15	43%	16	36%	3	27%	7	20%	4	9%	7	64%	22	63%	20	44%	.291	-	-	-
T11	11	33	45	5	45%	10	30%	19	42%	2	18%	10	30%	3	7%	7	64%	20	61%	22	49%	.080	-	-	-
T12	9	32	45	4	44%	12	38%	15	33%	1	11%	7	22%	1	2%	5	56%	19	59%	16	36%	**.040**	.893	.481	**.032**
L1	10	32	43	6	60%	10	31%	9	21%	0	0%	6	19%	1	2%	6	60%	16	50%	10	23%	**.009**	.170	.077	.053
L2	12	32	43	3	25%	11	34%	11	26%	1	8%	2	6%	0	0%	4	33%	13	41%	11	26%	.287	-	-	-
L3	12	34	44	2	17%	11	32%	7	16%	1	8%	3	9%	1	2%	3	25%	14	41%	8	18%	.178	-	-	-
L4	10	34	46	1	10%	8	24%	4	9%	0	0%	1	3%	0	0%	1	10%	9	26%	4	9%	.179	-	-	-
L5	9	31	46	0	0%	3	10%	3	7%	0	0%	0	0%	0	0%	0	0%	3	10%	3	7%	.839	-	-	-
S1	14	34	43	0	0%	2	6%	0	0%	0	0%	0	0%	0	0%	0	0%	2	6%	0	0%	.275	-	-	-
Total T1-T6	56	209	264	4	7%	23	11%	12	5%	1	2%	6	3%	2	1%	5	9%	29	14%	14	5%	**.022**	.709	.709	**.014**
Total T7-T12	64	202	268	27	42%	82	41%	111	41%	9	14%	41	20%	16	6%	36	56%	123	61%	127	47%	**< .001**	.555	.152	**< .001**
Total T	120	411	532	31	26%	105	26%	123	23%	10	8%	47	11%	18	3%	41	34%	152	37%	141	27%	**< .001**	.654	.082	**< .001**
Total L+S1	67	197	265	12	18%	45	23%	34	13%	2	3%	12	6%	2	1%	14	21%	57	29%	36	14%	**< .001**	.421	.227	**< .001**
Total All	187	608	797	43	23%	150	25%	157	20%	12	6%	59	10%	20	3%	55	29%	209	34%	177	22%	**< .001**	.312	**.031**	**< .001**

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; comparisons were performed including the differences of size of Schmorl's nodes (absence, small SN, large SN); *N*, number of observable vertebrae; *n*, number of vertebrae affected by SN

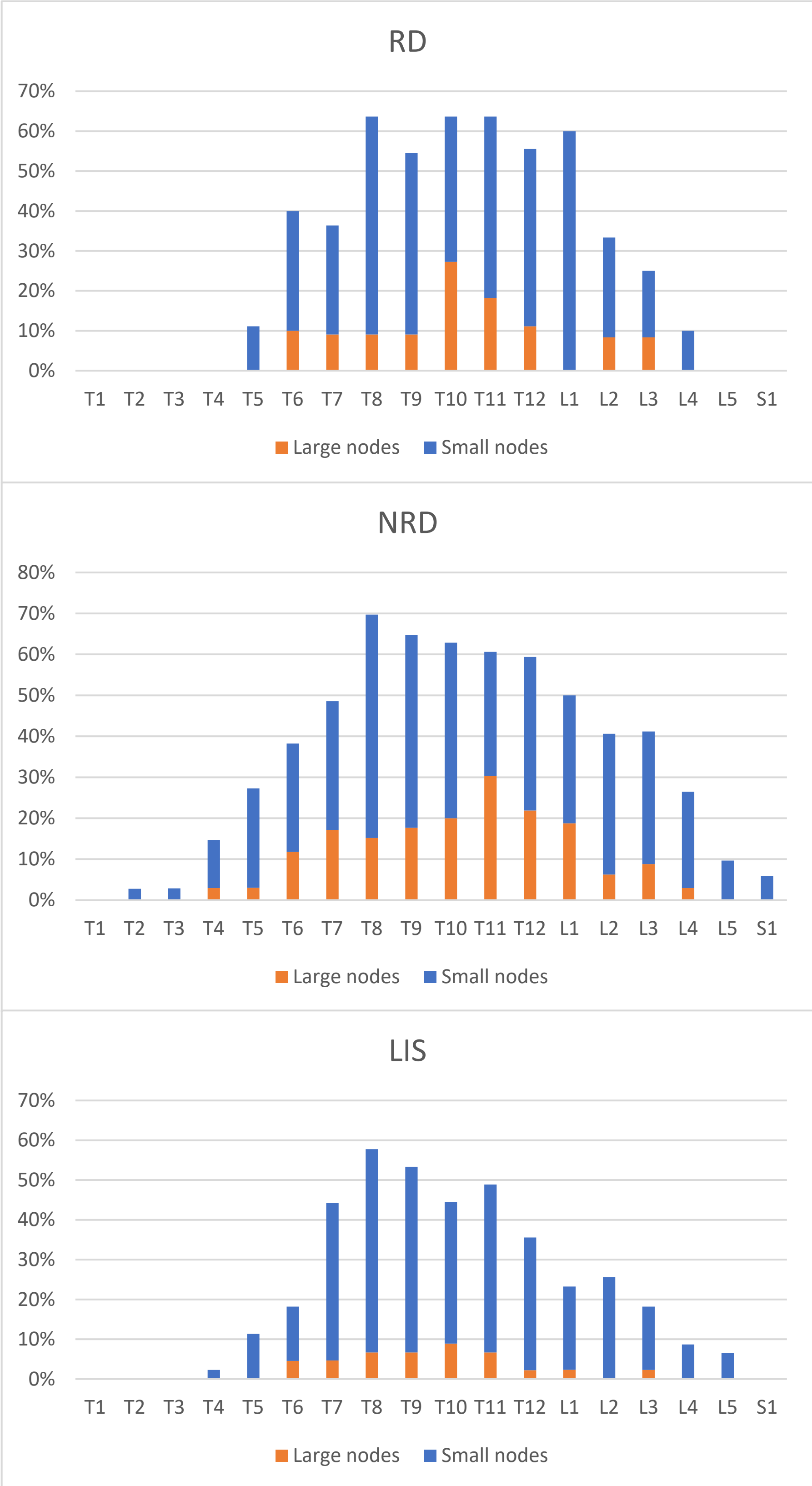

Figure 29. Frequency of Schmorl's nodes by size on the thoracic (T), lumbar (L), and the first sacral (S) vertebrae in the Hungarian groups with (RD) and without riding deposit (NRD), and the comparison group from Lisbon (LIS)

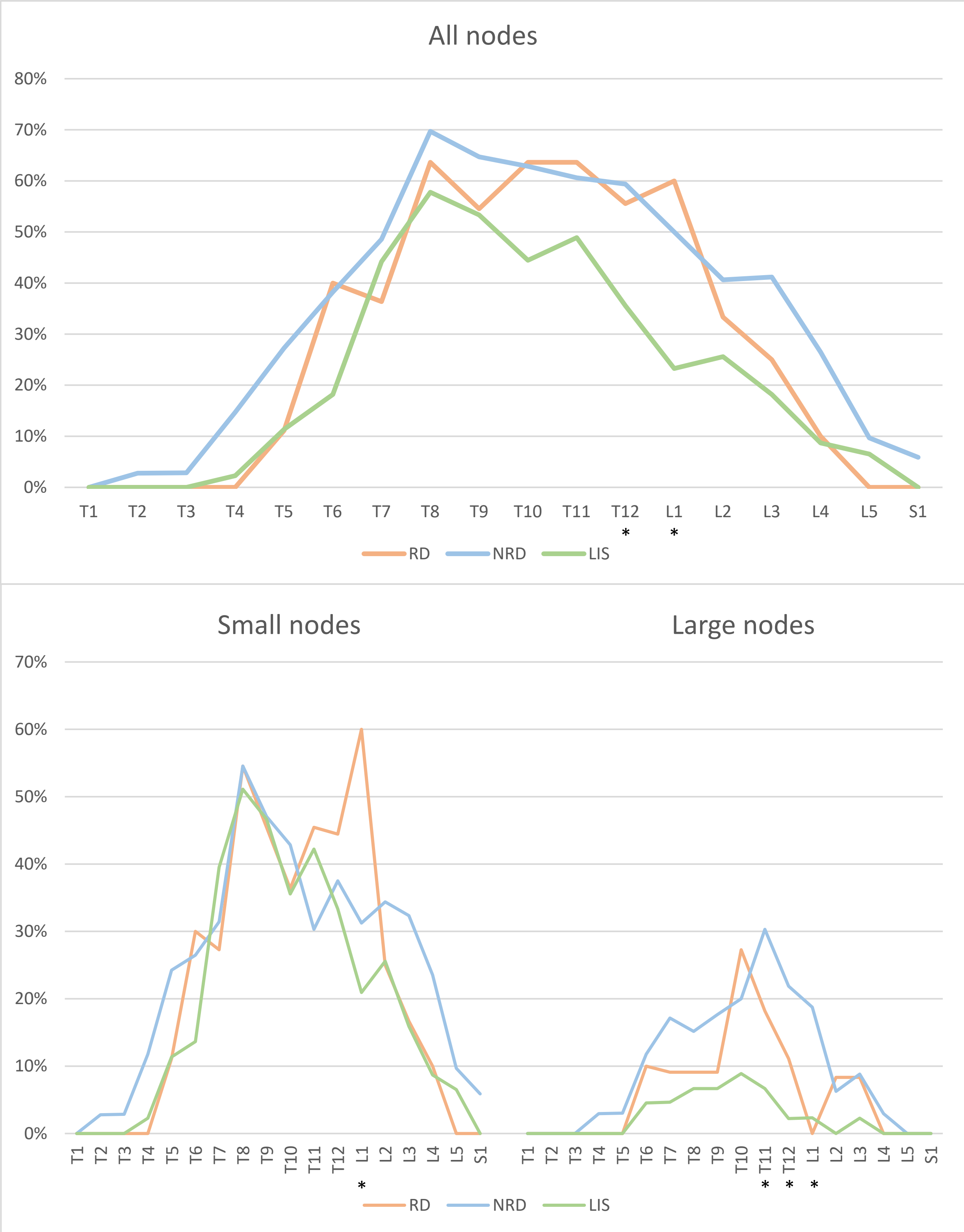

Figure 30. Frequency and distribution by size of Schmorl's nodes on the thoracic (T), lumbar (L), and the first sacral (S) vertebrae in the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS). * indicates statistically significant differences between groups (see Table 37)

Figure 31. Frequency and distribution by grouped vertebrae and by size of Schmorl's nodes on the thoracic (T), lumbar (L), and the first sacral (S) vertebrae in the Hungarian groups with (RD) and without riding deposit (NRD), and the comparison group from Lisbon (LIS). There were statistically significant differences at all levels between groups taking size difference into account (see Table 37)

I.D.2. Spondylolysis

On a total of 1835 vertebrae (from the 3rd cervical to the 1st sacral vertebra) that could be identified and observed for this trait, we observed only 12 (0.7%) reliable cases of spondylolysis in the entire sample. Only the 2nd, 4th, and 5th lumbar vertebrae, as well as the 1st sacral vertebra, were affected, the 5th lumbar being the most frequently affected (8.5% in the entire sample). Six cases were found in the LIS group, and 6 were found in the NRD group. There were 6 cases of unilateral spondylolysis and 6 cases of bilateral spondylolysis (3 in each group). Considering the extremely low number of observations for this trait, no further analysis was performed.

I.E. Results of the analysis of traumatic lesions

Reliable signs of 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 head (skull and mandible), sacrum, patella, and tarsal bones were not affected. Considering anatomical regions, the upper limb was the most affected (21%), followed by the thorax (ribs, 10%), and the lower limb (8%). Intergroup comparisons revealed that the frequency of fractures was higher in the RD group (41%), compared to the NRD (34%), and the LIS groups (30%; Table 38 and Figure 32). 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 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, and pairwise comparisons with corrected p values indicated that there were significantly more clavicle fractures in the RD group (24%) than in the LIS group (0%, p adjusted = .013). We observed a large difference between the upper limb (35%) and the lower limb (0%) in the RD group but pairwise comparisons with corrected p values did not reveal that it was significant (p adjusted = .055). In contrast, there was only little difference between the upper limb and the lower limb in the NRD group (24% versus 10%, respectively), and in the LIS group (13% versus 9%, respectively). More precisely, considering the distribution of fractures within each group, the LIS group was the most homogenous, with an approximate balance of traumas according to the anatomical region, while 61% of the fractures in the NRD group were found in the upper limb, which increased to 89% in the RD group (Figure 33).

Table 38. Frequency and distribution of fractures in the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS), and statistical comparison

Bone(s)/region	RD			NRD			LIS			*p* exact	*p* exact adjusted		
	N	*n*	*n/N*	*N*	*n*	*n/N*	*N*	*n*	*n/N*		RD-NRD	RD-LIS	NRD-LIS
Head	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	-	-	-
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; *n*, number of individuals affected by at least one fracture; HPH, hand phalanges; FPH, foot phalanges

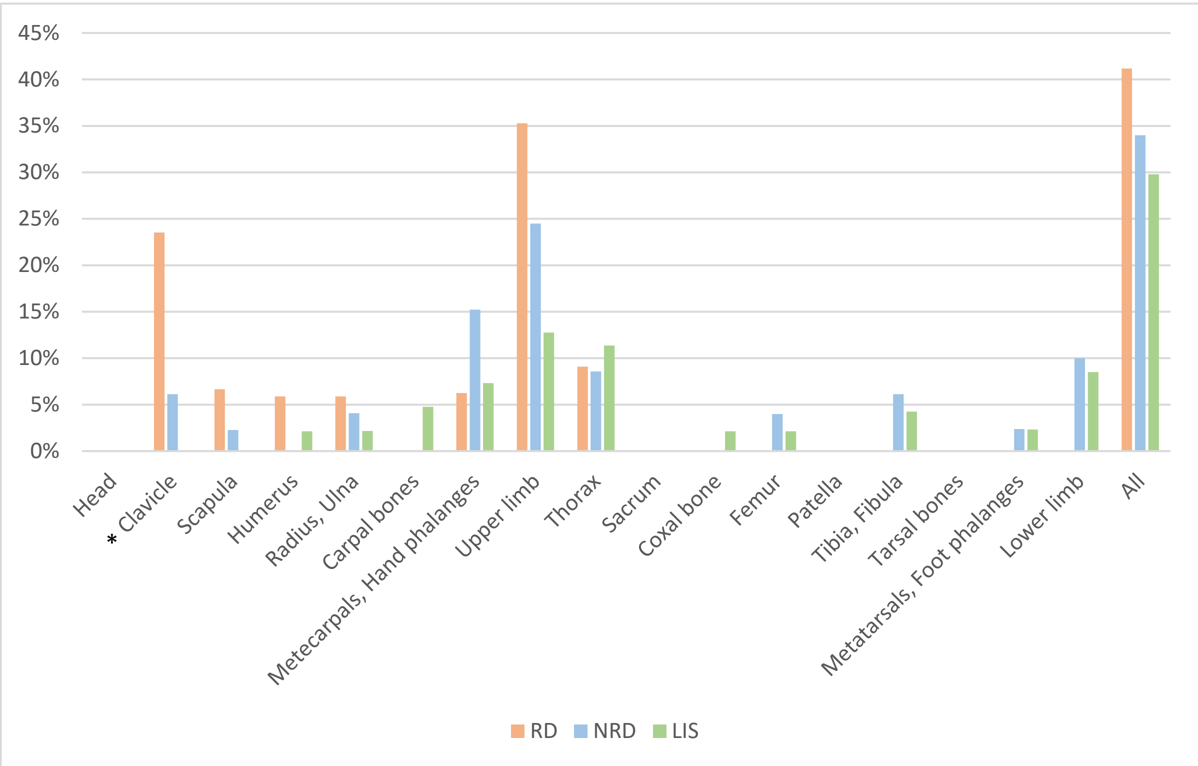

Figure 32. Distribution of fractures in the Hungarian groups with (RD) and without riding deposit (NRD), and the comparison group from Lisbon (LIS). * indicates statistically significant differences between groups (see Table 38)

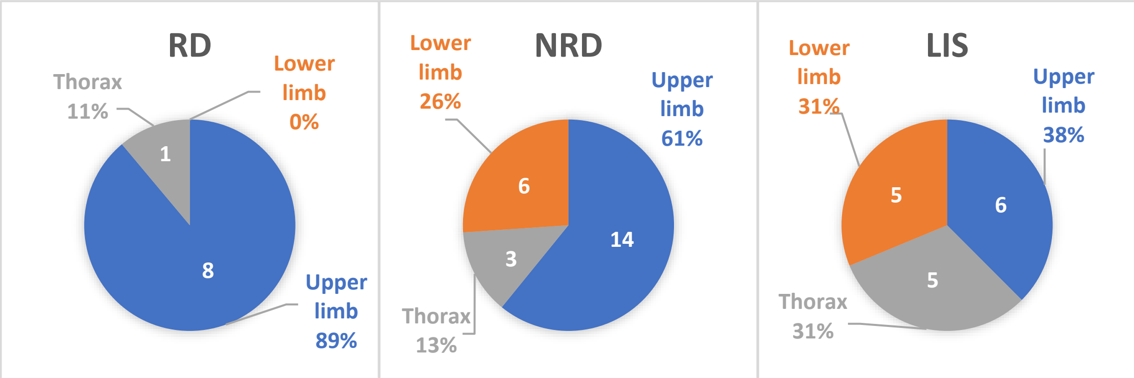

Figure 33. Distribution of fractures by anatomic region in the Hungarian groups with (RD) and without riding deposit (NRD), and the comparison group from Lisbon (LIS). No fracture was recorded on the head

In addition, we observed 10 cases of polytraumatism, where different bones or groups of bones considered in the study (as presented in Table 13), were affected by a fracture. There were 2 cases in the RD group, 6 in the NRD group, and 2 in the LIS group. Only one individual, from the NRD group, showed a fracture both at the upper and lower limb, while 2 individuals, also from the NRD group, had fractures on the same bone on both sides (the radius for one, and the clavicle for the other).

II. Results of the osteometric analyses

II.A. Index of ovalization of the acetabulum

II.A.1. Inter- and intraobserver agreement evaluation

Inter- and intraobserver agreement tests relied on 15 pairs of coxal bones selected randomly in the collection of Sárrétudvari-Hízóföld. There was a very good concordance between the series of measurements taken by Observer A and Observer B for the horizontal and vertical diameters of the acetabulum (Table 39). The mean absolute difference was indeed close to 1 mm in each case and the concordance correlation coefficient was superior to .900, which is considered as very satisfying. Additionally, we observed an excellent concordance for both diameters between the 2 series of measurements taken by Observer A, with a mean absolute difference not higher than 0.5 mm and concordance correlation coefficients superior to .970. The concordance was almost perfect in the case of the horizontal diameter, with a coefficient of .993.

Table 39. Interobserver (A–B) and intraobserver (A1–A2) agreement in the measurement of the maximum diameters of the acetabulum (n = 30)

	Observer A – Observer B		Observer A1 – Observer A2	
	Vertical diameter	Horizontal diameter	Vertical diameter	Horizontal diameter
Mean of each series (mm)	57.5 (A) 57.8 (B)	56.1 (A) 55.0 (B)	57.6 (A1) 57.5 (A2)	56.1 (A1) 56.1 (A2)
Mean difference (mm)	-0.3	1.1	0.2	-0.1
Mean absolute difference (mm)	0.8	1.1	0.5	0.3
Concordance correlation coefficient	.949	.911	.979	.993

A concordance correlation coefficient close to 1 indicates a strong concordance between two series of values

II.A.2. Intergroup comparisons

The preservation of the coxal bones was a limiting factor in the Hungarian archaeological groups, and in the RD group, in particular. The composition of the samples of acetabula for which the index of ovalization of the acetabulum (IOA) could be calculated is presented in Table 40.

Table 40. Composition of the samples of observable acetabula in the Hungarian groups with (RD) and without riding deposit (NRD) and in the comparison group from Lisbon (LIS)

Group	*N* individuals	Individuals with at least one observable acetabulum	Observable acetabula			Pairs of observable acetabula
			Left	Right	Total	
RD	17	11	7	9	16	5
NRD	50	31	24	28	52	21
LIS	47	45	41	39	80	35
Total	114	87	72	76	148	61

The index values were compared between each group, for the left and right acetabula taken separately and combined, without considering if one or both sides were observable in an individual (Table 41 and 42; Figure 34).

Table 41. Summary statistics of the index of ovalization of the acetabulum in the Hungarian groups with (RD) and without riding deposit (NRD) and in the comparison groups from Lisbon (LIS)

Group	*n*			Minimum			Maximum			Mean			Standard deviation		
	L	R	L+R	L	R	L+R	L	R	L+R	L	R	L+R	L	R	L+R
RD	7	9	16	0.972	0.994	0.972	1.112	1.101	1.112	1.040	1.045	1.043	0.051	0.039	0.043
NRD	24	28	52	0.951	0.974	0.951	1.071	1.065	1.071	1.011	1.020	1.016	0.031	0.027	0.029
LIS	41	39	80	0.942	0.938	0.938	1.080	1.058	1.080	1.007	1.014	1.011	0.034	0.034	0.034

n, number of coxal bones that could be measured; L, left side; R, right side

Table 42. Statistical comparison for the index of ovalization of the acetabulum (IOA) between the Hungarian groups with (RD) and without riding deposit (NRD) and the comparison group from Lisbon (LIS)

Index	*H* (*df* = 2)	*p* value Monte Carlo	RD-NRD		RD-LIS		NRD-LIS	
			U	*p* exact adjusted	*U*	*p* exact adjusted	*U*	*p* exact adjusted
IOA L	2.752	.257	-	-	-	-	-	-
IOA R	4.183	.129	-	-	-	-	-	-
IOA L+R	7.313	**.025**	262	**.050**	374	**.024**	1907.5	.424

Kruskal-Wallis H test with Monte Carlo estimate for an exact test based on 10000 sampled tables; Mann-Whitney U 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; L, left side; R, right side

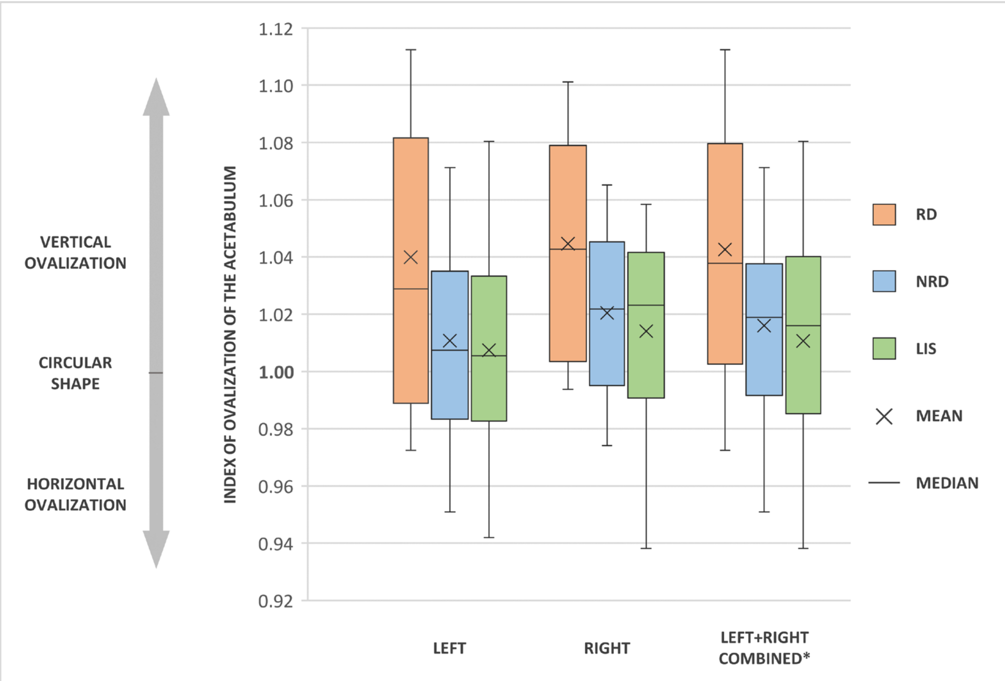

Figure 34. Index of ovalization of the acetabulum (vertical/horizontal diameter), by side and combined, on unpaired coxae in the Hungarian groups with (RD) and without riding deposit (NRD) and in the comparison group from Lisbon (LIS). * indicates statistically significant differences between groups (see Table 42)

In the entire sample, the acetabula were not circular on average, but they tended to be a bit higher than wide (IOA lightly superior to 1), which corresponds to a normal morphology (Bräuer, 1988). The RD group was characterized by higher index values, including a higher median value, and by a greater variation (especially interquartile range), compared to the NRD and LIS groups, which showed rather similar distributions (Table 41; Figure 34). The differences were statistically significant between groups when left and right indices were combined (p = .025), and pairwise comparisons with corrected p values indicated that the significant differences were found between the RD and LIS groups (p adjusted = .024), in particular (Table 42). The acetabula were significantly higher and narrower (i.e., vertically ovalized) in the RD group. There was also a borderline significant difference between the RD and NRD groups (p adjusted = .050).

II.A.3. Bilateral asymmetry

As a further step, we evaluated the bilateral asymmetry of the acetabular shape, excluding, in that case, the individuals with only one observable acetabulum. In all groups, we observed a bilateral asymmetry, although it was not significant (Table 43). This asymmetry was however inverted in the case of the RD group compared to the NRD and LIS groups (Table 43; Figure 35). Although the median and the variation were greater on the left side concerning the RD group, the spread of the values appeared to be higher on the right side in the two other groups (median and interquartile range in particular). Thus, the acetabula tended to exhibit a more important vertical ovalization on the left side in the RD group and on the right side in the NRD and LIS groups.

Table 43. Summary statistics for the asymmetry of the index of ovalization of the acetabulum measured on paired coxae in the Hungarian groups with (RD) and without riding deposit (NRD) and in the comparison group from Lisbon (LIS), and statistical comparison

Group	*n* pairs	Minimum		Maximum		Mean		Standard deviation		*Z*	*p* exact
		L	R	L	R	L	R	L	R		
RD	5	0.989	1.002	1.112	1.101	1.047	1.037	0.050	0.040	-.813	.500
NRD	21	0.951	0.986	1.071	1.065	1.012	1.021	0.033	0.025	-1.704	.090
LIS	35	0.942	0.938	1.066	1.058	1.005	1.014	0.034	0.033	-1.352	.180

Wilcoxon signed-rank test, two-tailed; L, left side; R, right side

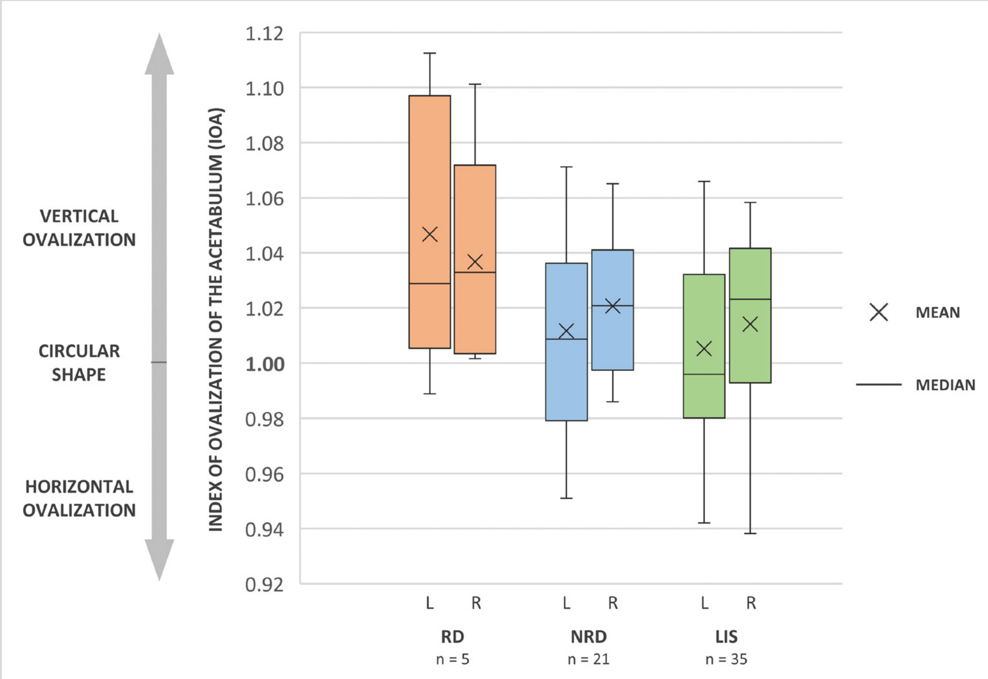

Figure 35. Asymmetry of the index of ovalization of the acetabulum on paired coxae in the Hungarian groups with (RD) and without riding deposit (NRD), and the comparison group from Lisbon (LIS)

We also calculated the difference between the right and left index values for each pair of acetabula to compare the degree and direction of bilateral asymmetry between groups (Table 44; Figure 36). The tendencies concerning the bilateral asymmetry were confirmed, with a negative median in the RD group and a positive median in the NRD and LIS groups, respectively. The left acetabula in the RD group appeared to be higher and narrower than the right ones, but they tended to be shorter and wider than on the right side in the NRD and LIS groups. While the differences between groups were not significant (p = .276), we observed that the direction of the asymmetry differed between the RD and the other groups.

Table 44. Evaluation of the asymmetry (right minus left value) of the index of ovalization of the acetabulum on paired coxae in the Hungarian groups with (RD) and without riding deposit (NRD) and in the comparison group from Lisbon (LIS), and statistical comparison between groups

Group	*n* pairs	Minimum	Maximum	Mean	Standard deviation	*H* (*df* = 2)	*p* value Monte Carlo
RD	5	-0.039	0.013	-0.010	0.022		
NRD	21	-0.048	0.047	0.009	0.024	2.614	.276
LIS	35	-0.044	0.086	0.009	0.031		

Kruskal-Wallis H test with Monte Carlo estimate for an exact test based on 10000 sampled tables

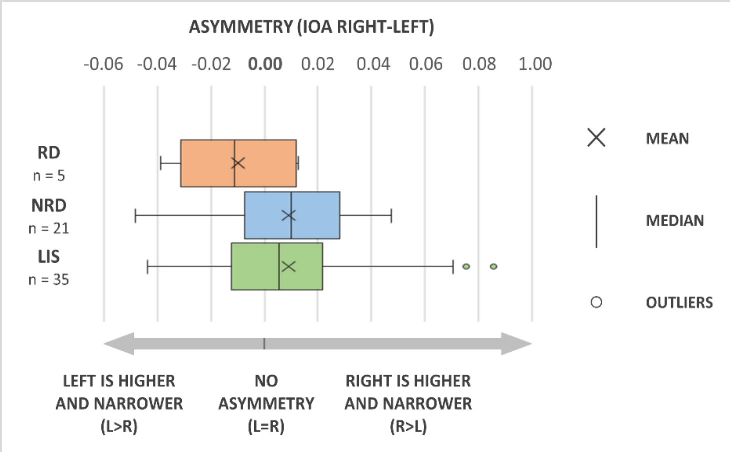

Figure 36. Difference between the right and left indices of ovalization of the acetabulum (IOA) on paired coxae in the Hungarian groups with (RD) and without riding deposit (NRD), and the comparison group from Lisbon (LIS)

II.B. Other indices of shape and robusticity

II.B.1. Intergroup comparisons

The description of the other indices that were calculated on the lower limb bones is shown in Table 14. The index values were compared between each group, for the left and right values taken separately and combined, without considering if one or both sides were observable in an individual. The summary statistics of the indices of shape and robusticity are shown in Table 45 and the results of the statistical comparison are presented in Table 46. A total of 2430 index values could be calculated in the entire sample and were included in the analysis. On a total of 14 indices that were calculated, higher values were observed for half of them in the RD compared to the NRD and LIS groups, while 4 indices showed higher values on average in the NRD group, and 3 showed higher values in the LIS group. Statistically significant differences were reached for a majority of these indices (12/14), including FEM I1, for which there was a borderline significant difference between groups (p = .050). Pairwise comparisons with corrected p values revealed significant differences between pairs of groups for the eleven other indices. For a majority of these indices (10/11), we found a significant difference between the NRD and LIS groups, in particular, while, in addition, there was also a significant difference between the RD and LIS groups for 6 of them. Two indices only indicated a significant difference between the RD and NRD groups: the index values were lower in the RD group for TIB I2 and higher for TAL I2.

Table 45. Summary statistics of the indices of shape and robusticity in the Hungarian groups with (RD) and without riding deposit (NRD) and in the comparison groups from Lisbon (LIS)

Index		RD					NRD					LIS				
		n	Min	Max	Mean	*SD*	*n*	Min	Max	Mean	*SD*	*n*	Min	Max	Mean	*SD*
FEM I1	L	12	18.60	22.05	20.34	0.90	36	17.81	21.95	20.23	1.07	43	17.18	22.88	19.75	1.18
	R	12	19.01	21.67	20.16	0.80	37	17.75	21.95	20.19	0.99	43	17.84	25.29	20.04	1.32
	L+R	24	18.60	22.05	20.25	0.84	73	17.75	21.95	20.21	1.02	86	17.18	25.29	19.89	1.25
FEM I2	L	15	89.83	111.72	98.71	7.05	43	88.38	122.42	101.44	8.83	43	84.97	122.35	104.01	7.95
	R	14	88.41	115.86	101.93	7.93	44	87.16	121.94	102.41	7.92	43	89.04	117.15	105.72	6.25
	L+R	29	88.41	115.86	100.26	7.53	87	87.16	122.42	101.93	8.35	86	84.97	122.35	104.86	7.16
FEM I3	L	15	74.02	101.89	87.41	7.06	42	73.63	107.48	86.78	7.18	43	76.22	100.78	91.67	6.00
	R	14	75.92	106.52	90.00	8.23	42	70.95	108.96	87.07	8.34	43	80.61	105.78	91.97	6.41
	L+R	29	74.02	106.52	88.66	7.62	84	70.95	108.96	86.92	7.73	86	76.22	105.78	91.82	6.17
FEM I4	L	10	32.73	40.37	35.95	2.49	30	31.93	39.13	35.24	1.60	40	29.52	39.21	34.23	2.35
	R	9	31.03	41.00	35.61	2.69	34	30.22	39.02	34.70	1.96	42	28.93	38.13	33.72	2.14
	L+R	19	31.03	41.00	35.79	2.52	64	30.22	39.13	34.95	1.80	82	28.93	39.21	33.97	2.25
FEM I5	L	8	21.11	24.47	22.24	1.21	34	20.07	23.65	21.69	0.91	43	18.50	23.78	20.47	1.17
	R	10	20.85	24.65	22.16	1.19	33	19.94	23.30	21.69	0.94	42	18.27	23.92	20.77	1.21
	L+R	18	20.85	24.65	22.20	1.16	67	19.94	23.65	21.69	0.92	85	18.27	23.92	20.62	1.19
PAT I1	L	8	84.89	101.12	94.13	5.40	24	81.19	112.50	93.94	6.43	28	88.46	113.16	98.44	6.15
	R	8	81.19	102.27	93.09	6.58	28	82.68	102.13	92.73	5.32	32	88.25	109.73	96.94	6.13
	L+R	16	81.19	102.27	93.61	5.84	52	81.19	112.50	93.29	5.83	60	88.25	113.16	97.64	6.13
TIB I1	L	16	20.06	24.42	21.62	1.16	39	19.77	24.70	21.71	1.29	43	18.83	25.15	21.43	1.52
	R	16	20.67	25.41	21.85	1.34	43	19.36	24.78	21.86	1.32	41	18.47	25.08	21.64	1.46
	L+R	32	20.06	25.41	21.74	1.24	82	19.36	24.78	21.79	1.30	84	18.47	25.15	21.53	1.49
TIB I2	L	16	54.65	74.24	66.73	5.18	44	59.53	87.38	70.34	5.42	43	56.32	90.26	68.56	6.35
	R	16	57.88	72.46	65.71	4.04	45	58.55	88.13	69.66	5.59	42	56.20	80.89	67.35	5.30
	L+R	32	54.65	74.24	66.22	4.60	89	58.55	88.13	70.00	5.49	85	56.20	90.26	67.96	5.86
FIB I1	L	8	8.56	11.56	10.37	1.00	18	7.63	12.73	10.20	1.37	29	7.71	11.96	9.90	1.20
	R	7	9.49	12.89	10.80	1.07	20	7.65	12.18	10.35	1.41	28	8.38	12.23	10.26	0.97
	L+R	15	8.56	12.89	10.57	1.02	38	7.63	12.73	10.28	1.38	57	7.71	12.23	10.08	1.09
TAL I1	L	13	75.30	84.29	79.73	2.71	31	70.13	86.10	78.00	3.51	39	67.78	82.23	74.41	3.43
	R	13	75.63	83.23	79.61	2.35	36	71.67	86.89	77.93	3.56	41	69.57	84.39	74.98	3.94
	L+R	26	75.30	84.29	79.67	2.48	67	70.13	86.89	77.96	3.51	80	67.78	84.39	74.70	3.69
TAL I2	L	14	56.94	69.08	60.86	3.47	34	54.30	62.73	58.70	2.37	39	52.93	76.34	57.65	3.77
	R	14	57.49	65.38	60.48	2.64	37	52.91	63.85	58.43	2.46	41	52.83	75.76	57.51	3.60
	L+R	28	56.94	69.08	60.67	3.03	71	52.91	63.85	58.56	2.40	80	52.83	76.34	57.58	3.66
TAL I3	L	12	77.58	93.71	85.03	5.73	32	74.24	93.39	84.95	4.78	39	70.66	93.31	82.09	5.59
	R	15	74.12	91.72	82.30	4.63	38	74.37	94.03	83.30	4.77	41	75.14	93.00	81.96	4.86
	L+R	27	74.12	93.71	83.52	5.23	70	74.24	94.03	84.05	4.81	80	70.66	93.31	82.03	5.19
CAL I1	L	12	48.80	60.27	52.47	2.88	32	47.41	56.55	52.83	2.21	39	45.85	56.99	51.18	2.95
	R	10	49.41	56.08	52.50	2.16	32	48.75	57.92	52.78	2.44	38	45.49	58.11	51.56	3.13
	L+R	22	48.80	60.27	52.48	2.52	64	47.41	57.92	52.80	2.31	77	45.49	58.11	51.37	3.03
CAL I2	L	14	46.91	63.24	52.97	4.07	36	45.35	58.11	51.86	3.00	40	42.11	57.75	48.76	3.79
	R	11	47.56	58.23	52.70	3.12	36	45.35	57.75	51.77	3.10	40	42.35	57.97	48.77	3.83
	L+R	25	46.91	63.24	52.85	3.61	72	45.35	58.11	51.82	3.03	80	42.11	57.97	48.76	3.79

n, number of calculated index values; Min, minimum; Max, maximum; *SD*, standard deviation; L, left side; R, right side

Table 46. Statistical comparison for the indices of shape and robusticity in the Hungarian groups with (RD) and without riding deposit (NRD) and in the comparison groups from Lisbon (LIS)

Index		*H* (*df* = 2)	*p* value Monte Carlo	RD-NRD		RD-LIS		NRD-LIS	
				U	*p* exact adjusted	*U*	*p* exact adjusted	*U*	*p* exact adjusted
FEM I1	L	5.533	.057	-	-	-	-	-	-
	R	0.982	.615	-	-	-	-	-	-
	L+R	5.846	**.050**	874.0	.988	804.0	.199	2502.5	.083
FEM I2	L	4.541	.100	-	-	-	-	-	-
	R	6.064	**.047**	304.0	.950	215.0	.227	673.5	.061
	L+R	9.849	**.006**	1118.0	.364	817.5	**.016**	2945.5	**.031**
FEM I3	L	11.580	**.003**	285.5	.599	206.0	.077	534.5	**.003**
	R	8.165	**.015**	235.0	.543	246.5	.543	581.5	**.013**
	L+R	20.440	**< .001**	1054.5	.285	890.5	.042	2192.5	**< .001**
FEM I4	L	6.358	**.041**	124.5	.436	126.0	.149	418.5	.092
	R	6.856	**.029**	121.0	.349	99.0	.075	527.5	.103
	L+R	13.771	**.001**	488.0	.196	446.5	**.008**	1870.5	**.008**
FEM I5	L	25.076	**< .001**	101.0	.272	47.0	**.001**	294.5	**< .001**
	R	16.082	**< .001**	136.0	.416	83.0	**.005**	372.0	**.001**
	L+R	41.337	**< .001**	475.5	.173	255.0	**< .001**	1326.0	**< .001**
PAT I1	L	7.272	**.024**	85.0	.648	73.0	.287	195.0	**.027**
	R	5.928	**.049**	99.0	.641	93.0	.493	288.0	.051
	L+R	12.702	**.001**	375.5	.564	330.5	.113	970.5	**.001**
TIB I1	L	0.569	.756	-	-	-	-	-	-
	R	0.251	.888	-	-	-	-	-	-
	L+R	0.739	.694	-	-	-	-	-	-
TIB I2	L	3.878	.145	-	-	-	-	-	-
	R	5.950	**.050**	216.0	.052	279.5	.331	760.0	.234
	L+R	9.684	**.006**	920.5	**.008**	1149.0	.199	3099.0	.079
FIB I1	L	0.899	.647	-	-	-	-	-	-
	R	1.060	.600	-	-	-	-	-	-
	L+R	1.930	.378	-	-	-	-	-	-
TAL I1	L	24.810	**< .001**	134.0	.085	55.0	**< .001**	284.0	**< .001**
	R	17.911	**< .001**	152.0	.064	95.0	**.001**	423.0	**.002**
	L+R	42.805	**< .001**	582.0	.013	287.5	**< .001**	1408.0	**< .001**
TAL I2	L	13.973	**.001**	161.5	.084	101.0	**.001**	444.5	**.030**
	R	15.499	**< .001**	145.5	**.031**	92.0	**< .001**	548.5	**.035**
	L+R	29.315	**< .001**	617.5	**.003**	394.0	**< .001**	1969.5	**.002**
TAL I3	L	5.366	.064	-	-	-	-	-	-
	R	1.648	.454	-	-	-	-	-	-
	L+R	6.298	**.044**	874.5	.574	898.5	.390	2149.5	**.042**
CAL I1	L	5.920	.052	-	-	-	-	-	-
	R	3.212	.204	-	-	-	-	-	-
	L+R	8.663	**.012**	621.0	.415	680.5	.326	1771.5	**.012**
CAL I2	L	17.043	**< .001**	217.0	.457	113.5	**.001**	386.5	**.001**
	R	16.836	**< .001**	170.0	.491	89.0	**.004**	375.5	**.001**
	L+R	33.513	**< .001**	771.5	.292	411.0	**< .001**	1534.5	**< .001**

Kruskal-Wallis H test with Monte Carlo estimate for an exact test based on 10000 sampled tables; Mann-Whitney U 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; L, left side; R, right side

II.B.2. Bilateral asymmetry

As a further step, we evaluated the bilateral asymmetry, excluding, in that case, for each index, the individuals with only one observable side. Summary statistics of the paired index values are shown in Table 47, and the results of statistical tests are presented in Table 48. For a majority of indices, there was no significant bilateral asymmetry, even if, in general, more right index values tended to be higher. Five indices only revealed a statistically significant difference between sides. FEM I2 was significantly higher on the right side in the RD and LIS groups (p = .040 and p = .014, respectively), FEM I4 was significantly higher on the left side in the LIS group (p = .002), FIB I1 was significantly higher on the right side in the NRD group (p = .042), and TAL I3 was significantly higher on the left side in the RD group (p = .027). TIB I1 was significantly asymmetrical in all groups, with a right-side dominance.

Table 47. Summary statistics for the asymmetry of indices of shape and robusticity calculated from paired bones in the Hungarian groups with (RD) and without riding deposit (NRD) and in the comparison group from Lisbon (LIS)

Index		RD					NRD					LIS				
		n	Min	Max	Mean	*SD*	*n*	Min	Max	Mean	*SD*	*n*	Min	Max	Mean	*SD*
FEM I1	L	10	18.60	22.05	20.26	0.96	30	17.81	21.95	20.20	1.13	40	17.18	22.88	19.81	1.19
	R		19.01	21.67	20.21	0.88		17.75	21.95	20.24	1.06		17.84	22.20	19.89	1.06
FEM I2	L	13	89.83	111.72	99.31	7.15	40	88.38	122.42	101.83	8.97	40	84.97	122.35	103.70	8.03
	R		88.41	115.86	102.81	7.51		87.16	121.94	102.86	8.09		89.04	117.15	105.94	6.42
FEM I3	L	12	74.02	101.89	87.67	7.92	37	73.63	107.48	86.83	7.01	40	76.22	100.69	91.61	5.97
	R		75.92	106.52	90.45	8.79		70.95	108.96	87.29	8.48		80.61	105.78	91.94	6.42
FEM I4	L	7	32.73	40.37	36.40	2.57	24	31.93	38.47	35.24	1.53	38	29.52	39.21	34.29	2.39
	R		31.03	41.00	35.84	3.06		31.69	39.02	34.92	1.88		28.93	38.13	33.54	2.06
FEM I5	L	6	21.11	24.47	22.28	1.34	27	20.07	23.57	21.67	0.91	39	18.50	23.78	20.52	1.17
	R		20.85	24.65	22.23	1.47		20.00	23.26	21.71	0.91		18.27	23.92	20.64	1.13
PAT I1	L	5	84.89	98.77	93.06	5.99	16	81.19	98.01	91.62	5.19	26	88.46	113.16	98.76	6.15
	R		81.19	102.27	92.35	8.26		82.68	98.14	91.31	5.03		88.25	109.73	97.78	6.30
TIB I1	L	15	20.06	24.42	21.62	1.20	36	19.77	24.70	21.74	1.34	38	18.83	25.15	21.46	1.41
	R		20.67	25.41	21.92	1.36		20.00	24.78	22.03	1.30		18.47	25.08	21.61	1.35
TIB I2	L	15	54.65	74.24	67.11	5.13	42	59.53	87.38	70.32	5.47	39	56.32	80.33	68.11	5.57
	R		57.88	72.46	65.57	4.14		58.55	88.13	69.74	5.67		56.20	80.89	67.67	5.20
FIB I1	L	3	9.88	10.63	10.15	0.41	11	7.63	11.63	10.18	1.43	20	7.86	11.96	10.01	1.19
	R		10.14	11.20	10.63	0.53		7.65	12.10	10.38	1.39		8.38	12.23	10.23	0.99
TAL I1	L	12	75.30	84.29	79.52	2.72	27	70.13	86.10	78.05	3.68	36	67.78	82.23	74.36	3.41
	R		77.08	83.23	79.94	2.11		71.67	86.89	78.08	3.44		69.57	83.27	74.98	3.61
TAL I2	L	13	56.94	65.52	60.23	2.64	29	54.30	62.73	58.69	2.50	36	52.93	76.34	57.52	3.89
	R		57.49	65.38	60.25	2.60		52.91	63.85	58.31	2.47		52.83	75.76	57.57	3.63
TAL I3	L	12	77.58	93.71	85.03	5.73	28	74.24	93.39	85.04	4.82	36	70.66	93.31	81.80	5.53
	R		74.12	91.72	82.77	5.08		75.75	94.03	84.38	4.65		75.14	93.00	81.93	4.85
CAL I1	L	8	50.25	54.21	52.13	1.42	22	47.41	56.25	52.51	2.18	35	46.00	56.99	51.26	2.96
	R		49.41	56.08	52.59	2.14		49.40	56.51	52.69	2.09		45.49	58.11	51.49	3.26
CAL I2	L	9	46.91	57.69	52.41	3.25	29	45.35	58.11	51.63	3.09	37	42.11	57.75	48.70	3.89
	R		47.56	58.23	52.80	3.38		45.35	57.75	51.78	3.11		42.35	57.97	48.73	3.92

n = number of paired index values calculated; Min, minimum; Max, maximum; *SD*, standard deviation L, left side; R, right side; See Table 14 for the codes of the indices

Table 48. Statistical evaluation of the asymmetry of indices of shape and robusticity calculated from paired bones in the Hungarian groups with (RD) and without riding deposit (NRD) and in the comparison group from Lisbon (LIS)

Index	RD				NRD				LIS			
	n pairs	*Z*	*p* exact	Asym.	*n* pairs	*Z*	*p* exact	Asym.	*n* pairs	*Z*	*p* exact	Asym.
FEM I1	10	-0.153	.902	-	30	-0.227	.827	-	40	-1.068	.291	-
FEM I2	13	-2.062	**.040**	R>L	40	-1.405	.163	-	40	-2.446	**.014**	R>L
FEM I3	12	-1.490	.151	-	37	-1.124	.268	-	40	-0.746	.462	-
FEM I4	7	-1.483	.188	-	24	-1.872	.061	-	38	-3.075	**.002**	L>R
FEM I5	6	-0.524	.688	-	27	-0.408	.692	-	39	-1.429	.156	-
PAT I1	5	-0.944	.438	-	16	-0.362	.744	-	26	-1.867	.062	-
TIB I1	15	-2.103	**.035**	R>L	36	-3.243	**.001**	R>L	38	-2.248	**.024**	R>L
TIB I2	15	-1.533	.135	-	42	-1.482	.140	-	39	-0.471	.646	-
FIB I1	3	-	-	-	11	-2.045	**.042**	R>L	20	-1.736	.084	-
TAL I1	12	-0.628	.569	-	27	-0.264	.804	-	36	-1.838	.066	-
TAL I2	13	-0.314	.787	-	29	-1.139	.262	-	36	-0.470	.645	-
TAL I3	12	-2.197	**.027**	L>R	28	-0.900	.377	-	36	0	1	-
CAL I1	8	-1.014	.375	-	22	-0.503	.633	-	35	-0.453	.658	-
CAL I2	9	-1.014	.375	-	29	-0.875	.392	-	37	-0.020	.988	-

Wilcoxon signed-rank test, two-tailed; *p* values in bold indicate a statistical significance at the .05 level; the asymmetry for FIB I1 was not tested in the RD group regarding the low sample size; Asym, asymmetry (side dominance); see Table 14 for the codes of the indices

We also calculated the difference between the right and left index values for each pair of values to compare the degree and direction of bilateral asymmetry between groups (Table 49). There was no statistically significant difference in the bilateral asymmetry between groups. In general, the direction of the asymmetry was similar for each index. Only few cases of inverted direction were found between the RD group and the two others (FEM I1 and FEM I5), between the NRD group and the two others (TIB I1 and TAL I2), and between the LIS group and the two others (TAL I3).

Table 49. Evaluation of the asymmetry (right minus left value) of the indices of shape and robusticity calculated from paired bones in the Hungarian groups with (RD) and without riding deposit (NRD) and in the comparison group from Lisbon (LIS), and statistical comparison between the three groups

Index	RD					NRD					LIS					*H* (*df* = 2)	*p* value Monte Carlo
	n	Min	Max	Mean	*SD*	*n*	Min	Max	Mean	*SD*	*n*	Min	Max	Mean	*SD*		
FEM I1	10	-0.88	0.55	-0.05	0.44	30	-0.94	0.97	0.04	0.43	40	-1.00	0.87	0.07	0.47	0.848	.663
FEM I2	13	-4.55	12.06	3.50	5.31	40	-14.63	10.93	1.03	4.83	40	-13.60	14.06	2.24	6.30	3.174	.210
FEM I3	12	-6.74	17.18	2.78	6.24	37	-7.71	9.09	0.46	3.60	40	-8.27	7.09	0.32	3.79	1.448	.491
FEM I4	7	-2.02	0.63	-0.56	0.97	24	-1.63	1.83	-0.32	0.87	38	-3.77	2.74	-0.75	1.38	2.150	.358
FEM I5	6	-0.69	0.60	-0.05	0.43	27	-0.82	1.16	0.05	0.50	39	-0.60	1.27	0.12	0.42	0.727	.709
PAT I1	5	-3.69	3.51	-0.71	2.64	16	-4.58	3.92	-0.31	2.50	26	-6.87	2.90	-0.98	2.14	1.075	.596
TIB I1	15	-0.52	1.06	0.29	0.46	36	-0.75	1.19	0.29	0.45	38	-0.38	0.86	0.15	0.34	3.849	.148
TIB I2	15	-9.09	3.22	-1.54	3.48	42	-5.75	7.36	-0.59	3.12	39	-8.62	5.81	-0.44	3.52	1.186	.555
FIB I1	3	0.26	0.60	0.48	0.19	11	-0.49	0.75	0.20	0.31	20	-1.13	1.70	0.22	0.60	1.928	.404
TAL I1	12	-2.75	3.93	0.42	2.12	27	-3.48	5.78	0.03	2.00	36	-3.03	5.42	0.62	1.82	2.161	.338
TAL I2	13	-1.68	1.88	0.02	1.03	29	-4.47	1.87	-0.38	1.47	36	-2.83	3.66	0.04	1.46	0.891	.643
TAL I3	12	-6.81	2.73	-2.27	2.95	28	-6.09	7.01	-0.66	3.46	36	-5.91	8.48	0.12	3.53	3.617	.162
CAL I1	8	-1.18	1.87	0.46	1.12	22	-2.06	3.57	0.19	1.49	35	-2.45	4.41	0.23	1.57	0.569	.764
CAL I2	9	-1.95	2.32	0.39	1.28	29	-2.05	2.67	0.15	1.07	37	-2.61	4.41	0.03	1.32	0.920	.641

Kruskal-Wallis H test with Monte Carlo estimate for an exact test based on 10000 sampled tables; *n*, number of calculated index values; Min, minimum; Max, maximum; *SD*, standard deviation

CHAPTER 4. DISCUSSION

In this chapter, we will first discuss the results of each type of analysis specifically, and then present general interpretations regarding the methodological and ethnoarchaeological aspects of this research, as well as general limitations and suggestions for future research.

I. Entheseal changes

I.A. Young and mature adult individuals

Based on the anthropological literature on horse riding and taking into consideration the muscle functions involved during the practice of horse riding, we selected thirteen entheses of the lower limb (see Chapter 2, III.A.1; Table 9). Entheseal changes (EC) and age being closely related, two series of analyses were performed: one with young and mature adult individuals (YMA) only, and the other one with individuals in all adult age categories. When including YMA only, three entheses showed significant differences between groups, and the first element that we can highlight is that these differences occurred only between each of the Hungarian groups, with (RD) and without riding deposit (NRD), and the group from the modern documented collection from Lisbon (LIS). There was no significant difference between both Hungarian groups, which suggests that there was no major difference in their use of lower limb muscles. If only the Hungarian group with riding deposit was practicing horse riding, we would expect to observe differences with the group without riding deposit for some entheses related to muscles strongly involved in this practice. If we assume that EC are influenced, at least in part, by activity, then these first results tend to indicate that the practice of horse riding was frequent in both Hungarian groups, regardless of the goods in the grave. This point will be discussed further below (see IX below).

Concerning the three entheses that showed significant differences between groups, for the first one, EC at the tibial tuberosity (TIB E1) were significantly higher in the group from Lisbon while they were never observed in the Hungarian groups. This suggests that this enthesis is not influenced by the practice of horse riding. The tibial tuberosity is the insertion site of the *quadriceps femoris*, related to hip flexion and knee extension (Putz & Pabst, 2001). In riding with long stirrups, these muscles push the heel down by putting more weight through the stirrups, while with short stirrups, they contribute to stability by holding the body weight and controlling the position of the seat (Willson, 2013). We can hypothesize that the absence of changes at the tibial tuberosity might be related to the fact that the four muscles composing the *quadriceps femoris* insert first to the patella via the quadriceps tendon, which becomes then the patellar ligament. The effect of activity on the tibial tuberosity could therefore be diminished. There was however no significant difference for the insertion of the *quadriceps femoris* on the anterosuperior part of the patella, which indicates that this group of muscles or, at least, that the insertion sites (as opposed to the origin sites) of these muscles may not represent a good indicator for the practice of horse riding.

The second enthesis was the adductor tubercle (FEM E7). Although significant differences were observed between the three groups, pairwise comparisons did not identify significant differences between paired groups. We observed, nevertheless, that EC were higher in the Hungarian groups, and especially in the RD group (38%), compared to the LIS group (5%). The adductor tubercle is the insertion site of the *adductor magnus* on the distal femur. This muscle controls for hip adduction, lateral rotation, flexion (anterior part), and extension (posterior part), and is one of the main muscles used in riding (Putz & Pabst, 2001; Pugh & Bolin, 2004; Djukic, 2016; Baillif-Ducros, 2018). With the other adductor muscles, it keeps the legs pressed against the horse's flanks while riding, and these muscles are often overworked by riders (Willson, 2013). Adductor strain is the first limiting factor in professional riders and tendinopathies can be a consequence of this overwork (Auvinet, 1980a; Auvinet & Ginet, 1980). The differences observed between groups can therefore well be explained by the practice of horse riding in the Hungarian groups. We should however remind that the adductor tubercle is a fibrous enthesis, for which the correlation with activity is more debated than for the fibrocartilaginous type of entheses (see Chapter 1, I.C, and Chapter 2, III.A.1). As the normal aspect of fibrous entheses is not fully acknowledged, the scoring of EC at this site may be more difficult and subjective, and this enthesis would require further methodological investigation.

The third enthesis showing significant differences in EC between groups in the YMA sample was the calcaneal tuberosity (CAL E1), and it is the one that presented the largest differences. EC at this site were much higher in the Hungarian groups compared to the LIS group (69% in NRD, 56% in RD, and 11% in LIS, with sides combined), even when each side was taken separately. Pairwise comparisons also revealed that the significant differences were between the RD and LIS groups, and the NRD and LIS groups. The calcaneal tuberosity is the insertion point of the calcaneal (or Achilles) tendon, which attaches the calf muscles (*triceps surae*: *soleus*, *gastrocnemius*; and *plantaris* muscle) to the calcaneus. These muscles are involved in ankle plantar flexion, talotarsal supination, as well as knee flexion (Putz & Pabst, 2001). In riders, the *gastrocnemius*, in particular, needs to be long, and thus regularly stretched, as the heel is pushed down below the level of the toes (Willson, 2013). With this in mind, the practice of horse riding in the Hungarians groups seems to be a very reasonable explanation for the large differences observed with the LIS group.

These results are of great interest but we must keep in mind that sample sizes were very limited including only YMA individuals, which should lead to consider these interpretations with some caution.

I.B. Individuals in all adult age categories

Analyses including individuals in all adult age categories were characterized by higher sample sizes and revealed even more significant differences between groups. Most importantly, there was still no significant difference observed between each Hungarian group, but only between the Hungarian groups and LIS group. This supports the observations made on the YMA sample, and especially the hypothesis that both Hungarian groups might have practiced horse riding in a similar way, regardless of the goods in graves. The three entheses that were previously noted (FEM E7, TIB E1, and CAL E1) were still showing identical differences between groups, and they were complemented in this analysis by six more entheses, with five of them revealing significant differences between paired groups. The anterior inferior iliac spine (COX E1), the ischial tuberosity (COX E2), the trochanteric fossa (FEM E3), the *linea aspera* (FEM E6), and the soleal line (TIB E2) were all showing significantly more EC in the NRD group compared to the LIS group, and, for the trochanteric fossa, the adductor tubercle, and the calcaneal tuberosity, also in the RD group compared to the LIS group. The function of the quadriceps muscles (*rectus femoris*, *vastus medialis*, *vastus intermedius*, and *vastus lateralis*, notably involved in the anterior inferior iliac spine and the *linea aspera*), and the adductors (*linea aspera*, adductor tubercle) was already discussed above. The hamstrings (involved in the ischial tuberosity) notably bend the knee and extend the hip (Putz & Pabst, 2001); they contribute to stabilizing the heel and lower leg against the horses' side, and, this way, to keep the seat deep in the saddle. Riders have very tight and stiff hamstring muscles (Willson, 2013). The internal (notably involved in the *linea aspera*) and external rotators of the hip (involved in the trochanteric fossa) rotate the thigh inwards and outwards, respectively, thus controlling for the direction of the toes, which should keep pointing forward in riding (Willson, 2013). The *soleus* muscle (involved in the soleal line and the calcaneal tuberosity), part of the *triceps surae*, contributes to ankle plantar flexion and talotarsal supination, as mentioned previously (see I.A above). All these entheses are origin or insertion sites of muscles that are essential in riding, and we can therefore assume that the higher frequencies of EC observed in the Hungarian groups may be related to the regular practice of horse riding.

Although the analysis includes more individuals than with the YMA sample, we must remind that the presence of old adult individuals may influence the results, the development of EC being closely related to aging. As explained previously (see Chapter 2, III.C.2), the fact that old adults are present in all groups should still, however, allow making comparisons to identify differences between groups. Due to the larger sample sizes, this second analysis provides more information than the first one. If this complementary information must be considered with caution, it confirms the observations performed with young and mature adult individuals only.

I.C. Further interpretations and considerations

In addition to the previous remarks, the absence of significant differences for other entheses also deserves a comment. Considering the function of the muscles that are attached there, we would expect some entheses to be involved in horse riding, and consequently, to show significantly more EC in the Hungarian groups. This is the case, for instance, for the gluteals. In the analysis with all adult individuals, the anterior surface of the greater trochanter (FEM E1), insertion site of the *gluteus minimus*, is the only enthesis related to a gluteal muscle that presents a significant difference between groups, but pairwise comparisons did not provide more precision. For each gluteal muscle insertion site (FEM E1, as well as the superior lateral surface of the greater trochanter, FEM E2, and the gluteal tuberosity, FEM E5), frequencies of EC were higher in the NRD group, and there was no EC observed at the greater trochanter (both anterior and superior lateral surfaces) in the RD group. Gluteal muscles notably extend, abduct, and rotate the hip and control the amount of bend in the trunk (Putz & Pabst, 2001; Willson, 2013). The lack of significant differences between the Hungarian groups and the LIS group may indicate that the individuals from Lisbon were practicing activities that also involved these muscles. Gluteals are active while walking or climbing stairs, and are notably strong running muscles (Willson, 2013; Djukic, 2016). Riders use them in the jumping position and in the rising trot (Willson, 2013), which might concern more modern riders than populations from the 10th century. Similarly, the lack of significant differences observed for the lesser trochanter (FEM E4), insertion site of the *iliopsoas* (*iliacus*, *psoas major*, *psoas minor*), may indicate that it is not a good indicator for the practice of riding. These muscles are important for standing, walking, and running, and they control for lumbar lateral flexion and extension (increasing lumbar lordosis), and for hip flexion and rotation (Putz & Pabst, 2001). It is therefore possible that other activities or working postures adopted by the individuals from Lisbon influenced the development of EC at this site. The effect of aging could also partly explain the results observed for the gluteal and *iliopsoas* muscles.

No enthesis revealed high frequency of bilateral asymmetry and there was no significant difference in the pattern of asymmetry between groups. This indicates that no activity or posture practiced in each group led to the asymmetrical development of EC. Riding is generally considered as involving profound symmetrical stresses between muscles, since both legs are involved (Willson, 2013; Djukic et al., 2018). The analysis of bilateral asymmetry was however performed on all individuals, including older adults, which could confound the results.

Although our results must be taken with caution, they are rather consistent with prior methodological studies which precisely investigated the relationship between EC and the practice of horse riding. Specifically, Tichnell (2012) performed multiple comparisons between Pre- versus Post-Contact Arikara populations as well as between Post-medieval British city- versus country-dwelling populations. The author observed significant correlations with horse riding for two entheses, the gluteal tuberosity and the adductor tubercle, and also observed that the greater and lesser trochanters had no predictive value for identifying horse riders. Later on, Djukic (2016) observed significantly more pronounced EC at the ischial tuberosity, *linea aspera*, and the adductor tubercle on the femur, in horse riding populations (Avars) compared to agricultural populations from medieval Serbia. The author considered the EC at the adductor muscles attachment site, in particular, as the most reliable indicators for the identification of riders as the action of keeping the legs together is not common in other daily activities than horse riding (Djukic et al., 2018).

With the exception of the anterior inferior iliac spine (COX E1), all other EC that we analyzed were also mentioned in the literature as being associated with horse riding (see Chapter 1, II.D.1; Table 3), but it was either not in the frame of systematic methodological investigations, either the entheseal changes were simply assumed to be related to horse riding, either there was no evidence for the practice of this activity in the concerned individuals and populations, or studies relied on single individuals, which does not give credit to the reliability of the relationship between these EC and horse riding.

We will discuss the general contributions and limitations of this research in a further section (see X below), and the main limitations to be considered in the analysis of EC, in particular, were discussed previously (see Chapter 1, I.C). Among various aspects, it is clear that the main challenge that we had to take into account to be able to make interpretations in terms of physical activities in past populations was the multifactorial etiology of entheseal changes (see XI below).

II. Joint changes

As for the analysis of entheseal changes, the correlation between the development of joint changes and aging led us to perform two series of analyses, one including young and mature adult individuals (YMA) only, and another one, with larger sample sizes, including individuals in all adult age categories. The main articular surfaces of the lower limb bones were combined into the acetabulofemoral, patellofemoral, tibiofemoral, and talocrural joints (see Chapter 2, III.A.2; Table 10). There were almost no significant differences between groups. In the analysis with the YMA sample only, we observed only a significant difference between the three groups for the frequency of all joint changes together when both sides were combined. Pairwise comparisons did not provide more precision, even if we observed more joint changes in the group from the documented collection from Lisbon (LIS) than in the Hungarian groups, and in the group with riding deposit (RD), in particular. We observed, in fact, almost no joint changes in the RD group in the YMA sample. This may partly be related to the limited size of the sample used in this analysis. When including all individuals in a second analysis, frequencies of joint changes were much more similar between groups, and there was no significant difference. In addition, there was only light asymmetry observed in each group and for each joint, and no difference in the pattern of asymmetry between groups either.

Degenerative joint changes are commonly used to analyze variation in behavior and mobility between populations (see for instance Knüsel, 2000b; Jurmain et al., 2012; Schrader, 2019, and see Chapter 1, I.B). Contrary to the analysis of entheseal changes, the results of the analysis of joint changes did not show differences that could possibly be related to the practice of horse riding in one or both Hungarian groups. As the practice of horse riding was very likely, at least for a part of the sample from the 10th century, and very unlikely in the group from Lisbon (see Chapter 2, II.C.1), we can assume that joint changes of the lower limb are not good indicators for this activity. The lack of specificity of these changes could explain these results, as various activities and postures might lead to the development of changes at those weight-bearing joints. These results could also be related to the fact that we used a binary scoring method for the analysis (see Chapter 2, III.A.2), which did not allow identifying differences according to the severity of the joint changes. We can, however, highlight that joint changes were scored as present only when clearly discernible, hence discarding very light changes. In addition, during our examination of the entire sample, we observed only a few cases of severe joint changes and eburnation.

Besides the main joints of the lower limb, we also analyzed, independently, the osteophytes at the *fovea capitis* of the femoral head. If the analysis in the YMA sample did not reveal any difference between groups, the analysis with all individuals showed a significant difference between groups when both sides were combined. Pairwise comparisons did not provide further precision, but there were more perifoveal osteophytes in the RD (57%) and NRD groups (53%), compared to the LIS group (34%). Considering the presence of old adults in the sample and the close correlation between such osteophytes and age, we must be cautious in the interpretation of this observation.

In a methodological study of Merovingian series from northeastern Gaul, including some individuals with riding-related grave goods, Baillif-Ducros (2018) systematically scored the presence of "osteophytic hip" when there was the combined presence of perifoveal osteophytes and osteophytosis on the margin of the femoral head. The author noted that this criterion was not specific to riders but suggested that it could be a good indicator when observed in association with other changes such as Poirier's facet and the ovalization of the acetabulum, especially if it occurred in young adult individuals. This would be related to the effect of the position of the rider on the hip joint. Similarly, the author scored the presence of osteoarthritis at the femoropatellar joint and suggested that this criterion completes the previous skeletal changes for the identification of horse riding, and the use of stirrups, in particular, in young and mature adult individuals.

As mentioned above, our results did not go in this direction since there was no significant difference between groups for the acetabulofemoral (without perifoveal osteophytes) and patellofemoral joints, and especially in the sample of young and mature adult individuals. The absence of differences between groups at the knee joint is particularly noticeable since the populations from the Hungarian Conquest period were using stirrups, as demonstrated by the archaeological goods discovered in the cemeteries (Nepper, 2002; Révész, 2003). The analysis of joints of the upper limb (such as the shoulders) may provide more information as the upper body plays an essential in riding too (Willson, 2013).

III. Morphological variants of the femur

Morphological variants were investigated as some of them are suspected to be influenced by mechanical aspects and were considered as being related to the practice of horse riding, in particular (see Chapter 1, II.D.1; Table 4; and Chapter 2, III.A.3). Six morphological variants of the femur were analyzed and compared between groups, in the entire sample of individuals.

Significant differences between groups were observed for three morphological variants (Table 34). Poirier's facet (FEM V1) and the third trochanter (FEM V5) were significantly more observed in the Hungarian group with riding deposit (RD) compared to the group from Lisbon (LIS). The third trochanter was also more frequent in the Hungarian group without riding deposit (NRD) compared to the LIS group, while we observed one of the rare significant differences between the RD and NRD groups for Poirier's facet (left side only). There was also only little bilateral asymmetry for each variant in each group, and no significant difference in the pattern of asymmetry between groups.

We highlight that our study is one of the few to distinguish the variations of the anterior aspect of the femoral head-neck junction, and especially Poirier's facet and the anteroiliac plaque (Villotte & Knüsel, 2009; Radi et al., 2013), which were often mentioned in the anthropological literature on horse riding but rarely distinguished (see Chapter 1, II.D.1). Based on this distinction and our observations, it seems that both features are influenced, at least partly, by different factors, since the anteroiliac plaque (FEM V2) was observed in high frequency in all groups. It was furthermore more present in the LIS group compared to the Hungarian groups, even if there was no significant difference. Our results suggest that the anteroiliac plaque, if related to activity, is not specific to horse riding. It could, for instance, result from repeated postures involved in various other activities that have been practiced by the individuals from Lisbon. Jennings et al. (2004) analyzed the presence of Poirier's facet, the anteroiliac plaque, Allen's fossa, and the posterior cervical imprint in femurs from a Byzantine monastery, and observed a significant asymmetry for the anteroiliac plaque only. The authors interpreted this observation as the consequence of repeated kneeling and genuflection among monks, which was consistent with historical and liturgical accounts.

Poirier's facet seems, however, to show a more promising relationship with the practice of horse riding, as it was significantly more frequent in the RD group compared to the LIS group, but not in the NRD group compared to the LIS group. As no, or little, interpopulation variation is expected between both Hungarian groups, these observations suggest a mechanical influence on the apparition of Poirier's facet, and the practice of horse riding in the RD group and absence of practice of riding in the LIS group is a reasonable and logical explanation in this context.

Among all studies that mentioned a possible link between Poirier's facet and horse riding, rare were those which relied on a systematic methodological investigation or on a sample of confirmed riders. In her methodological study of Merovingian series from northeastern Gaul, including some individuals with riding-related grave goods, Baillif-Ducros (2018) observed a significant difference for Poirier's facet between the individuals with and without riding deposit in their grave. In association with the osteophytic hip and the ovalization of the acetabulum, the author suggested that it represents a reliable indicator for the practice of horse riding. The appearance of Poirier's facet would indeed be a consequence of the femoroacetabular impingement related to the repeated sitting position of the rider, which involves a flexion of the hip.

The contact produced between the femoral head and the rim of the acetabulum by extreme flexion and abduction of the thigh would be a cause for the appearance of Poirier's facet (Capasso et al., 1999). With medical insights, Villotte and Knüsel (2009) provided a more precise explanation. Cam impingement (by opposition to pincer impingement) is caused by the movements of a non-spherical femoral head in the acetabulum during forceful movements, such as the flexion of the hip. More specifically, it would result from a "bump", an abnormal extension onto the femoral neck and increased thickness of the neck that is composed of subchondral bone and degenerative hyaline cartilage. This ossification would be stimulated by biomechanical forces (involved during flexion especially) and the extension of the articular surface of the head onto the neck, i.e., Poirier's facet, would correspond to the medial part of the bump, after the disappearance of soft tissues (Villotte & Knüsel, 2009). From their investigation, the authors suggest that the morphological variants at the femoral head-neck junction could, indeed, be considered as possible activity-related markers.

Contrary to the analysis of entheseal changes and joint changes, the significant difference observed here between the RD and NRD group tends to indicate that there was a difference in the level of horse riding practice between them, except if other factors are involved. We must, for instance, note that, despite a recent redefinition of Poirier's facet and the anteroiliac plaque (Radi et al., 2013), it may sometimes be uneasy to distinguish them, and, specifically, to identify their simultaneous presence. This difficulty, as well as the rather small sample size in the RD group, compared to the other groups, may have partly influenced our results.

Concerning the third trochanter, large and significant differences between both Hungarian groups and the LIS groups could also be explained by the practice of horse riding as the gluteus maximus muscle is considered as a primary factor governing its expression (Lozanoff et al., 1985; Bolanowski et al., 2005; Ghosh et al., 2014). However, we already discussed that the gluteal muscles might not, in fact, be relevant muscles for the identification of horse riding in our sample, as we observed no significant differences between groups and as their functions are involved in other activities or postures (see I.C above). The etiology of the third trochanter is still debated, and genetic and environmental factors are among the possible causes for its apparition (Ghosh et al., 2014). It was also notably suggested that this trait can be relevant for human taxonomy studies (Lozanoff et al., 1985). The possibility that the large differences observed between both Hungarian groups and the LIS group are due to interpopulation variation is, therefore, rather important.

Finally, in addition to Poirier's facet and the third trochanter, the hypotrochanteric fossa (FEM V6) showed a significant difference between the three groups (both sides combined) but not between paired groups, even if we observed that its frequency was higher in both Hungarian groups compared to the LIS group, in particular. The etiology of this trait is even more debated than for the third trochanter, and recent investigations highlighted how obscure are the causes of its apparition (Ghosh et al., 2014). Our results do not allow determining if mechanical factors are more likely to have influenced this factor compared to genetic factors, in particular. The quasi absence of bilateral asymmetry observed for these traits is an argument toward a genetic influence.

It should furthermore be noted that we did not find any explicit mention of the hypotrochanteric fossa as a possible indicator for horse riding in the anthropological literature, and very rare ones regarding the third trochanter (see Chapter 1, II.D.1; Table 4). These traits were investigated here in an exploratory approach.

This analysis underlined how little is known regarding the etiology of morphological variants. This is notably due to the fact that most of them are asymptomatic and non-lethal. As few clinical studies are focusing on these aspects, most of our knowledge comes therefore from anatomical and anthropological literature (Henderson, 2009).

IV. **Vertebral changes**

IV.A. Schmorl's nodes

Although their etiology is still debated, Schmorl's nodes are commonly interpreted as indicators of physical stress in past populations (see Chapter 2, III.A.4.a). We analyzed the presence of Schmorl's nodes for each vertebra and different groups of vertebrae (upper thoracic, lower thoracic, lumbar levels), taking into account the size of nodes (small and large; see Chapter 2, III.A.4.a; Table 12). Significant differences were observed between groups at all vertebral levels, with higher frequencies in the Hungarian groups, and in the NRD group compared to the LIS group, in particular. Concerning individual vertebrae, there were significant differences for the twelfth thoracic and first lumbar vertebrae specifically, with notably a higher frequency of large nodes in the NRD group compared to the LIS group. We observed no significant differences between both Hungarian groups, which supports the results of the analyses of the entheseal changes and joint changes, and suggests that there was no major difference in behavior or mobility pattern between these groups.

Even though other factors (e.g., congenital defects, spinal diseases, vertebral morphology) could influence the apparition of Schmorl's nodes, they are particularly common in individuals, young ones especially, whose high-level physical activity imposes great stress on their lower spine, such as elite athletes (Waldron, 2009). They could notably result from trauma related to hard physical activities, heavy lifting, or a fall from height (Mann & Hunt, 2013). In sports medicine, it is acknowledged that significant spinal loading forces and repetitive microtrauma over the years can cause disc herniations (Pugh & Bolin, 2004). Depending on the riding style, horse riding can cause high stresses on the vertebral column. The repetition of microtraumas on the vertebrae could lead to a fragilization of the outer ring of fibrous cartilage (*annulus fibrosus*) that surrounds the nucleus pulposus, which may ultimately result in disc herniations (Baillif-Ducros, 2018).

Schmorl's nodes are typically more frequent in lower thoracic and upper lumbar vertebrae, between the seventh thoracic and first lumbar vertebra (Hilton et al., 1976; Üstündağ, 2009; Dar et al., 2010). This is related to the different movements of the vertebral column, which are not equally free in all portions (Üstündağ, 2009). The lumbar vertebrae allow only minimum axial rotation compared to the thoracic vertebrae, even though their mobility is limited due to the attachment of the ribs (Üstündağ, 2009; Dar et al., 2010). The transition between the stiffer thoracic level and the more mobile lumbar level results in structural weakness for torsional stress, which makes this region more prone to injuries (Üstündağ, 2009). We can also mention that the twelfth thoracic and first lumbar vertebrae are the most frequent seat of vertebral fractures, which indicates that this region may be relatively susceptible to stress (Hilton et al., 1976).

In addition, regarding the size of Schmorl's nodes, it was previously demonstrated that the formation of large nodes could result from acute traumas, while small nodes would be more likely related to repeated microtraumas (Takahashi & Takata, 1994; Üstündağ, 2009).

Based on all these considerations, the practice of horse riding represents a possible explanation for our results and the differences observed between the Hungarian groups and the group from Lisbon, where it is very unlikely that individuals were performing this activity.

In her study of Merovingian populations, Baillif-Ducros (2018) did not observe the presence of the Scheuerman's disease (notably characterized by a cuneiformization of the vertebrae and the presence of Schmorl's nodes), while its prevalence is high in modern riders (Auvinet, 1999; Humbert, 2000). The presence of Schmorl's nodes alone was not however discussed. She suggested that this difference may be explained by the fact that modern riders are looking for high-level sports performance, and are thus affected differently by the practice of horse riding. Earlier, Üstündağ and Deveci (2011) attributed a case of Scheuermann's disease to a trauma or repeated trauma related to vertical forces due to riding stress. The individual was found in an Islamic cemetery (13-14th century) with a horse skeleton as a co-burial.

A study of archaeological samples of Mongolian pastoralists also revealed that populations from the Xiongnu Empire and Mongol Empire, known for their mounted warriors, showed significantly higher rates of Schmorl's nodes compared to a sample from the Bronze Age, when pastoralism emerged (Eng, 2013). The relationship between Schmorl's nodes and the practice of horse riding was also suggested for other Mongolian pastoralists (Karstens et al., 2018), as well as in several other studies relying on presumed riding populations, such as Post-Contact Native Americans (Miller & Reinhard, 1991; Sandness & Reinhard, 1992; Reinhard et al., 1994; Reinhard & Wall, 2002), or Scythian warriors (Wentz & de Grummond, 2009). In addition, a relatively high frequency of Schmorl's nodes was observed in young adult individuals from the Seventh Cavalry, who fought and died at the Battle of Little Bighorn on 25, June 1876, along with Lieutenant Colonel George A. Custer, during the American Civil and Indian Wars. These lesions occurred mostly in the lower thoracic and upper lumbar vertebrae and were attributed to axial trunk loading and compressional forces that could be related to horse riding, possibly accentuated by the lifting and carrying of heavy weapons and the use of hard saddles (Willey, 1997).

Sports medicine does not demonstrate the existence of an association between Schmorl's nodes and the practice of horse riding. This is partly due to the fact that their apparition seems to be influenced by other factors than activity or posture. Although previous anthropological studies often lack direct evidence of a link between the individuals and horse riding, they suggest that this activity could lead to the apparition of Schmorl's nodes. This hypothesis seems to be supported by our results.

IV.B. Spondylolysis

Although spondylolysis was often used as an indicator of stress in past populations and was previously referred to as possibly being related to the practice of horse riding (see Chapter 2, III.A.4.b), we observed only few (12) cases of vertebrae affected by spondylolysis in our sample, with an equal distribution between the NRD and LIS groups. If this trait was positively associated with horse riding, we would have expected higher rates in the Hungarian groups, and at least some cases observed in the group with riding deposit.

Spondylolysis is considered as indicative of a fatigue fracture, and in sports medicine, it is common in young athletes, and especially in those whose practice involves repetitive hyperextension of the back. As for gymnasts, this is notably the case of riders, who absorb significant forces with their lumbar spine in extension (Pugh & Bolin, 2004). Spondylolysis can lead to spondylolisthesis, the anterior slippage of a vertebra out of its original position onto the inferior vertebra, which is not present in higher rates in professional riders than in the general population (3-5%; Auvinet, 1999; Humbert, 2000).

This and our results suggest either that spondylolysis is not related to horse riding or that it is not specific to this activity. Spondylolysis is also among the numerous skeletal changes for which etiology is still debated, possibly being influenced by genetic and other factors in addition to mechanical factors (see Chapter 2, III.A.4.b). In the end, it seems not to represent a good indicator for the practice of horse riding in past populations. We can nevertheless mention the fact that healed fractures may not necessarily be visible during macromorphological examinations of skeletal remains (Merbs, 1989). The use of radiographic methods might contribute to a better identification of this process, and thus, to a better understanding of this condition and its possible relationship with physical activity.

V. Traumatic lesions

Although macrotraumas can be considered as anecdotical, reflecting accidental wounds or interpersonal injuries, they can provide information on the lifestyles and behaviors in past populations, completed by the analysis of other types of skeletal changes (see Chapter 2, III.A.5). Concerning horse riding, sports medicine reveals that fractures are the second most common type of injuries, after soft tissue injuries, and that a majority of these fractures result from a fall from the horse (Bixby-Hammett & Brooks, 1990).

Our analysis of fractures on the upper and lower body reveals that the upper limb was the most affected anatomic region in our sample and that there were generally higher rates of fractures in the Hungarian groups compared to the group from Lisbon. This difference was statistically significant only for the clavicle and concerned the RD and LIS groups, in particular (Table 38). Fractures of the clavicle mainly occurred at midshaft and were visible due to the presence of a callus, angular deformity, and diaphyseal shortening (Figure 37).

Figure 37. Oblique fracture of a left clavicle that might be related to a fall from a height. Collection of Sáarrétudvari-Hízóföld (10th century)

In sports medicine, the injuries related to horse riding concern mostly the upper limbs (see for instance Baillif-Ducros, 2018, and see Chapter 1, II.B). This would notably be related to the attempt of self-protection that occurs during a fall. 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 Chapter 1, II.D.1; Table 5). Fractures at the clavicle midshaft often occur from falls from a moderate height, such as from a bicycle or horse (Wedel & Galloway, 2013). It was postulated that such fractures mostly result from a fall on the outstretched hand, but it was demonstrated that they could also result, for instance, from a blow to the point of the shoulder due to a fall with landing on the shoulder, or also from a direct trauma to the clavicle (Wedel & Galloway, 2013).

Our results and these considerations suggest that the significant difference observed between groups for clavicle fractures could be a consequence of the practice of horse riding in the Hungarian group with riding deposit, at least. Among other studies, Khudaverdyan et al. (2016) notably described a case of oblique fracture with angular deformity on one clavicle of an individual from a Late Iron Age cemetery in Armenia. The individual showed multiple trauma, 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 higher rates of fractures in the upper limb in both Hungarian groups, compared to the thorax (ribs) and the lower limb, also coincides with the observations from sports medicine on horse riders (Bixby-Hammett & Brooks, 1990; Baillif-Ducros, 2018), while the distribution of fractures was equivalent between these three anatomical regions in the LIS group (Table 38; Figure 33).

With the exception of a cut wound and symbolic or surgical trepanations in the Hungarian series, which were not scored in this analysis, we did not observe traumas of the head, in any group, 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; Baillif-Ducros, 2018). This absence could partly be related to bone preservation in the archaeological materials. Some traumas may also have not let 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 the cemeteries from that period, found in association with the individuals in their graves, and the presence of earthen forts, built throughout the Carpathian Basin (Visy, 2003). Compared to individuals who were mostly urban workers living in Lisbon during the first half of the 20th century, higher rates of traumatic lesions 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). This could partly reflect the fact that our sample from Lisbon was composed of manual workers, relatively prone to accidental injuries (Alves Cardoso, 2008).

VI. **The ovalization of the acetabulum**

Vertical elongation of the acetabulum or anterosuperior extension of the acetabular rim are among the most discussed skeletal changes that could be related to the practice of horse riding (see Chapter 1, II.D.1; Table 4). Unlike most of them, variations of the shape of the acetabulum can be measured, and different methods have been used to investigate this aspect. We followed the same approach as Baillif-Ducros et al. (2012), Sarry et al. (2016), and Baillif-Ducros (2018), which is the calculation of a vertical/horizontal diameter index, or, index of ovalization of the acetabulum (IOA). Our results revealed that the individuals from burials with archaeological items related to horse riding showed an increased overall acetabular vertical ovalization compared with the ones from the graves with no riding-related goods in the Hungarian series, as well as with individuals from a modern population from Lisbon. The individuals from this comparison group almost certainly did not practice horse riding, intensively or regularly.

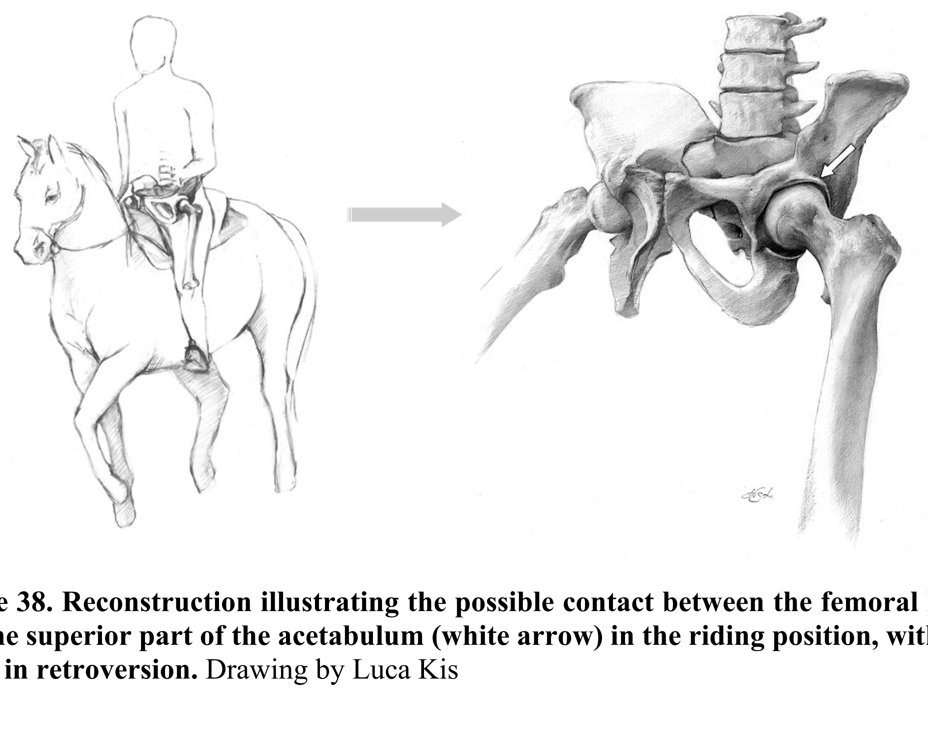

Figure 38. Reconstruction illustrating the possible contact between the femoral head and the superior part of the acetabulum (white arrow) in the riding position, with the pelvis in retroversion. Drawing by Luca Kis

The position that is privileged by riders is characterized by a pelvis in retroversion (tilted backward) and a diminished lumbar lordosis that allows a better absorption of vertical stresses (Auvinet, 1999; Humbert, 2000). When the hip is placed in that position, pressure is applied by the femoral heads on the superior and anterosuperior parts of the acetabula (Baillif-Ducros, 2018; Baillif-Ducros et al., 2012; Figure 38). Although the possibility that this skeletal modification could also result from other postures cannot be excluded, the vertical ovalization of the acetabulum can clearly be explained by the practice of horse riding.

Methodological research on the shape of the acetabulum as a possible indicator of the practice of horse riding was initiated by Erickson et al. (2000), who performed a Fourier analysis of the shape of the acetabulum on adult males from two Native American Arikara populations, respectively presumed riders and non-riders. They observed significant differences (set level of $\alpha = .1$) between both groups, with expanded anterosuperior acetabular rims in the presumed rider group. Inspired by this study, Garofalo (2004), with linear measurements taken at intervals of ten degrees from the midpoint of the acetabular notch to the acetabular rim, obtained significant differences between two British medieval series and individuals from the Robert J. Terry Anatomical Skeletal Collection. These differences were, however, not correlated with other presumed horse riding-related skeletal changes, and the author could not positively associate the elongation of the anterosuperior margin of the acetabulum with the practice of horse riding within those groups, mentioning individual skeletal variation as a possible causal factor. Later on, a morphometric analysis of the acetabular rim shape performed with the use of 3D scans on samples of ancient Mongolian pastoralists revealed significant differences between the Scythians and other Mongolian samples, but not with a reference collection (Eng, Baker, Tang, Thompson, & Gomez, 2012). According to the authors, these results could be related to the riding style or sample and methodological limitations. More recently, Ciurletti (2017) studied individuals from the Bronze Age necropolis of Olmo di Nogara, in Veneto, Italy, and analyzed the shape of the acetabulum (Feret's analysis, shape descriptors) with variables obtained using photographs. However, the limited sample size, and especially, the lack of comparison groups with the confirmed presence of horse riders and nonriders, limited the interpretations. Despite this, high frequencies of the extension of the superior rim of the acetabulum, visually scored, were noted, especially in males (95%) compared to females (58%). This, and the presence of other morphological variants and entheseal changes on the femur and the coxal bone led the author to confirm the hypothesis of the practice of horse riding in the population.

Finally, through direct measurements and the calculation of an index vertical/horizontal diameter of the acetabulum, which is the approach that we followed in our study, one probable Merovingian horse rider revealed very elongated acetabula compared to a reference collection (Baillif-Ducros et al., 2012), whereas, with the same method, Sarry, Courtaud, and Cabezuelo (2016) did not observe particularly elongated acetabula in a La Tène period mass burial associating eight horses and eight human individuals, but bone preservation was a limiting factor. This approach was also recently used in a more extensive way on Merovingian series from northeastern Gaul, including individuals with riding-related grave goods (Baillif-Ducros, 2018). The author found elongated acetabula in a notable part of these populations (with a predominance in males), including in three out of seven individuals with riding deposit in their graves. Her results, and the fact that this trait can be explained by the rider's posture, led the author to suggest that the elongation of the acetabulum, associated with other traits like Poirier's facet and hip joint changes, can represent a reliable indicator for the practice of horse riding,

Beside entheseal changes, no other skeletal change presumed to be related to horse riding was this precisely investigated in the frame of methodological studies. A major limitation found in most of the previous studies focusing on this aspect is, however, that the authors were only assuming the presence of the practice of horse riding in their studied populations, without direct evidence associated with the individuals, and without comparison groups of non-riders. Furthermore, several studies relied on the comparison between female and male individuals, which should necessarily lead to caution in the interpretations of skeletal changes in terms of activity.

Our promising results support the hypothesis that the vertical ovalization of the acetabulum may represent a potential indicator for the practice of horse riding in an archaeological population.

VII. The shape and robusticity of lower limb bones

External bone measurements have been used to infer behaviors and activities in past populations, and are considered as reliable for testing biomechanical hypotheses (e.g., Larsen, 1997; Capasso et al., 1999; Wescott, 2006; Campbell, 2018). Although cross-sectional geometry may provide more precise information, by taking into account the internal architecture of the bone, it was demonstrated that external dimensions can also reflect the results of cross-sectional geometry and can be used with validity for testing biomechanical hypotheses

(Wescott, 2006). These methods are, however, better suited to the study of general loading patterns than the analysis of specific activities, for which entheseal changes, for instance, are more likely to be informative (Tichnell, 2012).

In an exploratory approach, with the aim of evaluating general differences in activity or mobility patterns between groups, we calculated fourteen indices from direct measurements taken on the major bones of the lower limb: femur, patella, tibia, fibula, talus, and calcaneus. These indices are general descriptors of the shape and robusticity of the lower limb bones (Table 14). The values of a majority of the indices were significantly different between groups denoting variations in the shape and robusticity of the concerned bones (Table 46). Specifically, most of the indices (ten out of fourteen) revealed significant differences between the Hungarian group without riding deposit (NRD) in the graves and the comparison group from the Lisbon collection (LIS), and six indices were also significantly different between the Hungarian group with riding deposit (RD), and the LIS group. In contrast, we observed significant differences between the two Hungarian groups, RD and NRD, for only two indices.

Our results indicate a much greater variation, in general, between the Hungarian groups and the LIS group than between each Hungarian group. At this point, we wish to remind that both Hungarian groups, RD and NRD, come from the same cemetery. These results were thus expected as the Hungarian groups and the LIS group come from two very different populations, on the geographical, chronological, and cultural level. Interpopulation variation could, therefore, partly explain these differences. It is notably acknowledged that genetics are among the factors that can influence bone shape and robusticity (e.g., Ruff & Larsen, 2014).

Since no, or much less, interpopulation variation is expected between the RD and NRD groups, the fact that there was almost no significant difference between them is of great interest. It indicates that the series from Sárrétudvari-Hízóföld constitute, in fact, a rather homogenous population, which is supported by the majority of the previous analyses. Differences in shape and robusticity of bones can be interpreted as indicative of variation in habitual loading, and thus activity or mobility (e.g., Knüsel, 2000b; Marchi, 2008; Ruff & Larsen, 2014; Stock & Macintosh, 2016), and we can therefore assume that there were no major differences in behaviors between the two Hungarian groups. Specifically, if only the individuals from the group with riding deposit were practicing horse riding, or if they were riding in a significantly more frequent or intensive way than the individuals without deposit, we would expect to observe more variations in shape and robusticity of the lower limb bones between these two groups. Thus, our results tend, once again, to suggest that the individuals without riding deposit were practicing horse riding on a similar basis as the individuals with riding deposit in their graves.

Another possible explanation for the little variation observed between both Hungarian groups could be, however, that the selected indices of shape and robusticity do not reflect the influence of the practice of horse riding on the skeleton or that horse riding has no influence on bone morphology.

As far as we know, studies establishing a relationship between shape and robusticity of lower limb bones and the practice of horse riding are very scarce and relied sometimes rather on cross-sectional geometry than external measurements. Ruff (1994) compared Pre- and Post-horse Arikara populations and observed a slight trend towards femoral midshaft circularity that could be related to the use of horses, but that was not significant. The author also predicted that increased practice of horse riding might lead to increased mediolateral bending stress, and therefore to a decline in the anteroposterior-mediolateral diameter index (pilastric, at midhshaft). This aspect was observed, later on, by Wescott (2001) in other equestrian nomadic populations (Sioux, Crow, Cheyenne, etc.). They showed significantly more robust long bones at the femoral midshaft and subtrochanter, and a slightly more circular femoral midshaft, compared to other hunter-gatherer and horticulturalist populations. Later on, the author gave, however, a more nuanced picture, claiming that there were only few significant differences between equestrian hunter-gatherers and other populations, and that the observed differences could result from activity, diet, genetics, or other factors (Wescott, 2008). More recently, in two populations from Post-Contact period villages from the Great Plains, Campbell (2018) observed a reduction of bone strength variables in males, and attributed this to a reduction in mobility notably related to the introduction of the horse. By using horses for transportation, less stress is indeed expected on the lower limb, therefore leading to less bending and compression (Campbell, 2018).

The indices that we used in our study were selected in an exploratory way as indicators to observe general differences in activity or mobility level between groups. In spite of this, if we attempt to focus more specifically on the index values, we observe significant differences regarding the shape of midshaft and subtrochanter of the femur: the indices (FEM I2 and FEM I3, respectively) were significantly higher in the LIS group compared to each Hungarian group. This indicates that the femoral diaphyses in the Hungarian groups tended to be wider in the mediolateral plane (or less elongated in the anteroposterior plane) compared to the LIS group. FEM I2 values were also closer to the value of 100 in the Hungarian groups compared to the LIS group, which indicates that diaphyses were more circular at midshaft in the Hungarian groups. This reminds the observations made by Ruff (1994) and Wescott (2001) concerning mediolateral bending stress and the circularity of femoral diaphyses (see above). Circular femoral diaphyses, in particular, have been, in fact, linked to a decrease in mobility (Capasso et al., 1999; Stock & Macintosh, 2016). We could therefore assume from these results that the Hungarian groups were less bipedally mobile (i.e., walking or running), which could be explained by the daily practice of horse riding. This is supported by the fact that the populations from the Conquest period were semi-nomadic societies, where horses played an important role in daily life.

The assumption that the Hungarian groups were less bipedally mobile because of their use of horses can, however, be contradicted by other index values. We observed, indeed, a significant difference in the robusticity of femurs (FEM I1) when both sides were combined. Pairwise comparisons did not succeed to reveal between which groups were found these significant differences, but we observed that the femurs were more robust in the Hungarian groups compared to the LIS group. In addition, low pilastric (FEM I2) and platymeric (FEM I3) index values have been linked to more mechanically stressed bones (Larsen, 1997), which would thus be the case in the Hungarian groups compared to the LIS group. Finally, the platycnemic index values (TIB I2), which described the shape of the shaft of the tibia, also showed inconsistent results, as the values were higher in the NRD group, and lower in the RD and LIS groups. This index was even one of only two that showed a significant difference between both Hungarian groups. As the measurements involved in the calculation of this index are not taken at a fixed point but at the nutrient foramen, which location is variable, some have, however, questioned its reliability and value (Andermann, 1976; Ponce, 2010).

As far as we know, there are only very few studies, beside ours, that analyzed indices of shape and robusticity of the lower limb on a sample of individuals associated with horse remains or riding deposit in their graves. In the medieval necropolis of Vicenne (Italy), Belcastro and Facchini (2001) compared thirteen “horsemen” with the rest of the individuals with the aim of identifying possible interpopulation variations. Among other things, the main indices of shape and robusticity of the lower limb were calculated. The authors did not observe significant differences between the samples and did not comment further those results. It is however interesting to highlight that the group of “horsemen”, although of a very limited sample size, also presented lower values for the femoral pilastric and platymeric indices compared to the other male individuals, in the same way as for our Hungarian groups compared to the Lisbon group. In addition, when Blondiaux (1989, 1994) analyzed different northern French series from the High and Late Middle Ages, he observed that the only series showing clear platymeric femurs (i.e., with low platymeric index values) was the one from a High Medieval cemetery in which were found horse burials (Blondiaux, 1989, 1994).

In the end, the mixed results of our analysis make it difficult to determine if the Hungarian groups were more or less mobile than the group from Lisbon. A factor that should also be considered is that, although the semi-nomadic populations from the Conquest period were riding horses, it is difficult to evaluate it the use of stirrups and the practice of mounted archery, which requires very strong stabilization, may have had an effect on bone shape and robusticity. Wescott (2008) claimed, referring specifically to the studies on the Plains, that biomechanical studies of long bones have raised more questions than they have answered. With this exploratory analysis, we highlighted how little is known about the influence of the practice of horse riding on bone shape and robusticity, and how this very complex question will require further investigation. A better selection of variables, less exploratory, and more enlightened regarding biomechanical aspects, could already represent a promising further step.

VIII. **The identification of reliable horse riding-related skeletal changes**

Finally, many statistically significant differences were revealed from our analyses of different types of skeletal changes and comparisons between two groups of individuals from the same archaeological Hungarian collection, those with (RD) and without riding deposit (NRD) in their graves, and a group of presumed non-riders from the modern documented collection from Lisbon (LIS).

On the one hand, most of the analyses showed no significant difference between both Hungarian groups. This was the case for the entheseal changes, joint changes, and Schmorl's nodes, and for a majority of the morphological variants of the femur and indices of shape and robusticity.

On the other hand, all types of analyses and a majority of the investigated skeletal changes indicated significant differences between either the Hungarian group with riding deposit and the Lisbon group, either between the Hungarian group without riding deposit and the Lisbon group, or between both Hungarian groups and the Lisbon group.

A majority of the skeletal changes involved in this study have a multifactorial etiology, which includes genetic factors. Interpopulation could therefore explain, at least partly, the similarity observed between both Hungarian groups and the differences with the Lisbon group. However, all types of analyses and almost all skeletal changes included here were selected because they are commonly used as general or specific indicators of activity or mobility in past populations. It was indeed demonstrated that they are, to a certain extent, influenced by mechanical factors (e.g., Knüsel, 2000b; Jurmain et al., 2012; Schrader, 2019). Since interpopulation variation alone cannot explain the differences observed between groups and considering the fact that we applied strict methodological criteria to limit the influence of other factors (e.g., sex, age, pathological conditions), we can assume that our results reflect some differences in behavior and activity between groups.

The populations from the Hungarian Conquest period were semi-nomadic societies, in which horses took an essential role. The presence of equipment related to horse riding (stirrups, girth buckles, bits) or horse bones associated with the individuals in the graves strongly suggests that the concerned individuals were riding during their life, and it confirms, in general, the presence of horse riders in the population.

Only the analysis of comparative samples of known performers and non-performers can allow distinguishing skeletal markers that are specific to an activity (Tichnell, 2012). The modern documented collection from Lisbon was chosen as a comparison group because we could assume that the individuals were not practicing horse riding, or at least not in a regular and intensive way (see Chapter 2, II.C.1). In addition, the occupation of each individual was known, which allowed selecting only physically "active" workers, whose skeletal remains were prone to show some activity-related skeletal changes. A comparison between the semi-nomadic individuals from the Hungarian Conquest period and modern urban dwellers with only low level of physical activity (i.e., office workers, students) would have been, indeed, of very limited interest.

Taking into account all those considerations, it is only reasonable to suggest that the main difference in behavior or activity between the Hungarian groups and the Lisbon group was the practice of horse riding. A great majority of the skeletal changes that showed significantly higher rates or values in the Hungarian groups compared to the Lisbon group can, in fact, be explained by anatomical and functional aspects involved in the practice of horse riding. In addition, their association with this activity was previously mentioned in the anthropological literature, including sometimes on other presumed riding populations.

In the end, our results allowed identifying several promising skeletal changes for which the relationship with the practice of horse riding is probable:

- **The entheseal changes at the ischial tuberosity and anterior inferior iliac spine of the coxal bone, the adductor tubercle, trochanteric fossa, and *linea aspera* of the femur, the soleal line of the tibia, and the calcaneal tuberosity.** Since only entheseal changes at **the adductor tubercle of the distal femur and the calcaneal tuberosity** showed significant differences between groups on a sample that strictly excluded old adult individuals, and thus, limited the influence of aging, these two entheses are considered as the most promising ones;
- **Poirier's facet on the femoral neck**, which should be distinguished from other modifications of the femoral head-neck junction;
- **Schmorl's nodes**, especially at the thoracolumbar transition, and including large nodes;
- **A vertical ovalization of the acetabulum.**

We must highlight that, although these skeletal changes may indeed be influenced by the practice of horse riding, they should not be considered as a set of skeletal changes that are specific for this activity. This way, the presence of some or all of these skeletal changes in particular individuals cannot be considered as evidence that they were riders during their life, but it can naturally lead bioarchaeologists and paleopathologists to regard them as potential riders.

The presence of several of these skeletal changes together can, however, contribute to identify, statistically, the practice of horse riding in a group or population. Specifically, the most adequate research approach that we recommend would be to compare the frequencies and values of those skeletal changes observed in a group of interest with populations of confirmed — or, failing that, presumed — riders and non-riders, to evaluate the possibility that horse riding was a prevailing activity in this group. In this respect, we believe that our results can represent pertinent comparative data for future research, considering the nature of the collections that we studied and the scoring methods that we used.

Following this approach, we also note that **higher frequencies of fractures observed on the bones of the upper limb, and notably at the clavicle**, compared to other anatomical regions, can represent a complementary indication, in addition to some of the skeletal changes previously mentioned.

The interest of researchers on horse riding-related skeletal changes followed the influential contributions of Miller and collaborators (Miller & Reinhard, 1991; Miller, 1992; Reinhard et al., 1994), and Pálfi and Dutour (Pálfi, 1992; Pálfi & Dutour, 1996; Pálfi, 1997), who, especially, identified the signs of a "Horse Riding Syndrome" in several individuals from the collection of Sárrétudvari-Hízóföld. This doctoral research relied on a reexamination of this series in the frame of a systematic and comparative methodological investigation of different types of skeletal changes. Our results allowed evaluating the reliability of these changes as possible indicators for the practice of horse riding, and notably confirmed the promising value of several of the traits that had originally been mentioned: the entheseal changes at the adductor tubercle and *linea aspera* of the femur, and at the ischial tuberosity of the coxal bone, as well as the extension of the articular surface of the femoral head onto the neck and the superior extension of the acetabulum.

IX. The horse riders from the Hungarian Conquest period

As mentioned previously, this study relied on the comparison between two groups of individuals from the series from the Hungarian Conquest period cemetery of Sárrétudvari-Hízóföld. The distinction between the two groups of individuals was based only on one criterion, the presence or absence of any equipment related to horse riding or horse bones (or both) in their graves. The working hypothesis was that the individuals from the group with riding deposit, at least, was regularly practicing horse riding during their life and would, therefore, show skeletal changes related to this activity. Through multiple comparisons between the two Hungarian groups and an out-sample group of non-riders, we observed that the Hungarian groups showed higher rates for different skeletal changes that can be related to the practice of horse riding according to anatomical and functional aspects. Our interpretations were supported by previous observations from the anthropological literature and by sports medicine data. There was, however, no significant difference between both Hungarian groups with or without riding deposit for a large majority of the analyses that we performed. If only the individuals with riding deposit in their graves were practicing horse riding, we would expect to observe more differences for all skeletal changes between them and the group of individuals without riding deposit, and notably in the analyses of entheseal changes and Schmorl's nodes, and in the metric analyses. **This led us to suggest that the individuals without riding deposit in their graves were likely practicing horse riding as well.**

On the large amount of skeletal changes that were tested, significant differences between both Hungarian groups were in fact observed only for Poirier's facet, the index of ovalization of the acetabulum (with a borderline significant *p* value of .050), and for two indices calculated from measurements on the lower limb bones (which concerned the tibia and talus). Although it is not impossible that these observations might reflect differences in the intensity or regularity of the practice of horse riding, we consider that they are not enough to claim that only the individuals with riding deposit were riders, compared to the numerous skeletal changes that revealed no difference between both Hungarian groups. Those were all the entheseal changes that we investigated, as well as all joint changes, five out of six morphological variants of the femur, Schmorl's nodes at all vertebral levels, and twelve out of fourteen indices of shape and robusticity.

The populations from the Hungarian Conquest period were unanimously described by other cultures (e.g., Muslims, Byzantines, Western Christians) as nomadic horse riders. Around 900, the abbot Regino of Prüm wrote that "they spend all their time on horseback; they travel, rest, think, and talk on their horses" (Engel, 2001: 15). Descriptions made by the Byzantine Emperor Leo VI also mention that the Hungarians grew up on horseback and that they were unable to fight on foot. Horses were essential during campaigns, for warfare but also as a source of food and milk, and they were very numerous (Róna-Tas, 1999; Engel, 2001). Furthermore, the importance of the horse for these populations is documented by archaeological evidence found in the cemeteries, such as symbolic horse burials, equipment related to riding, sometimes including lavishly ornated harnesses or stirrups, or also widespread artistic depictions of horse figures on braid ornaments (Visy, 2003). Bearing this in mind, the idea that the practice of horse riding was prevailing in the population (or at least in the male population) is reasonable.

The presence or absence of archaeological grave goods may raise different hypotheses regarding funerary practices (Härke, 1997). In light of our results, the possibility that riding deposits may have concerned only actual riders in the population is rather unlikely. Instead, the distinction between individuals who were associated or not with riding deposit and horse bones may have rather been based on various social, religious, or symbolic aspects (e.g., recognition of a certain status, rank, or military skills). This is supported by the fact that graves with horse riding-related deposit are relatively rare in the Carpathian Basin, representing approximately 10% of around 30 000 known graves (Vörös, 2013). **In that respect, the anthropological data contribute to clarify the differences observed between the historical and archaeological sources.**

We must finally also consider a more pragmatic reason for the differences in archaeological goods between the individuals: the elements originally deposited in the graves may simply not have been preserved due to various factors (e.g., taphonomic processes, disappearance of organic materials, and lootings). Thus, it must be acknowledged that some individuals without deposit in their graves may have initially received a deposit. If the presence of riding equipment or horse bones in the graves concerned only horse riders, this could have contributed to mitigating significant differences between both Hungarian groups.

X. **Main contributions, limitations, and perspectives**

One of the main objectives of this study was to represent a methodological contribution to the bioanthropological research on activity-related skeletal changes, by investigating the possible influence of the practice of horse riding on the skeletal specifically. In the end, we can claim that this study represents the first methodological contribution to the research on horse riding-related skeletal changes to meet all the following criteria:

- It relies on an anthropological collection of confirmed horse riders, with a direct association between particular individuals and the activity provided by archaeological evidence;
- It includes a comparison group from a population in which the practice of horse riding was very unlikely;
- It is based on a systematic analysis of different types of skeletal changes commonly used as indicators of activity and behaviors in past populations;
- It relies on samples large enough to allow statistical analyses (unlike several studies based on single cases);
- It takes into account multiple methodological bias factors such as sex, age, and pathological conditions, and attempts to limit their influence using strict analytical criteria;
- It discusses the observed skeletal changes and their possible relationship with the practice of horse riding in light of anatomical and functional aspects, with the support of sports medicine literature.

Specifically, we must highlight the pertinence of the archaeological collection that was used, and which represents an essential strength of this study. The series from the 10th-century cemetery of Sárrétudvari-Hizóföld included, indeed, 32 graves with either a deposit of equipment related to horse riding, either horse bones, or both, in association with the individuals. The strict methodological criteria used in this investigation led us to include 17 of these individuals, which 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.

Although numerous studies mentioned skeletal changes as possible indicators for horse riding, most of them failed to meet several of the essential criteria presented above. Specifically, the main limits that we identified in the literature were the fact that the practice of horse riding was often only assumed without any direct evidence or the lack of a comparison sample and the lack of consideration of some methodological confounding factors. We should however underline that, beside the early contributions that initiated the interest on this topic in the 1990's (Miller & Reinhard, 1991; Miller, 1992; Pálfi et al., 1992a; Reinhard et al., 1994; Pálfi & Dutour, 1996; Pálfi, 1997), the methodological studies led by Belcastro and collaborators (Belcastro & Facchini, 2001; Belcastro et al., 2001; Belcastro et al., 2007), Djukic and collaborators (2016; Djukic et al., 2018), and Baillif-Ducros and collaborators (Baillif-Ducros et al., 2012; Baillif-Ducros, 2018) particularly stand out among the rest of the anthropological literature on the topic.

On another note, we must remind that research on activity-related skeletal changes is characterized by many pitfalls (e.g., Dutour, 1992; Jurmain et al., 2012; Schrader, 2019), and that, despite our efforts, this study showed also some limitations. Although several of them are specific to each type of analysis and were already addressed in the relevant parts of this discussion chapter (see above I to VII), we can mention here some of the main issues that we have been dealing with.

The first and main challenge that we faced was the multifactorial etiology of most (if not all) of the skeletal changes that are used as activity-related indicators (see Chapter 1, I.C). Acknowledging this problem led us to include in this doctoral research only a small part of the individuals from the Hungarian series, i.e., 67 out of a total of 265 individuals that were uncovered from the 262 graves of the cemetery. The strict methodological criteria that we applied allowed limiting the influence of some confounding factors: we selected only adult individuals to limit the influence of growth and developmental changes; we focused on males to eliminate the influence of sexual dimorphism; we distinguished the young and mature adults in the analyses of entheseal and joint changes to limit the effect of aging; we excluded pathological cases (e.g., DISH, traumas, dysplasia) that could influence the development of the investigated changes. Despite genetics, body size and weight are also among the other possible factors that can influence some of the investigated skeletal changes. These are factors that can be controlled, with more or less reliable estimations based on equations, or inferred directly from bone measurements (e.g., Ruff et al., 2012). Including these aspects in our study would have, however, limited too much the sample sizes and, thus, diminished the reliability and quality of the statistical analyses.

This leads to the second major challenge that we faced, and that is closely related: the rather limited sample sizes. This problem considerably limited our analyses and led us to interpret some of the results with caution. It concerned especially the group from the archaeological series with riding deposit. Even if this sample of 17 individuals represents, as mentioned above, the largest of its kind, it is still not a large size for conducting analyses, especially if we consider the fact that bone preservation and the exclusion of some data in certain analyses (e.g., old adults, pathological cases, unpaired bones in asymmetry analyses) contributed to decreasing the number of possible observations in this sample. This issue was also the main reason why we performed two series of analyses in the case of entheseal and joint changes, one on young and mature adult individuals only, and one, of a larger sample size, on all adult individuals, regardless of the age category.

Future attempts to address the different limitations mentioned above represent our main perspectives. The main one will be to collect more data from other series from the Hungarian Conquest period that also include direct archeological evidence for the practice of horse riding by individuals, such as the rich cemeteries of Karos, in northeastern Hungary (Révész, 1996b, 2003). Larger sample sizes in the archaeological groups will allow us performing more reliable and powerful analyses, including multivariate analyses, which we chose not to perform at this stage as they generally require large sample sizes and few missing data. With more data and larger samples, we should also be able to control for additional confounding factors such as body size and weight. In addition, the sex of several adult individuals in the Hungarian series could not successfully be determined, mostly due to occasionally poor bone preservation. Performing a secondary sexual diagnosis, based on discriminant functions elaborated with postcranial measurements that are dimorphic within the population, will allow including more individuals in the analyses (Murail et al., 1999; Thomas, 2011).

This leads to another important perspective that is the investigation of the activity-related skeletal changes in female samples. We expect that it will provide valuable insights into the possible participation of women in warfare, as well as the organization of the societies of the Hungarian Conquest period and the significance of some funerary practices. We notably remind that, in the cemetery of Sárrétudvari-Hízóföld, at least one of the 32 graves with riding deposit concerned a female adult individual. Genetic analyses might also help to determine the sex of the subadult individuals with riding deposit in their graves, which would also significantly contribute to improving our understanding of these societies.

Furthermore, the question of the riding style will be another point of interest as we ignore so far if the steppe nomad style of the populations from the Hungarian Conquest period (Uray-Kőhalmi, 1972) and other riding styles may result in similar bone modifications. Different styles may indeed involve different movements, and thus different muscular action (Djukic et al., 2018). This analysis focused only on one semi-nomadic population. There is therefore a possibility that our interpretations regarding the association between the skeletal changes and the practice of horse riding may be valid only in the case of this population. Only a few authors mention this aspect (Eng et al., 2012; Tichnell, 2012; Eng, 2016; Baillif-Ducros, 2018) (see Chapter 1, II.D.2.c), and the only study that addresses this question suggests that there may indeed not be a universal suite of features related to horse riding (Tichnell, 2012). Baillif-Ducros (2018) also suggests that horse riding indicators may be specific to a chronological period. A future comparative analysis including other nomadic and semi-nomadic populations (e.g., Early- and Middle Avars, Mongols, Post-Contact Native Americans) should allow us to identify the possible existence of specific or common features according to the riding style. In that regard, a more detailed analysis of the upper body (entheseal and joint changes of the upper limbs, in particular) may contribute not only to extend our analyses and to identify possible additional skeletal changes related to horse riding, but also to give insights into this riding style question.

Some valuable information might also be provided by individuals who, nowadays, perform reconstructions of mounted archery, with the attempt to be as close as possible to the historical techniques used in various periods and cultures. Certain people became specialists in this activity and have been performing such reconstructions for decades, following an approach that could be considered, to some extent, as experimental ethnoarchaeology. This is the case, for instance, of the team from the Ópusztaszer National Heritage Park, in Hungary, whom we had the opportunity to visit during this doctoral research (Figure 39). This notably helped to visualize and understand better the actual movements involved in mounted archery in the style of the populations who conquered the Carpathian Basin. Future collaborations with experimenters would be of great interest to provide more information regarding the influence of horse riding, and mounted archery, in particular, on the skeleton and the body.

Figure 39. Reconstruction of mounted archery in the style of the populations from the Hungarian Conquest period, from the Ópusztaszer National Heritage Park, in Hungary. Photo by Luca Kis, edited by Fara Muci

Finally, the multifactorial etiology of the entheseal changes was the reason that led us to perform an exploratory analysis of the microstructure of an enthesis, using µ-CT acquisitions and 3D reconstructions (see XI below). The objective was to determine if "mechanical" entheseal changes, related to activity, could be distinguished from changes related to other causes (see II.D.2.c). This preliminary investigation paved the way for further research (see XI below).

XI. The activity-related changes in the microstructure of the enthesis: an exploratory investigation

As previously discussed, the entheseal changes (EC) have been used for decades for the reconstruction of activities in past populations. Although various methodologies have been developed for their analysis, the fact that can be influenced by multiple factors remains an essential problem that limits the interpretations. Before the interpretation of EC in terms of possible activities, it is indeed important to consider how we can distinguish "mechanical" EC from changes related to other causes. The definition of the entheses and their changes and details regarding their use for the reconstruction of activities are presented in Chapters 1 and 2.

While entheses and their changes have been extensively studied with clinical, radiological, histological and osteological methods at macroscopic and microscopic scales (e.g., Cooper &

Misol, 1970; Resnick & Niwayama, 1983; Olivieri et al., 1998; Benjamin et al., 2002; Claudepierre & Voisin, 2005; Maffulli et al., 2005; Villotte, 2009; Junno et al., 2011; Schlecht, 2012; Henderson, 2013a; Henderson et al., 2016; Miszkiewicz & Mahoney, 2016), the 3D approach has also begun to be used as a tool for studying EC, but these researches focus mostly on entheseal surfaces (Pany et al., 2009; Henderson, 2013b; Noldner & Edgar, 2013; Nolte & Wilczak, 2013; Karakostis & Lorenzo, 2016). In the frame of our methodological investigation on the activities of the populations from the Hungarian Conquest period, we attempted to address the question of the cause of the EC through an exploratory and experimental approach with the complementary use of microtomodensitometry (μ-CT) and 3D imaging, which has been little applied to occupational markers so far (Djukic et al., 2015; Djukic, 2016; Mulder et al., 2016). In their study, Djukic et al (2015) used μ-CT for performing metric analyses of bone microarchitecture on several lower limb entheses, to study the relationship between macro- and microstructure, as well as between cortical and trabecular parameters at the entheseal level. They showed a lack of correlation between the stages of a macroscopic scoring system and the microstructural features at the entheses.

While we did not have the intention to elaborate a complete methodology and to base our final interpretations on the preliminary results obtained from this investigation, we expected to lay the foundation for further studies on that aspect. The particular relevance of our study materials, a population from the Hungarian Conquest period, whose activities are historically and archaeologically well-documented, was a major motivation to initiate this investigation. The aim was to determine if it could be possible, in the long run, to reliably distinguish an enthesis modified by mechanical factors from an enthesis altered by degenerative or pathological processes.

XI.A. The selection of the enthesis

We decided to focus for this part on the upper limb, and thus, on archery, the other main activity that is acknowledged for the populations from the Hungarian Conquest period. The main criterion that led us to proceed in this direction was the enthesis to study. We determined that the bicipital tuberosity of the radius would be particularly pertinent for this investigation. The *tuberositas radii*, which is the insertion site of *biceps brachii*, is one of the fibrocartilaginous entheses (Benjamin et al., 1986). These are the most documented and relevant group of entheses (the other group being the fibrous entheses) in the attempt to reconstruct past activities (Havelková & Villotte, 2007; Villotte, 2009; Villotte et al., 2010; Henderson et al., 2013; Villotte & Knüsel, 2013; Thomas, 2014; Weiss, 2015; Henderson et al., 2017b). *Biceps brachii* is one of the flexor and supinator muscles of the elbow, and changes at *tuberositas radii* were previously interpreted to be linked with occupation (Dutour, 1986; Hawkey & Merbs, 1995; Pálfi, 1997; Robb, 1998; Molnar, 2006; Weiss, 2007; Baker et al., 2012; Thomas, 2014; Tihanyi et al., 2015). Agricultural and building activities, especially carrying heavy loads, have proved to be a potential cause for EC at this enthesis (Commandré, 1977; Galera & Garralda, 1993; Al-Oumaoui et al., 2004; Havelková et al., 2011; Rojas-Sepúlveda & Dutour, 2014). In 1986, Dutour investigated the skeletal remains of Neolithic Saharan populations of hunters-fishermen-gatherers from Mali and Niger and identified the presence of EC on the upper limbs of several individuals. The changes observed at the bicipital tuberosity of the radius, associated with asymmetrical changes at other insertion sites (for triceps brachii and teres minor especially), led to the hypothesis of the habitual practice of archery. In 2014, Thomas investigated the frequency of EC in a Neolithic population from the Cerny culture (Paris Basin, France). Among 36 identified adult males, 13 were buried in association with arrowheads. Her results reveal a higher frequency of EC at several insertion sites among the group of individuals buried with arrowheads, the difference with the other group being significant for the radial tuberosity in particular. Those are examples of studies suggesting archery as an activity prone to lead to EC at this specific insertion site.

Finally, another motivation for the choice of the radial tuberosity for this part was more practical. This fibrocartilaginous enthesis has quite well-defined margins, which is a particularly determinant criterion in order to perform the micro-computed tomography (μ-CT) acquisition and the 3D reconstruction of the regions of interest.

XI.B. Materials

For this exploratory research, the methodology of the analysis of the microstructure of the bicipital tuberosity had already been elaborated and tested on two adult individuals from Hassi-el-Abiod (northern Mali), belonging to a Neolithic population of hunters-fishermen-gatherers who lived close to lake or wetland areas about 7 000 BP. This material had been studied by Dutour in the first place, and EC observed at the bicipital tuberosity of the radius contributed to the hypothesis of the practice of archery (Dutour, 1986, 1989). This preliminary exploration consisted in the comparison between an enthesis with EC and a normal, regular, and smooth enthesis, in order to observe a possible difference in their microstructure (Berthon et al., 2015a). The promising results led us to go further and apply this methodology on our materials of early Hungarians from the Conquest period to investigate if the repeated movement involved in archery could result in differences in the entheseal microstructure compared to the normal and pathological aspect of the enthesis (Berthon et al., 2016a).

To that end, we relied on three pairs of radii, belonging to three adult males (Figure 40).

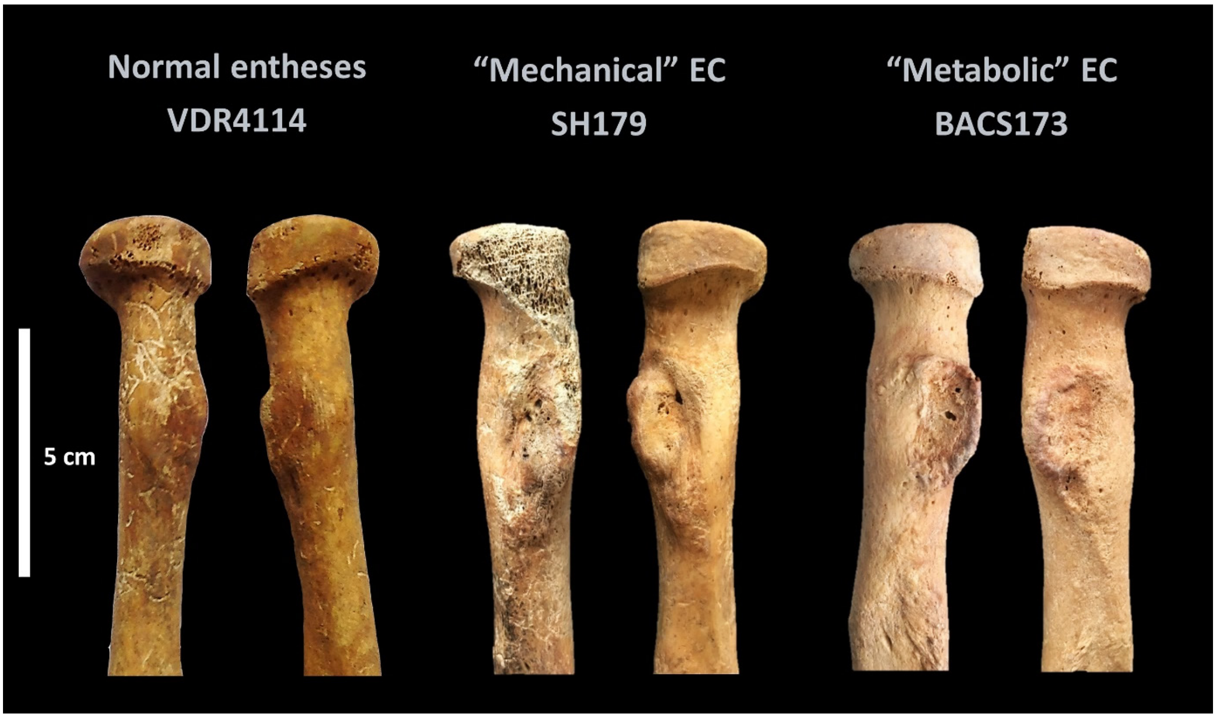

Figure 40. Three pairs of analyzed radii for normal condition (VDR4114), "mechanical" entheseal changes (EC) (SH179), and "metabolic" entheseal changes (BACS173). Photos by William Berthon & Olivier Dutour

1) The first individual is presumed to represent the normal aspect of the enthesis. He comes from the Merovingian-Carolingian (7-10th centuries) cemetery of Val-de-Reuil "Le Chemin aux Errants", in Normandy, France. The excavation was led by the French National Institute for Preventive Archaeology (INRAP), under the supervision of Yves-Marie Adrian, in 2012. A total of 230 burials were excavated and studied (Beurion, 2009; Berthon et al., 2015b). No evidence for warfare context had been uncovered. The examination of the skeletal remains of the selected individual (VDR4114), a 20-50 years old male, did not suggest any particular pathological condition or stress prone to lead to bias in the analysis of entheseal changes. Both radial tuberosities showed smooth-rounded contour and smooth and regular surface, despite slight taphonomic alterations likely due to roots in the soil.

2) The second individual is presumed to show activity-related EC at bicipital tuberosities. This mature male comes from the main collection of this doctoral research, the Hungarian Conquest period cemetery of Sárrétudvari-Hízóföld. The selected individual (SH179) was buried with arrowheads and bow elements discovered in association with the skeleton

(Nepper, 2002). The two radii of this "presumed archer" exhibited raised margins, bone formation, macro-porosity, and fine porosity as well as erosive areas at bicipital tuberosities.

3) The third and last individual has been selected to represent EC probably related to a metabolic condition. This mature male comes from the Hungarian Late Middle Ages – Early Modern times cemetery (16-17th centuries) of Bácsalmás-Homokbánya. This cemetery was excavated in several phases between 1993 and 2003, by Erika Wicker, Zoltán Polgár and László Pintér, and 481 skeletons were unearthed. The archaeological and historical data suggest the presence of a population of farmers, with no evidence for warfare context (Lovász et al., 2013). The selected individual (BACS173) was affected by diffuse idiopathic skeletal hyperostosis (DISH) or Forestier's disease. This metabolic disorder is particularly characterized by the calcification and ossification of soft tissues, including ligaments and entheses (Resnick & Niwayama, 1976; Waldron, 2009; Holgate & Steyn, 2016). The main diagnostic criteria that were observed on the skeleton for this metabolic disorder are: ossification of the right side anterior longitudinal ligament from T2 to L5 (complete and non-complete fusion), with a "candle wax" appearance; normal intervertebral disc spaces; entheseal changes at *radii*, *claviculae*, *patellae*, *calcanei*, or *ilii*; ossification of rib cartilage and sternocostal ligaments (Paja et al., 2010; Paja, 2013). The bicipital tuberosities, in particular, were characterized by raised and irregular margins, bone formation, irregular surface, and macroporosity.

XI.C. Methodology

All 6 radii were μ-CT scanned in order to investigate bone microarchitecture of the entheses. Microtomodensitometry provides, in a nondestructive way, an insight into the biomechanical properties of bone and the characteristics of bone remodeling through a three-dimensional approach (e.g., Lespesailles et al., 2006; Coqueugniot et al., 2010a; Colombo, 2014; Rittemard et al., 2014; Khoury et al., 2015). We applied the μ-CT acquisitions processing chain (Coqueugniot et al., 2011) developed in research unit PACEA (UMR 5199, CNRS/University of Bordeaux, Pessac, France), including image processing with TIVMI® (Treatment and Increased Vision for Medical Imaging) software. It is based on the HMH (Half Maximum Height) 3D algorithm, allowing the software to automatically identify the optimal limits between each material such as bone and air (Spoor et al., 1993; Dutailly et al., 2009). The radii were CT scanned at PLACAMAT (UMS 3626, CNRS/University of Bordeaux), Pessac, France, on a GE® Phoenix v|tome|x s, with an isotropic resolution between 15.7 and 17.8 μm. We focused the acquisitions on the enthesis area. The micro-CT was operated at 120 kV and 110 μA, with a 500 ms integration time per projection. The data, which are slices in the three orientations of space, were then treated with TIVMI® software to obtain 3D reconstructions from slices superposition.

Several preliminary steps were required in order to analyze the microarchitecture of the entheses. We realized a primary 3D reconstruction of the whole entheses to globally visualize the entheseal surface for selecting regions of interest (ROIs), on which observations were then performed. In each radius, three portions localized at different height levels (25, 50, and 75%) of the enthesis were selected (Figure 41). The total height was calculated as the number of horizontal slices between the level of the superior and inferior margins of the enthesis, which were visually determined. Each bounding box created in this way was 4 mm high, with the medium slice exactly located at the level of interest. The length and width of the boxes depended on the morphology of the bone itself. In general, we selected the ROIs on the medial half of the tuberosity, where *biceps brachii*'s tendon does attach to the bone. We also ensured that these ROIs were long enough to catch a portion on the outside of the entheses, in order to investigate the transition between normal diaphyseal bone (on the medial-posterior face of the bone) and the entheseal area.

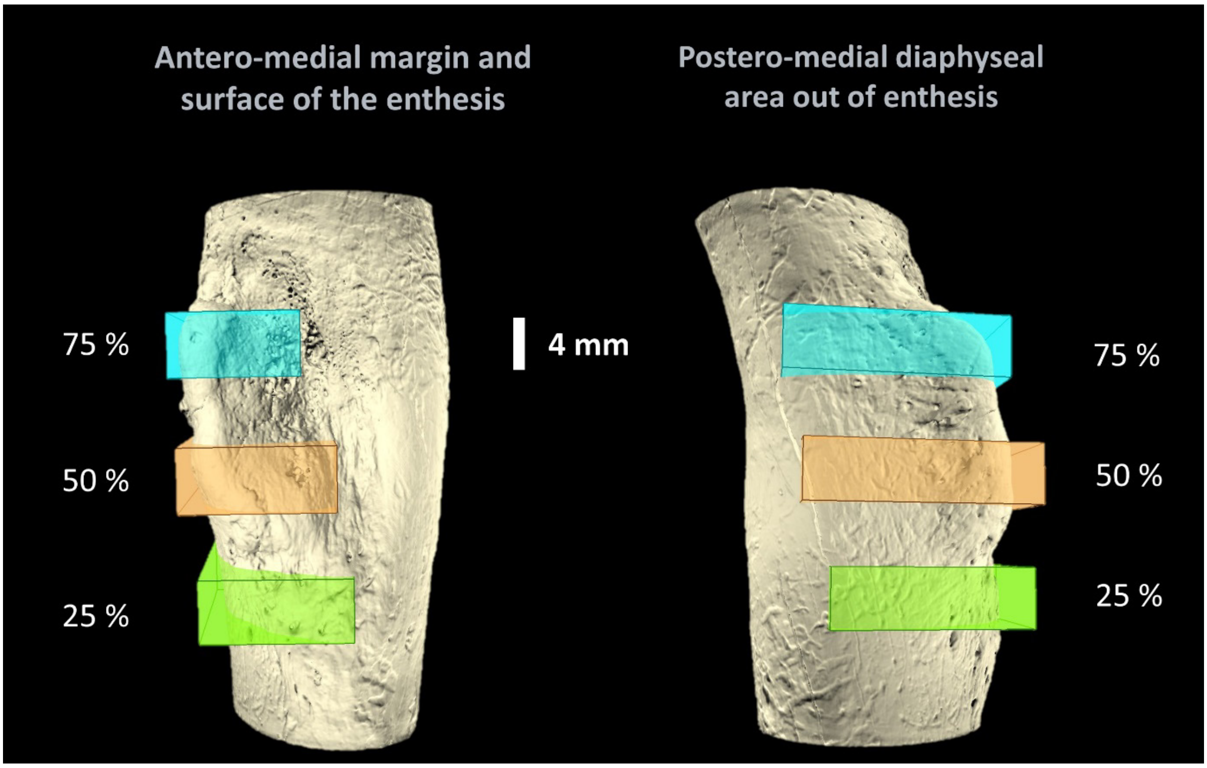

Figure 41. Example of a 3D reconstruction of the enthesis showing the selection of the regions of interest at different height levels. SH179, "presumed archer", left radius; reconstructions by William Berthon

We then operated a segmentation according to the grey level values of each component. It consists of the definition of subsets or materials in order to make the software able to distinguish bone from empty canals and medullary cavities, external vacuum, and sedimentary residues such as sand. Subsequently, a binary image was obtained using a double threshold. It consists of white pixels (the elements we want to keep in the 3D reconstruction) and black pixels (the elements to exclude). Finally, using the HMH algorithm, binary slices were superposed to reconstruct the canal system of the cortical bone, to observe its three-dimensional organization. This methodology, using μ-CT and 3D reconstructions with TIVMI® software program, has already been performed in a research focusing on trabecular bone microarchitecture during growth, with good repeatability (Colombo, 2014).

XI.D. Microstructural comparison of different types of entheseal changes

From the first observations of the final 3D reconstructions, it appeared that the most relevant level of interest for comparisons between the three groups was 50% of the enthesis height. At this medium region of the enthesis indeed, the organization of the canals of the cortical bone seemed to be less influenced by the morphology of the enthesis itself. At the upper and lower areas, a specific orientation of canals, for example, might be problematic to interpret, because they are transitional locations between a normal flat diaphysis and the most elevated part of the insertion site. Considering this, and in order to make the comparison easier, we decided to present here only the six reconstructions performed at this medium level (Figure 42). The main observations in each case are summarized in Table 50.

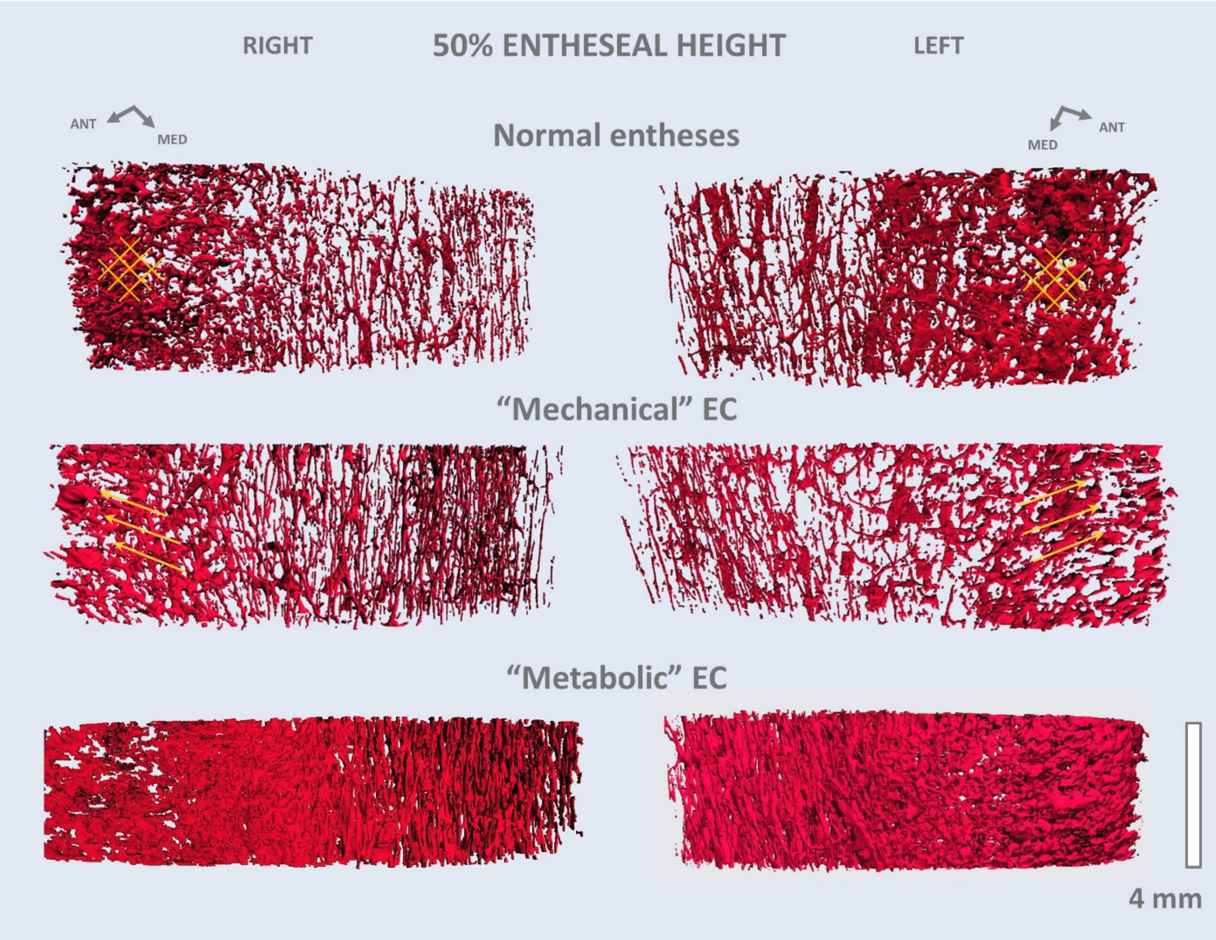

Figure 42. 3D reconstruction of the canals of the cortical bone for each enthesis, at 50% of the enthesis height. The normal aspect (VDR4114) shows, in particular, a reticulated organization at the medial margin; the “mechanical” EC (SH179) are characterized by a preferential orientation of the canals, while the “metabolic” EC (BACS173) exhibit an irregular, large and dense organization; reconstructions by William Berthon

The 3D reconstructions of the canal system of the cortical bone, as well as the medullary cavities, concerning a presumed normal enthesis, had already been described with more details in the preliminary experimentation (Berthon et al., 2015a). The “normal” enthesis of the present study exhibited a similar type of organization regarding the canals of the cortical bone. On the medial-posterior face of the shaft, outside the enthesis, we observed a normal Haversian organization, with thin and longitudinal Havers’ canals and a few transversal Volkmann’s canals. On the antero-medial margin of the enthesis, the canals, which were thicker, revealed a reticulated organization with roughly oblique interconnections.

In the case of the presumed activity-related EC, observed on a probable archer, the medial-posterior face of the diaphysis revealed the same longitudinal and thin organization of canals. At the antero-medial margin, however, they appeared to be globally oriented toward the same anterior and proximal direction.

The third case, with a DISH condition, showed considerable differences from the two others. Even if the longitudinal organization was preserved on the diaphysis, the canals were much larger. On the antero-medial face, the reticulation previously observed was not visible anymore. Instead, the organization appeared to be very irregular, with wide canals present in a higher density.

Table 50. Summary of the cortical bone canal organization differences observed between the three groups of entheses

	Medial-posterior diaphysis	Antero-medial entheseal margin
"Normal" entheses	Longitudinal; thin	Reticulated; rough
"Mechanical" entheses	Longitudinal; thin	Preferentially oriented
"Metabolic" entheses	Longitudinal; large	Loss of reticulation; irregular; wide; dense

XI.E. Could µ-CT and 3D reconstructions help to identify activity-related entheseal changes?

Focusing on the organization of the canal network of the cortical bone, this preliminary exploration of the microarchitecture of an enthesis already allows the identification of variations between the normal condition and EC seemingly related to different causes. We could observe a normal pattern, already identified in a previous work (Berthon et al., 2015a), with a Haversian organization out of the enthesis and a variation at the entheseal margin. We can assume that the reticulation observed in this case may correspond to the structural adaptation of osteons to normal mechanical constraints, in accordance with Wolff's law (Frost, 1994). Concerning the probable archer individual, there is only a slight variation from the normal organization, involving a bone remodeling with a preferential orientation of the canals. Could we consider this as the reflection of the adaptation to mechanical constraints involved in standardized gestures of specific activities like archery? In this exploratory work, and until further studies will be performed, we can at least support this hypothesis. The last case, with a metabolic disorder, is characterized by the loss of the osteonic organization inside the entheseal area. This suggests that calcification at entheses resulting from DISH condition might be related to a primary ossification process.

Finally, our preliminary results confirm that the use of µ-CT and 3D imaging can surely enhance our understanding of entheseal changes and their formation. While it is premature to give a definitive answer to the question of the distinction between mechanical and metabolic-related EC, we put forward the fact that the observations performed here are promising.

The next steps of this investigation should include larger samples in order to multiply the observations. The sampling will take into account the numerous biases inherent in studies aiming to reconstruct activities in ancient populations (e.g., Dutour, 1992, 2000; Villotte, 2009; Meyer et al., 2011; Jurmain et al., 2012; Milella et al., 2012; Alves Cardoso & Henderson, 2013; Perréard Lopreno et al., 2013; Thomas, 2014). Better comparative work requires more objective criteria. We must perform a "skeletonization" method on smaller regions of the 3D reconstructions (Blum, 1967; Plougonven, 2009; Douss, 2015). It consists in creating a simplified representation of an object, in making it thinner (1 voxel wide) to keep its basic structure. It is based on the sequential 3D curve-thinning algorithm developed by Palágyi et al. (2001). We obtain, in this way, a simplified modeling of the cortical microstructure allowing us to determine qualitative and quantitative parameters (Colombo, 2014). These parameters may be used to quantify the microarchitecture of normal and changed conditions and to test the interindividual variability. Once the methodology will be tested and validated, other susceptible etiologies for EC, such as inflammatory diseases, could be investigated, and various entheses could be analyzed. For instance, Djukic in 2016 has already been interested in the possible identification of horse riding practice in medieval series, confronting macromorphological observations and μ-CT analyses of different EC of the upper and lower limbs.

Under this framework, questions such as bilateral asymmetry or sex differentiation might be clarified in comparison with macromorphological examinations. This methodology might open up some interesting horizons for the research field on activities reconstruction, and therefore allow to build upon the knowledge regarding the lifestyles and behaviors in past populations such as those from the Hungarian Conquest period. Our observations encourage us to conduct further investigations on the microarchitecture of entheses, as well as other types of skeletal changes (e.g., Schmorl's nodes, morphological variants, spondylolysis) for which the multifactorial etiology represents an essential limit in their interpretation in terms of activity.

CONCLUSIONS

This doctoral research had two main objectives. The first one was to contribute to the research on activity reconstructions in past populations with the identification of skeletal changes that could be more reliably related to the practice of horse riding, in particular. The second objective was to use this knowledge to possibly improve our understanding of the funerary practices of the societies from the Hungarian Conquest period (10th century).

To do so, we analyzed different types of skeletal changes commonly used as indicators of activity: entheseal changes, joint changes, morphological variants, vertebral changes, traumatic lesions, as well as several indices of shape and robusticity of the lower limb bones. The comparison between two groups of individuals from a Conquest period cemetery, with and without deposit related to horse riding in their graves, and a group of modern known non-riders, from the documented collection of Lisbon, allowed identifying various skeletal changes that can be explained by the practice of horse riding. This is supported by anatomical and functional aspects, sports medicine, and previous anthropological studies led on riding populations. These skeletal changes included especially some entheseal changes of the coxal bone, femur, tibia, and calcaneus, Poirier's facet on the femoral head-neck junction, Schmorl's nodes at the thoracolumbar transition, and the vertical ovalization of the acetabulum.

Our results suggest that these skeletal changes can be used to evaluate, statistically, the possibility that a population of interest was practicing horse riding. For this purpose, the frequencies and values of these features should be compared with pertinent populations of known riders and non-riders. The data that we recorded on such collections could be used in future studies for comparative analyses.

This study took into consideration most of the pitfalls inherent to research on activity-related skeletal changes, leading to several limitations, such as relatively limited sample sizes. The main difficulty was the multifactorial etiology of most of the activity-related skeletal changes, such as the entheseal changes. An exploratory analysis of the microarchitecture of entheseal changes, using micro-CT acquisitions and 3D reconstructions revealed that microstructural variations could allow, with further research, distinguishing entheseal changes related to activity and those influenced by other factors.

We can consider that the two main objectives of this study were reached. It represents, indeed, a methodological contribution to the research on activity reconstructions in past populations, with the identification of skeletal changes that can probably be related to horse riding. It also revealed that, in our series from the Hungarian Conquest period, the individuals buried without a riding deposit in their graves were likely riding, in the same way as the individuals buried with a riding deposit. This funerary practice could, therefore, carry a more social or symbolic significance.

It also paved the way for future research directions, which should include the examination of larger samples with direct evidence of the practice of horse riding, from the Hungarian Conquest period but also other nomadic and semi-nomadic populations (e.g., Early- and Middle Avars, Mongols, Post-Contact Native Americans). The extension of the analyses of skeletal changes to the upper limb should also give a more complete picture of the influence of horse riding on the skeleton.

A notable conclusion that can be drawn is how essential it is to apply strict methodological criteria to avoid the major pitfalls associated with this type of research. Besides, we emphasize the fundamental importance of selecting pertinent anthropological collections, where specific activities can be assumed from direct evidence. This is one of the keys to reliably identify skeletal changes related to activity among past populations.

SUMMARY

Some pathological or nonpathological changes observed on human bones can be related to activities practiced during life. This results from bones' ability to adapt their shape and structure in response to mechanical loading. Scholars have considered the reconstruction of activities from skeletal changes in past populations as "Bioarchaeology's Holy Grail", representing, in fact, a sort of ultimate goal which is hardly accessible due to many methodological pitfalls that must be acknowledged. Among all activities, horse riding, in particular, has interested bioarchaeologists and paleopathologists for several decades as it brought profound and lasting changes in the history of human cultural evolution concerning major aspects such as trade, settlement, warfare, subsistence, social organization, and political ideology. In that regard, many types of skeletal changes have been described as part of a "horse riding syndrome", i.e., as being related to the regular or intense practice of horse riding. The lack of specificity of changes and their multifactorial etiology are, however, among the various confounding factors that characterize this field of research. This, together with the absence, in most of studies, of contextual evidence connecting the individuals with an activity and the lack of comparison groups, often result in limited or unreliable interpretations of skeletal changes in terms of specific activities, such as riding.

Archaeological and historical sources attest that tribes of semi-nomadic populations conquered the Carpathian Basin with powerful armies of mounted archers 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 that period often provide cases of deposits of archery and horse riding equipment as well as horse bones associated with the individuals in the graves. 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 doctoral research has two main objectives. The first one is to contribute to the research on activity reconstructions in past populations with the identification of skeletal changes that could more reliably be associated with the practice of horse riding, in particular. The second objective is to bring an ethnoarchaeological contribution by possibly improving our understanding of the funerary practices of the societies from the Hungarian Conquest period.

We limited the effect of sex and age on the development of skeletal changes by including only adult males in our materials. This way, we selected a sample of 67 individuals from the 10th-century Hungarian cemetery of Sárrétudvari-Hízóföld, which was divided into two groups of individuals, according to the presence or absence of riding deposit in their grave (17 and 50 individuals, respectively). We also selected a modern (19-20th century) comparison group of 47 presumed non-rider individuals from the documented collection of Lisbon. Moreover, the young and mature adult individuals were distinguished for certain analyses to limit the influence of aging.

We analyzed different types of skeletal changes commonly used as indicators of activity and behavior in past populations: entheseal changes (at the muscles attachment sites), joint changes, morphological variants, vertebral changes, and traumatic lesions. Various direct measurements of the lower limb bones were also used to calculate indices of shape and robusticity. We selected these skeletal changes considering anatomical and functional aspects, and taking into account the bioanthropological and sports medicine literature on horse riding.

Statistical analyses mostly revealed significant differences between the Hungarian groups with or without riding deposit and the comparison group from Lisbon. These differences concerned especially various skeletal changes that can be explained by the practice of horse riding, such as some entheseal changes at the coxal bone, femur, tibia, and calcaneus, a morphological adaptation on the femoral neck, intervertebral disc herniations at the thoracolumbar junction, or the ovalization of the acetabulum on the coxal bone. Our results suggest that these skeletal changes can be used with confidence to evaluate, statistically, the possibility that a population of interest was practicing horse riding. For this purpose, one should compare the frequencies and values of these features with pertinent populations of known riders and non-riders. In this respect, future comparative analyses could use the data that we have recorded. Along with these skeletal changes, we also propose to consider the higher frequency of fractures of the upper limb — notably the clavicle —, relatively to other bones' fractures, as a complementary indicator.

On another note, comparisons between groups for these skeletal changes revealed that the individuals from the Hungarian cemetery without riding-related deposits in their grave were likely riding horses as well. This would explain why historical sources mention great numbers of riders in the populations from the Conquest period while only a minority of the graves in the Carpathian basin contain riding deposits. This funerary practice could, as a consequence, carry a more social or symbolic significance.

We consider that we have achieved most of the two objectives of this research. It represents, indeed, a methodological contribution to the research on activity reconstructions in past populations, with the identification of skeletal changes that can probably be related to the practice of horse riding. It also improved our understanding of the societies from the Hungarian Conquest period and their funerary practices, in particular.

We took into consideration most of the pitfalls inherent to research on activity-related skeletal changes, leading to several limitations, such as relatively restricted sample sizes in the archaeological groups. This represents one of the main aspects that we should improve in the future by including additional collections from the Hungarian Conquest period, but also other nomadic and semi-nomadic populations. In addition, the multifactorial etiology of the skeletal changes represented one of the main difficulties for their interpretation in terms of activity. This limitation notably concerned the entheseal changes, which can be related to mechanical factors, but also be influenced by age, sex, genetics or pathological conditions. In that regard, we performed the exploratory analysis of the microarchitecture of a well-defined and documented enthesis, the bicipital tuberosity of the radius. Using micro-CT acquisitions and 3D reconstructions of the canals of the cortical bone, we observed that some microstructural variations could allow, with further research, distinguishing entheseal changes related to activity from those related to other factors, thus contributing to improving the reconstruction of activities of past populations.

In the end, a notable conclusion that can be drawn is how essential it is to apply strict methodological criteria to avoid the major pitfalls associated with this type of research. Besides, we emphasize the fundamental importance of selecting pertinent anthropological collections, where specific activities can be assumed from direct evidence, as well as comparison groups of non-performers. These are determinant factors for the reliable identification of activity-related skeletal changes among past populations.

RÉSUMÉ

Certaines modifications pathologiques ou non-pathologiques observées sur les os humains peuvent être liées à des activités pratiquées au cours de la vie. Ceci résulte de la capacité des os à adapter leur forme et leur structure en réponse à des charges mécaniques. Les chercheurs ont considéré la reconstruction des activités des populations passées à partir des modifications squelettiques comme le « Saint Graal de la bioarchéologie », représentant en effet une sorte de but ultime difficilement accessible en raison de nombreux écueils méthodologiques qui doivent être pris en compte. Parmi toutes les activités, la pratique cavalière, en particulier, intéresse les bioarchéologues et les paléopathologistes depuis plusieurs décennies car elle a apporté des changements profonds et durables dans l'histoire de l'évolution culturelle humaine concernant des aspects majeurs tels que les échanges, les peuplements, la guerre, la subsistance, l'organisation sociale et les idéologies politiques. À cet égard, de nombreux types de modifications squelettiques ont été décrits comme faisant partie d'un "syndrome du cavalier", c'est-à-dire comme étant liés à la pratique régulière ou intense de l'équitation. Cependant, différents facteurs de biais caractérisent ce champ de recherche, dont le manque de spécificité des modifications et leur étiologie multifactorielle. Cette situation, conjuguée à l'absence, dans la plupart des études, de preuves contextuelles reliant les individus à une activité, ainsi qu'à l'absence de groupes de comparaison, donne souvent lieu à des interprétations limitées ou peu fiables des modifications squelettiques en termes d'activités spécifiques, comme la pratique cavalière.

Les sources archéologiques et historiques attestent que des tribus de populations semi-nomades ont conquis le bassin des Carpates à l'aide de puissantes armées d'archers montés au tournant des 9[e] et 10[e] siècles, conduisant ainsi à la fondation du Royaume de Hongrie un siècle plus tard. Les cimetières de cette période fournissent souvent des cas de dépôts de matériel d'archerie et d'équitation ainsi que des ossements de chevaux associés aux individus dans les tombes. L'association étroite entre ces objets et les restes osseux, ainsi que le contexte historique bien connu, permettent de postuler que les individus concernés ont pratiqué l'équitation au cours de leur vie. Ces populations figurent donc parmi les plus pertinentes pour mener des études méthodologiques sur les modifications squelettiques liées aux activités et, en particulier, à la pratique cavalière.

Cette recherche doctorale a deux objectifs principaux. Le premier est de contribuer à la recherche sur la reconstitution des activités des populations passées en identifiant des

modifications squelettiques qui pourraient être associées plus fiablement à la pratique cavalière, en particulier. Le deuxième objectif est d'apporter une contribution ethnoarchéologique en améliorant éventuellement notre compréhension des pratiques funéraires des sociétés de la période de la Conquête hongroise.

Nous avons limité l'influence du sexe et de l'âge sur le développement des modifications squelettiques en n'incluant que des individus adultes masculins au sein de notre matériel d'étude. Nous avons ainsi sélectionné un échantillon de 67 individus issus du cimetière hongrois de Sárrétutudvari-Hízóföld, datant du 10^{e} siècle, qui a été divisé en deux groupes d'individus, selon la présence ou l'absence de dépôt lié à la pratique cavalière dans leur tombe (17 et 50 individus, respectivement). Nous avons également sélectionné un groupe de comparaison moderne (19-20^{e} siècle) de 47 individus présumés non-cavaliers, au sein de la collection documentée de Lisbonne. De plus, les individus adultes jeunes et matures ont été distingués des adultes plus âgés pour certaines analyses de façon à limiter l'influence du vieillissement.

Nous avons analysé différents types de modifications squelettiques couramment utilisées comme indicateurs d'activité et de comportement dans les populations passées : les modifications des enthèses (aux sites d'insertion des muscles), modifications articulaires, variations anatomiques, modifications vertébrales et les lésions traumatiques. Diverses mesures directes des os des membres inférieurs ont également été utilisées pour calculer des indices de forme et de robustesse. Nous avons sélectionné ces modifications squelettiques en considérant les aspects anatomique et fonctionnel, et en tenant compte des précédentes recherches en bioanthropologie et des données de la médecine sportive sur l'équitation.

Les analyses statistiques ont principalement révélé des différences significatives entre les groupes hongrois avec ou sans dépôt lié à la pratique cavalière et le groupe de comparaison de Lisbonne. Ces différences concernaient surtout diverses modifications squelettiques qui peuvent s'expliquer par la pratique de l'équitation, telles que certaines modifications des enthèses au niveau de l'os coxal, du fémur, du tibia et du calcanéum, une adaptation morphologique sur le col fémoral, la présence de hernies discales à la jonction thoraco-lombaire, ou l'ovalisation de l'acétabulum sur l'os coxal. Nos résultats suggèrent que ces modifications squelettiques peuvent être utilisées avec confiance pour évaluer, statistiquement, la possibilité qu'une population d'intérêt pratiquait l'équitation. Pour ce faire, il convient de comparer les fréquences et les valeurs de ces traits avec des populations pertinentes de cavaliers et de non-cavaliers connus. À cet égard, les données que nous avons enregistrées pourraient être utilisées dans le cadre de futures analyses comparatives. En sus de ces modifications squelettiques, nous proposons également de considérer la fréquence plus élevée de fractures du membre supérieur — notamment de la clavicule —, par rapport aux fractures d'autres os ou régions, comme un indicateur complémentaire.

Par ailleurs, les comparaisons entre groupes pour ces modifications squelettiques ont révélé que les individus du cimetière hongrois qui n'avaient pas de dépôt lié à la pratique cavalière dans leur tombe montaient aussi probablement à cheval malgré tout. Cela expliquerait pourquoi les sources historiques mentionnent des cavaliers en très grand nombre parmi les populations de l'époque de la Conquête alors qu'une minorité seulement des tombes du bassin des Carpates contiennent des dépôts liés à la pratique cavalière. Cette pratique funéraire pourrait, par conséquent, plutôt revêtir une signification sociale ou symbolique.

Nous considérons que les deux objectifs de cette recherche ont été majoritairement atteints. Cette étude représente, en effet, une contribution méthodologique à la recherche sur la reconstitution des activités des populations passées, avec l'identification de modifications squelettiques qui peuvent être liées de façon probable à la pratique cavalière. Notre étude a également contribué à améliorer notre compréhension des sociétés de l'époque de la Conquête hongroise et de leurs pratiques funéraires, en particulier.

Nous avons tenu compte de la plupart des écueils inhérents à la recherche sur les marqueurs osseux liés aux activités, ce qui a entraîné plusieurs limitations, comme la taille relativement restreinte des échantillons au sein des groupes archéologiques. C'est l'un des principaux aspects que nous devrons améliorer à l'avenir en incluant des collections supplémentaires de la période de la Conquête hongroise, mais aussi issues d'autres populations nomades et semi-nomades. De plus, l'étiologie multifactorielle des modifications squelettiques représente l'une des principales difficultés pour leur interprétation en termes d'activité. Cette limitation concerne notamment les modifications des enthèses, qui peuvent être liées à des facteurs mécaniques, mais aussi être influencées par l'âge, le sexe, des facteurs génétiques ou certaines pathologies. À cet égard, nous avons effectué l'analyse exploratoire de la microarchitecture d'une enthèse bien définie et documentée, la tubérosité bicipitale du radius. À l'aide d'acquisitions micro-CT et de reconstructions 3D des canaux de l'os cortical, nous avons observé que certaines variations microstructurales pourraient permettre de distinguer les modifications des enthèses liées aux activités de celles liées à d'autres facteurs, contribuant ainsi à améliorer les reconstructions des activités des populations passées. Cela encourage donc à mener des recherches plus approfondies sur le sujet.

Au final, une conclusion notable qui peut être tirée de cette recherche doctorale est qu'il est essentiel d'appliquer des critères méthodologiques stricts pour éviter les principaux écueils associés à ce type de recherche. En outre, nous tenons à souligner l'importance fondamentale de sélectionner des collections anthropologiques pertinentes, pour lesquelles la pratique d'activités spécifiques peut être assumée à partir de preuves directes, ainsi que des groupes de comparaison de non-pratiquants. Il s'agit là de facteurs déterminants pour l'identification fiable de modifications squelettiques liées aux activités au sein des populations du passé.

ÖSSZEFOGLALÓ

Bizonyos, az emberi csontokon megfigyelhető patológiás és nem patológiás elváltozások összefüggésbe hozhatók az egyén által rendszeresen végzett fizikai aktivitásokkal. Ez annak köszönhető, hogy a csontok – mind formájukban, mind szerkezetükben – képesek adaptálódni az őket érő mechanikai behatásokhoz. Az egykor élt népességek körében végzett fizikai aktivitások csontelváltozásokon alapuló rekonstrukcióját a történeti embertani iskolák a „Bioarcheológia Szent Gráljának" tekintik; ez a terület tulajdonképpen egyfajta végső célt reprezentál, ami csak nagy nehézségek árán érhető el, mivel számos metodológiai buktatót kell számításba venni a vizsgálatok során. Az elmúlt évtizedekben a fizikai aktivitások közül elsősorban a lovaglás vonta magára a történeti embertannal és paleopatológiával foglalkozó kutatók figyelmét, mivel annak elterjedése mélyreható és hosszútávú változásokat hozott az emberiség kulturális evolúciójába, olyan meghatározó elemeket érintve, mint a kereskedelem, a letelepedés, a hadászat, a létfenntartás, a társadalmi szerveződés vagy a politikai ideológia. A szakirodalomban számos léziót írtak le az úgynevezett „lovagló szindrómával", azaz a rendszeres vagy intenzív lovaglással összefüggésben, azonban az erre a kutatási területre fókuszáló vizsgálatokat többek közt a csontelváltozások specifikusságának hiánya és multifaktoriális etiológiája is nehezíti. Az említett tényezők mellett az is problémát jelent, hogy a legtöbb tanulmányban hiányzik az egyént az adott fizikai aktivitáshoz kapcsoló bizonyíték és az összehasonlítási csoport. A fentiek együttesen gyakran ahhoz vezetnek, hogy a léziók csak limitáltan vagy megbízhatatlanul interpretálhatók egy specifikus fizikai aktivitás, például a lovaglás szempontjából.

Régészeti és történeti források tanúsága szerint a 9. és 10. század fordulóján erős, lovasíjász hadsereggel rendelkező, nagyállattartásra berendezkedett törzsek hódították meg a Kárpát-medencét, ami egy évszázaddal később a Magyar Királyság megalapításához vezetett. Az erre a korszakra keltezhető temetőkben feltárt sírokból gyakran kerülnek elő íjászatra és/vagy lovaglásra utaló mellékletek, valamint lócsontok. Az említett mellékletek és az embertani leletek közti szoros kapcsolatot, valamint a jól ismert történeti hátteret figyelembe véve feltételezhetjük, hogy az ezekben a sírokban nyugvó egyének rendszeresen lovagoltak életük során. Ennek fényében a fent említett populációk a legmegfelelőbbek közé tartoznak abból a szempontból, hogy metodológiai vizsgálatokat végezzünk rajtuk az aktivitással, különösen a rendszeres lovaglással összefüggésbe hozható csontelváltozásokra vonatkozóan.

Doktori kutatási projektemnek két fő célkitűzése volt. Az első célom az volt, hogy hozzájáruljak az egykor élt népességek fizikai aktivitásainak rekonstrukcióját célzó kutatások fejlődéséhez olyan csontelváltozások azonosításával, amik megbízhatóbban összefüggésbe hozhatók a rendszeresen végzett lovaglással. A második célom az volt, hogy a magyar honfoglalás kori társadalom temetkezési szokásaival kapcsolatos ismereteink bővítése révén új társadalomrégészeti adatokat szolgáltassak.

Vizsgálataimba csak a felnőtt férfiakat vontam be, hogy ezzel minimalizáljam az életkor és a nemiség csontelváltozások kialakulására gyakorolt zavaró hatását. Ennek megfelelően Sárrétudvari–Hízóföld 10. századi temetőjéből 67 egyén embertani leletei képezték a vizsgálati anyagot, amit két csoportra osztottam aszerint, hogy a temetkezés tartalmazott-e lovaglásra utaló sírmellékletet (17 „lovas" és 50 „nem lovas" egyént különítettem el). Ezen felül egy modern (19–20. századi) összehasonlító csoportot is kiválasztottam, amit a lisszaboni dokumentált embertani gyűjteményből származó 47 olyan egyén alkotott, akiknél előzetesen ki lehetett zárni a lovas életmódot. Bizonyos elemzések során a fiatal és érett felnőtt korú egyéneket is elkülönítettem egymástól, hogy ezzel minimalizáljam az öregedéssel járó csonttani folyamatok zavaró hatását.

Doktori kutatási projektem keretein belül olyan léziótípusokat vizsgáltam, amelyeket a vonatkozó szakirodalomban a történeti népességek életmódjának és rendszeresen végzett fizikai aktivitásainak az indikátoraiként tartanak számon. Ezek a következők: enthesealis elváltozások (az izmok kapcsolódási területeinél), ízületi elváltozások, morfológiai variációk, csigolyaléziók és traumás eredetű elváltozások. Az egyes csontok alakját és robuszticitását leíró indexek meghatározásához további direkt méréseket is végeztem az alsó végtag csontjain. A megfelelő léziók kiválasztásánál anatómiai és funkcionális szempontokat is figyelembe vettem, és a lovaglással kapcsolatos bioantropológiai és sportorvosi szakirodalomi adatokat is felhasználtam.

A statisztikai vizsgálatok többnyire szignifikáns különbséget mutattak ki a magyar honfoglalás kori vizsgálati csoportok (lovaglásra utaló sírmellékletekkel vagy anélkül) és a lisszaboni széria között. Ezek a különbségek leginkább olyan csontelváltozások esetében jelentkeztek, amelyek kialakulását a rendszeres lovaglással lehet magyarázni. Ilyenek például a medencecsonton, a combcsonton, a sípcsonton és a sarokcsonton megfigyelhető bizonyos enthesealis elváltozások, a combcsont nyakának morfológiai adaptációja, a gerinc alsó háti és ágyéki szakaszán jelentkező porckorongsérv, illetve a csípőízületi vápa ovalizációja. Eredményeim azt mutatják, hogy ezek a léziók alkalmasak lehetnek arra, hogy statisztikai alapon nagy bizonyossággal megítélhessük, hogy egy adott populáció rendszeresen végzett-e lovas tevékenységet. Ennek eldöntéséhez a fent említett csontelváltozások gyakoriságait és értékeit kell összehasonlítani a releváns „lovas" és „nem lovas" populációkban. Eredményeim e tekintetben fontos összehasonlítási alapként szolgálhatnak a jövőbeni kutatások számára is. Továbbá úgy vélem, hogy a fent említett léziók mellett a felső végtagot, különös tekintettel a kulcscsontot érintő akut traumás eredetű töréseknek a csontváz más régióit érintő törésekhez képesti nagyobb előfordulási gyakoriságát is érdemes lehet indikátorként figyelembe venni az összehasonlítások során.

Másfelől, az általam vizsgált csoportok összehasonlító elemzése arra is rámutatott, hogy a Sárrétudvari–Hízóföld 10. századi temetőből előkerült, lovaglásra utaló mellékletek nélküli sírokban nyugvó egyének a lovaglásra utaló sírmellékletekkel eltemetett egyénekhez hasonlóan életük során valószínűleg rendszeresen lovagoltak. Ez a megállapítás magyarázattal szolgálhat arra az ellentmondásra vonatkozóan, hogy míg az írott források nagyszámú lovast említenek a honfoglalás kori populációkban, addig a honfoglalás kori Kárpát-medence területén feltárt sírok csak kis része tartalmazott lovaglásra utaló sírmellékleteket. A fentiek következményeként a vonatkozó mellékletek elhelyezése a sírokban vélhetően sokkal inkább valamifajta társadalmi vagy egyéb szimbolikus jelentéstartalommal bírhatott.

Doktori kutatási projektem két fő célkitűzését teljesítettem. Vizsgálataim során olyan csontelváltozásokat azonosítottam, amelyek a rendszeres lovaglás következményeként alakulhattak ki, így kutatási projektem egy metodológiai hozzájárulásnak tekinthető az egykor élt népességek fizikai aktivitásainak rekonstruálására irányuló vizsgálatok szempontjából. Kutatási eredményeim révén a magyar honfoglalás kori társadalommal, különösen a temetkezési szokásokkal kapcsolatos ismereteink is bővültek.

Vizsgálataim során arra törekedtem, hogy az aktivitással kapcsolatos csontelváltozások kutatásával együtt járó nehézségek, buktatók többségét figyelembe vegyem. Ez bizonyos limitációkat vont maga után, így például viszonylag kis mintaszámot eredményezett a honfoglalás kori vizsgálati csoportokban. Doktori kutatási projektemen belül az alacsony mintaszám jelenti az egyik olyan fő területet, ami a jövőben fejlesztésre szorul, amit további magyar honfoglalás kori anyagok, illetve egyéb nomád és félnomád populációk bevonása révén érhetek majd el. A fentiek mellett a csontelváltozások multifaktoriális etiológiája jelentette az egyik fő nehézséget a léziók fizikai aktivitás szempontjából történő interpretációja során. Ez a nehézség az enthesealis elváltozások értékelése során különösen megmutatkozott, mivel azok kialakulását a mechanikai tényezők mellett az egyén életkora, neme, genetikai háttere és különböző kórképek is befolyásolhatják. Mindezek tudatában doktori kutatási projektem keretében egy jól definiált és jól dokumentált *enthesis* – a kétfejű karizom (*musculus biceps brachii*) tapadási felületéül szolgáló orsócsonti érdesség (*tuberositas radii*) – mikroszerkezetének a felderítését szolgáló vizsgálatot is elvégeztem. A tömör csontállomány csatornáiról készült micro-CT felvételek és 3D rekonstrukció révén azt a megfigyelést tettem, hogy néhány mikroszerkezetbeli variáció – további kutatások elvégzését követően – lehetővé teheti majd az aktivitással összefüggésben létrejövő enthesealis csontelváltozások elkülönítését a más tényezők miatt kialakulóaktól, így elősegítve az egykor élt népességek körében végzett fizikai aktivitások rekonstrukciójának a fejlődését.

Végezetül fontos megjegyezni, hogy a szigorú metodológiai kritériumok alkalmazása nélkülözhetetlen az ezzel a típusú kutatással együtt járó fő nehézségek, buktatók elkerülése végett. Mindemellett, a vizsgálati anyagul szolgáló megfelelő antropológiai gyűjtemények kiválasztásának az alapvető jelentőségét is fontos kihangsúlyozni. Nemcsak azoknak az anyagoknak a körültekintő kiválasztása fontos, ahol a specifikus fizikai aktivitás végzésére közvetlen bizonyítékok utalnak, hanem azoknak az összehasonlító gyűjteményeknek a kiválasztása is, ahol nem végezték az adott fizikai aktivitást. A fentiek kulcsfontosságúak ahhoz, hogy az egykor élt népességekben megbízhatóan tudjuk azonosítani az aktivitással összefüggésbe hozható csontelváltozásokat.

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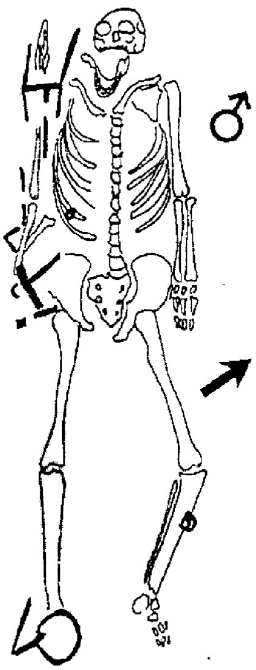
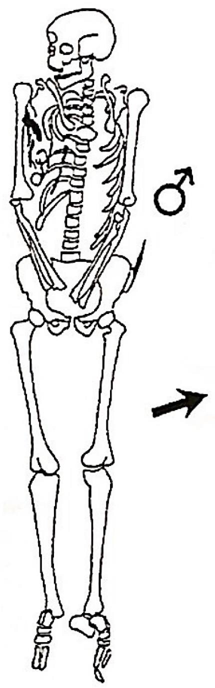
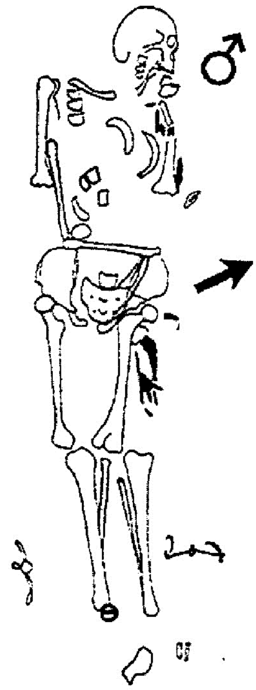
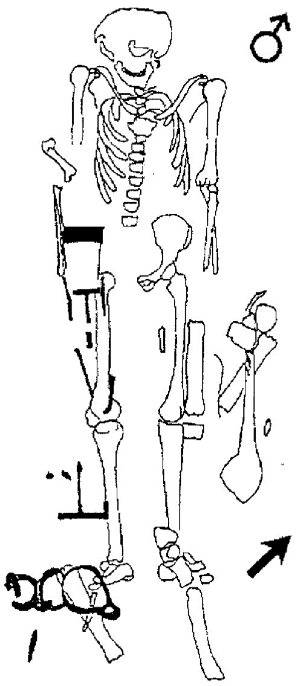
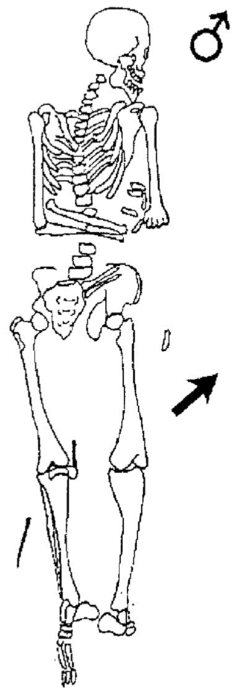
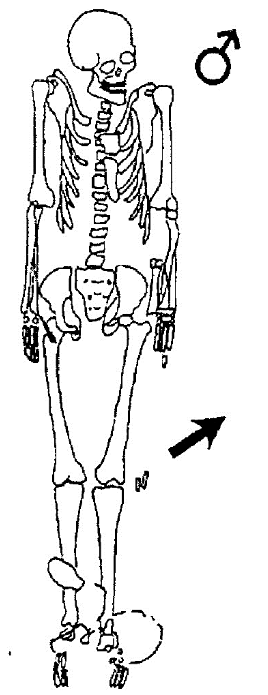
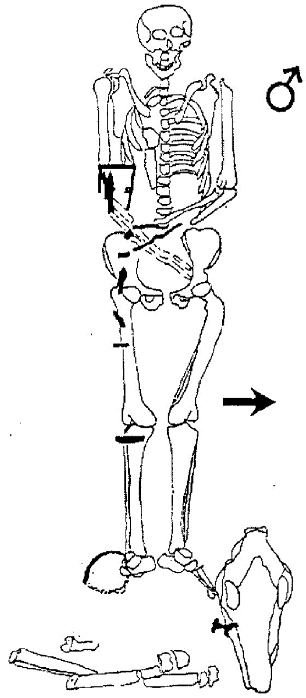
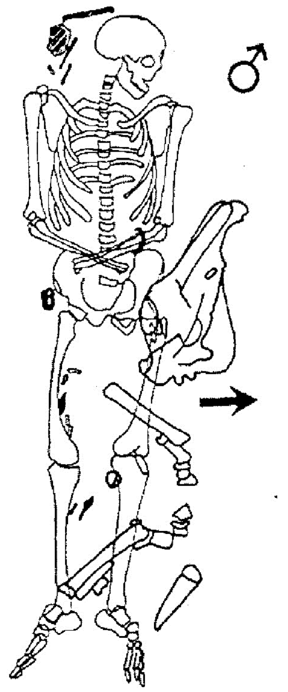
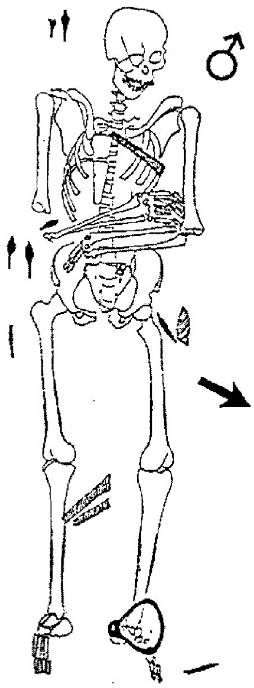
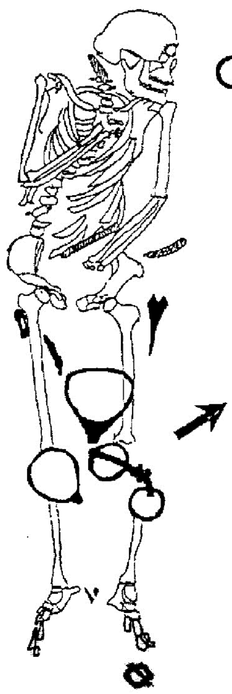
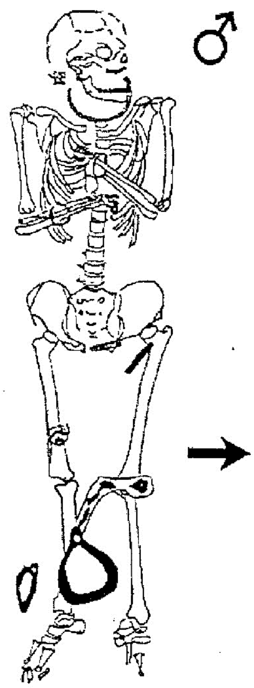
Appendix 1. Summary of the deposits related to horse and horse riding in the graves of the individuals from the Hungarian Conquest period cemetery of Sárrétudvari-Hízóföld

Grave number	Horse burial	Bit	Stirrup	Girth buckle	Saddle mounts
5		X	X	X	
29				X	
41		X	X	X	
81	X	X	X	X	
87		X	X		
90		X	X		
108		X	X	X	X
146	X	X	X		
160	X	X	X		
171			X		
183		X	X	X	
197		X	X	X	
213	X		X	X	
245	X				
252		X	X	X	
257	X	X		X	
259	X	X	X	X	

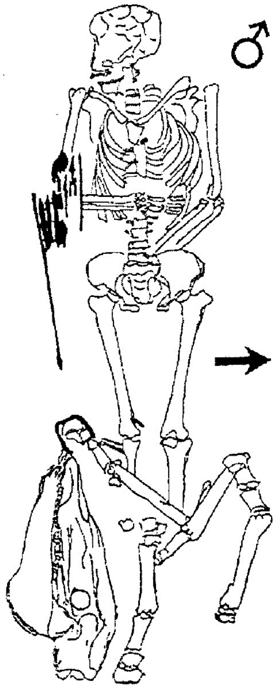
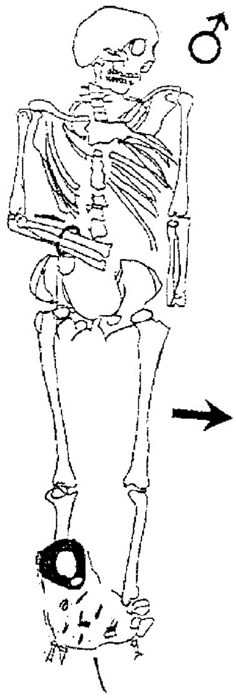
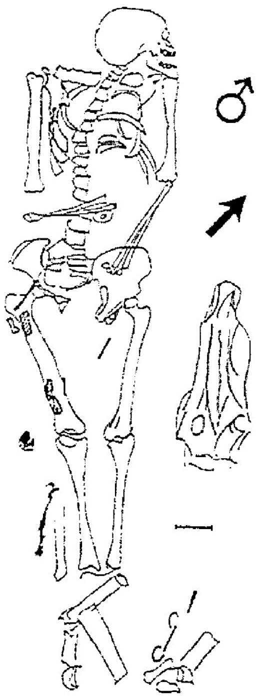
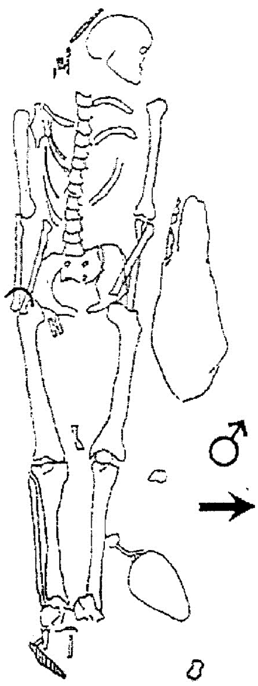
Appendix 2. Inventory with drawings of the graves from the RD group (adult males with riding deposit) from the Hungarian Conquest period cemetery of Sárrétudvari-Hízóföld (Nepper, 2002) (1/3)

Grave 5	Grave 29	Grave 41
bit, stirrup, girth buckle	girth buckle	bit, stirrup, girth buckle
		
Grave 81	**Grave 87**	**Grave 90**
horse burial, bit, stirrup, girth buckle	bit, stirrup	bit, stirrup
		not available

Appendix 2. (2/3)

Grave 108	Grave 146	Grave 160
bit, stirrup, girth buckle, saddle mounts	horse burial, bit, stirrup	horse burial, bit, stirrup
		
Grave 171	**Grave 183**	**Grave 197**
stirrup	bit, stirrup, girth buckle	bit, stirrup, girth buckle
		

Appendix 2. (3/3)

Grave 213	Grave 245	Grave 252
horse burial, stirrup, girth buckle	horse burial	bit, stirrup, girth buckle
	not available	
Grave 257	**Grave 259**	
horse burial, bit, girth buckle	horse burial, bit, stirrup, girth buckle	
		

Appendix 3. List of the individuals from the documented collection of Lisbon with their occupation

Individual number	Known age at death	Occupation as recorded in the documentation in Portuguese	Registered occupation translated into English (may be less accurate)
127	47	Marítimo	Maritime worker
154	35	Tipógrafo	Typographer
176	46	Electricista	Electrician
202	40	Servente	Servant
242	52	Carpinteiro	Carpenter
245	50	Sapateiro	Shoemaker
270	50	Trabalhador	Worker
272	56	Coveiro	Gravedigger
302	40	Pedreiro	Bricklayer
305	30	Cortador	Cutter
308	43	Estofador	Upholsterer
309	30	Impressor tipográfico	Typographical printer
321	54	Canalizador	Plumber
324	43	Calceteiro	Paver
329	38	Canalizador	Plumber
344	27	Fundidor	Smelter
355	31	Electricista	Electrician
391	20	Electricista	Electrician
405	32	Carpinteiro	Carpenter
419	31	Barbeiro	Barber
439	53	Calafate	Caulker (shipbuilder)
440	50	Operário	Factory worker
446	38	Caldeireiro	Boilermaker
450	50	Carpinteiro	Carpenter
500	45	Fogueiro	Stoker (coal worker)
508	53	Motorista	Driver
510	49	Cesteiro	Basket weaver
596	39	Tecelão	Weaver
604	33	Trabalhador	Worker
681	37	Serralheiro	Fitter
974	54	Serralheiro	Fitter
978	47	Motorista	Driver
1092	51	Motorista	Driver
1097	53	Lubrificador de automóveis	Car oiler
1101	21	Pintor	Painter
1265	39	Serralheiro	Fitter
1287	45	Trabalhador	Worker
1397	52	Serralheiro	Fitter
1414	48	Padeiro	Baker
1444	47	Electricista	Electrician
1549	53	Trabalhador	Worker
1614	28	Carpinteiro	Carpenter
1620	37	Tipógrafo	Typographer
1625	47	Pedreiro	Bricklayer
1626	20	Serralheiro	Fitter
1633	51	Pintor	Painter
1637	48	Tintureiro	Dyer

Appendix 4. Description of the analyzed entheses and function of the attached muscles (1/2)

Bone	Enthesis study code	Site of the enthesis	Type of enthesis	Muscles attached to the site (o. = origin site; i. = insertion site)	Muscle function
Coxal bone	COX E1	Anterior inferior iliac spine	FC	*Rectus femoris* (o., straight head)	Hip flexion; Knee extension
	COX E2	Ischial tuberosity	FC	*Semimembranosus* (o.); *Semitendinosus* (o.)	Hip extension, adduction, lateral rotation Knee flexion, medial rotation
				Biceps femoris (o., long head)	Hip extension, adduction, lateral rotation Knee flexion, lateral rotation
Femur	FEM E1	Anterior surface of greater trochanter	FC	*Gluteus minimus* (i.)	Ventral part: Hip abduction, flexion, medial rotation Dorsal part: Hip abduction, extension, lateral rotation
	FEM E2	Superior lateral surface of greater trochanter	FC	*Gluteus medius* (i.)	Ventral part: Hip abduction, flexion, medial rotation Dorsal part: Hip abduction, extension, lateral rotation
	FEM E3	Trochanteric fossa	FC	*Obturator externus* (i.); *Obturator internus* (i.)	Hip lateral rotation, adduction, extension
	FEM E4	Lesser trochanter	FC	*Iliopsoas* (i.): *iliacus*, *psoas major*, *psoas minor*	Hip flexion, medial rotation (lateral rotation when gluteal muscles contract simultaneously); Lumbar vertebral column lateral flexion, extension (increases lumbar lordosis)
	FEM E5	Gluteal tuberosity	F	*Gluteus maximus* (i.)	Knee extension (via iliotibial tract) Cranial part: Hip extension, lateral rotation, abduction Caudal part: Hip extension, lateral rotation, adduction

F = fibrous; FC = fibrocartilaginous; entheses description and muscles functions from Putz & Pabst (2001)

Appendix 4. (2/2)

Bone	Enthesis study code	Site of the enthesis	Type of enthesis	Muscles attached to the site (o. = origin site; i. = insertion site)	Muscle function
Femur	FEM E6	*Linea aspera* (middle medial and lateral lips)	F	*Adductor magnus* (i., medial lip);	Hip adduction, lateral rotation, flexion (anterior part), extension (posterior part)
				Adductor longus (i., medial lip);	Hip adduction, flexion, lateral rotation (most anterior fibers rotate medially)
				Adductor brevis (i., medial lip);	Hip adduction, flexion, lateral rotation
				Vastus medialis (o., medial lip)	Knee extension
				Vastus lateralis (o., lateral lip);	Knee extension
				Biceps femoris (o., short head, lateral lip)	Hip extension, adduction, lateral rotation Knee flexion, lateral rotation
	FEM E7	Adductor tubercle	F	*Adductor magnus* (i.)	Hip adduction, lateral rotation, flexion (anterior part), extension (posterior part)
Patella	PAT E1	Anterior surface (proximal)	FC	*Quadriceps femoris* (i.): *vastus medialis*, *vastus intermedius*, *vastus lateralis*, *rectus femoris*	Hip flexion (rectus femoris only) Knee extension
Tibia	TIB E1	Tibial tuberosity	FC	*Quadriceps femoris* (i., via the patella ligament): *vastus intermedius*, *vastus lateralis*, *vastus medialis*, *rectus femoris*	Hip flexion (rectus femoris only) Knee extension
	TIB E2	Soleal line	F	*Soleus* (o.)	Ankle plantar flexion Talotarsal supination
Calcaneus	CAL E1	Calcaneal tuberosity	FC	*Triceps surae* (i., via the Achilles tendon): *soleus*, *gastrocnemius*; *Plantaris* (i., via the Achilles tendon)	Knee flexion (gastrocnemius and plantaris only) Ankle plantar flexion Talotarsal supination

F = fibrous; FC = fibrocartilaginous; entheses description and muscles functions from Putz & Pabst (2001)

Appendix 5. Sex diagnosis on the left coxal bone using the Probabilistic Sex Diagnosis (DSP) in the individuals from the cemetery of Sárrétudvari-Hízóföld (see Murail et al., 2005; Bruzek et al., 2017 for the measurements) (1/3)

Individual	Group	PUM L	SPU L	DCOX L	IIMT L	ISMM L	SCOX L	SS L	SA L	SIS L	VEAC L	Probability Male L
3	NRD	76.70	31.00	249.00		133.20		77.40	81.55	42.31	64.80	**1.000**
5	RD						157.00	70.40	67.00	35.30	56.80	0.944
9	NRD	70.00	33.80					78.50	80.20			**1.000**
11	NRD											
14	NRD		29.00		43.90	112.70		69.90	75.40	32.55	59.50	**0.972**
16	NRD	68.40	31.40					72.25	70.60		59.20	**1.000**
20	NRD											
21	NRD											
29	RD			238.00	41.70	127.20		80.50	75.30	45.30	61.30	**1.000**
34	NRD		29.40	212.00	41.00	105.10	148.00	67.10	68.20	38.00	53.40	**0.971**
37	NRD	72.50	29.70	223.00		117.40		76.20	79.10	39.00	59.10	**1.000**
39	NRD			231.00	50.00	129.50				40.30	63.50	**0.999**
41	RD			212.00	37.80	116.70	159.00	74.30	78.70	39.70	60.70	**0.998**
48	NRD		26.80	211.00		110.70	150.00		68.00			**0.981**
49	NRD	68.90	35.50	217.00	39.30	107.80	160.00	70.60	67.50	38.40	60.60	**1.000**
62	NRD	67.20	30.30	236.00	44.20	122.40	170.00	78.10	75.20	41.60		**1.000**
65	NRD			237.00						38.90		
66	NRD		32.10			118.70		75.00	76.00			**0.998**
71	NRD			215.00	44.00	114.20	167.00	70.80	75.00	39.00	56.70	0.750
72	NRD	64.70	30.70	219.00	43.80	115.70	161.00	80.80	83.60	40.30	58.40	**1.000**
74	NRD	67.00	30.10	213.00	42.00	118.80		73.60	67.60	38.00	59.84	**1.000**

L, left; RD, riding deposit; NRD, no riding deposit; the probability of being a male is calculated with a minimum of 4 measurements; values in bold indicate that the sex can be assessed at the threshold of 0.95

Appendix 5. (2/3)

Individual	Group	PUM L	SPU L	DCOX L	IIMT L	ISMM L	SCOX L	SS L	SA L	SIS L	VEAC L	Probability Male L
80	NRD	74.00	27.00	226.00		120.30		79.20	86.30	36.70	62.10	**0.994**
81	RD	76.70	30.60	221.00		116.60		74.20	77.50	41.50	59.70	**0.987**
87	RD				50.90		167.00	80.60				
90	RD	73.00	32.00					74.00	75.15	42.50	57.80	**0.998**
100	NRD		32.20	210.00	49.20	114.00	164.00	82.10	84.20			**0.951**
105	NRD	73.10	33.60	220.00	44.90	116.50	163.00	76.20	76.80	42.90	62.00	**1.000**
106	NRD	72.20	30.60	225.00		121.00	164.00		67.80	43.40	62.00	**1.000**
108	RD	61.85	27.50		38.30	108.90		72.13	66.14	32.25	57.80	**1.000**
111	NRD		30.80					73.60	67.00	40.40		**0.996**
116	NRD	67.80	33.20		44.50		161.00	69.60	73.90	42.70	54.30	**0.998**
120	NRD		27.10		48.00	114.60		74.00	78.60	33.50	57.30	0.826
123	NRD											
124	NRD			220.00	44.50	117.30	170.00	81.20	81.30	41.10	60.20	**0.981**
128	NRD	64.50	26.80							31.20	51.30	0.629
145	NRD	66.90	30.90	211.00		118.60		73.00	76.10	36.60	70.30	**1.000**
146	RD	67.90	31.50	200.00	48.80	120.20	165.00	77.40	73.60	34.10	65.30	**1.000**
149	NRD	74.00	32.80	242.00				83.50	75.90		63.10	**1.000**
160	RD	76.40		231.00	42.00	119.30	156.00	69.70	72.40	35.40	57.10	**0.999**
169	NRD	70.70	28.50	231.00		113.50		70.10	77.40	37.90	54.50	**1.000**
171	RD	80.20	34.30			123.13			89.80	42.13	65.07	**0.999**
172	NRD	71.10	31.34			109.00			72.80		53.60	**0.992**
178	NRD	72.50	28.60			124.70		84.20	76.60	42.30	64.70	**1.000**
179	NRD	69.90	31.30	237.00		126.30		83.70		45.50	61.00	**1.000**

L, left; RD, riding deposit; NRD, no riding deposit; the probability of being a male is calculated with a minimum of 4 measurements; values in bold indicate that the sex can be assessed at the threshold of 0.95

Appendix 5. (3/3)

Individual	Group	PUM L	SPU L	DCOX L	IIMT L	ISMM L	SCOX L	SS L	SA L	SIS L	VEAC L	Probability Male L
181	NRD			217.00	42.00	117.60		76.90	70.80	39.20	58.10	**0.998**
182	NRD	77.20	34.50	234.00	48.34			77.00	81.00	42.10	60.60	**1.000**
183	RD	70.70	32.80		45.50	107.20		68.80	71.00	38.80	55.30	**0.976**
185	NRD	73.00		228.00	42.60	124.36		73.50	67.42	39.70	64.00	**1.000**
186	NRD			228.00	39.00	119.30				43.45	61.70	**0.999**
188	NRD	71.33	32.60	222.00	43.63	119.50	165.00	80.00	79.54	40.70	59.60	**1.000**
197	RD	63.10		215.00		105.90	153.00	70.90	75.00		51.30	**0.999**
201	NRD	69.40	33.30	230.00	47.50	120.90		75.40	71.50	36.50	62.50	**1.000**
206	NRD				52.00		167.00	83.40	86.25	40.60		0.829
213	RD		31.70			113.00		78.14	81.75	36.15	55.21	**0.974**
218	NRD	65.90	30.40	216.00	48.80		164.00	77.70	85.60	39.20	57.10	**1.000**
219	NRD			229.00		118.10			80.40	39.30	58.10	**0.960**
228	NRD	66.10	26.70					73.10	64.50	34.70	58.40	**0.999**
230	NRD		29.00		46.20	116.10		75.60	68.80	33.30	56.70	**0.995**
231	NRD			228.00	44.30	119.70	169.00	78.30	77.40		59.50	**0.997**
232	NRD		28.60	229.00	42.50	119.00		77.00	76.80	40.90	59.60	**0.996**
240	NRD	69.20	28.30					71.80	75.20	36.20	56.40	**0.968**
245	RD		33.10	228.00	52.40	118.70	165.00	78.60	84.70			**0.996**
247	NRD				45.94	119.10		75.40	77.30	37.60	59.60	0.988
252	RD											
257	RD	77.40	33.30	233.00	50.00	121.50	175.00	81.60	76.50	43.90	62.20	**1.000**
259	RD											
264	NRD	81.40	30.00					81.10	82.50	39.30		0.800

L, left; RD, riding deposit; NRD, no riding deposit; the probability of being a male is calculated with a minimum of 4 measurements; values in bold indicate that the sex can be assessed at the threshold of 0.95

Appendix 6. Sex diagnosis on the right coxal bone using the Probabilistic Sex Diagnosis (DSP) in the individuals from the cemetery of Sárrétudvari-Hízóföld (see Murail et al., 2005; Bruzek et al., 2017 for the measurements) (1/3)

Individual	Group	PUM R	SPU R	DCOX R	IIMT R	ISMM R	SCOX R	SS R	SA R	SIS R	VEAC R	Probability Male R
3	NRD		30.70	245.00		133.52		83.40	82.72	42.24	65.70	**1.000**
5	RD	67.50	29.50	211.00	43.20	112.80	159.00	68.90	68.70	34.50	57.70	**1.000**
9	NRD	69.30	33.40					76.30	77.50			**1.000**
11	NRD							72.30	71.60	38.00	57.00	**0.958**
14	NRD											
16	NRD		32.00					71.90	72.20	36.50	60.50	**0.999**
20	NRD											
21	NRD											
29	RD					126.00		83.00	78.00	45.30	63.40	**1.000**
34	NRD	64.00	28.70	212.00	41.70	106.80	148.00	66.90	68.10	37.00	55.10	**1.000**
37	NRD	71.20	30.30	222.00		116.60				39.30	56.90	**1.000**
39	NRD	72.00	33.70		50.00	127.65		77.16	75.82	41.90	63.35	**1.000**
41	RD			208.00	37.50	117.60		76.30		42.50	62.10	**1.000**
48	NRD	69.20	26.70	213.00	44.30	111.00	150.00				56.30	**0.994**
49	NRD	67.50	35.50	216.00	38.00	110.90		74.30	71.90	38.30	61.40	**1.000**
62	NRD	70.30	30.40	238.00	45.30	122.50	174.00	75.50	73.40	42.00		**1.000**
65	NRD	72.80	35.30			124.00	180.00				64.00	**1.000**
66	NRD	71.70	33.00		47.20	121.50		76.00	75.00	41.90	64.20	**1.000**
71	NRD	66.00	29.40	215.00	43.00		165.00	73.00	77.40			**1.000**
72	NRD	65.50	32.40	218.00	44.80	117.00	163.00	82.50	84.10	38.50	58.10	**1.000**

R, right; RD, riding deposit; NRD, no riding deposit; the probability of being a male is calculated with a minimum of 4 measurements; values in bold indicate that the sex can be assessed at the threshold of 0.95

Appendix 6. (2/3)

Individual	Group	PUM R	SPU R	DCOX R	IIMT R	ISMM R	SCOX R	SS R	SA R	SIS R	VEAC R	Probability Male R
74	NRD	67.20	29.20	211.00	43.80	116.60		70.60	64.90	38.00	57.50	**1.000**
80	NRD	72.20	28.70					79.50	86.10	35.10	63.50	**0.998**
81	RD	73.50	31.80						76.80		58.20	**0.997**
87	RD		31	>215		115					59.4	**>0,964**
90	RD	73.00	30.90	220.00		115.25		71.90	71.90	41.50	56.90	**1.000**
100	NRD	68.10	30.70	210.00	48.20	114.10		81.30	85.30		56.30	**0.999**
105	NRD		31.50	218.00		115.80		76.30			63.90	**0.996**
106	NRD	70.80	29.50	227.00		121.40		76.50	72.10		62.40	**1.000**
108	RD	59.50	27.60			107.00		72.90	69.11	31.10	56.32	**1.000**
111	NRD											
116	NRD	67.30	33.20	212.00	42.40	112.30	165.00	70.50	73.20	43.50	56.20	**1.000**
120	NRD	68.00	27.70							31.30	55.30	0.876
123	NRD	78.40			43.10		170.00	82.80	79.80	38.00		**0.950**
124	NRD											
128	NRD	62.70	27.00					71.60	69.50			**0.992**
145	NRD	68.00	30.80	216.00		121.60				37.00	68.94	**1.000**
146	RD	68.40	31.80		46.20			76.70	75.50	34.50	65.30	**1.000**
149	NRD					123.20		83.70		46.20	65.60	**0.998**
160	RD	72.50	28.00	231.00		119.50		71.90	74.50	37.30	56.70	**1.000**
169	NRD	73.30	29.00	229.00	58.30	113.00	162.00	71.60	78.00	38.60	55.10	0.949
171	RD	80.43	33.75	239.00		124.35		85.82	87.21	41.77	64.71	**1.000**
172	NRD		32.15	203.00		109.00		72.70	73.70		54.14	**0.979**
178	NRD	73.40	29.80			123.10		82.10	73.10		62.40	**1.000**

R, right; RD, riding deposit; NRD, no riding deposit; the probability of being a male is calculated with a minimum of 4 measurements; values in bold indicate that the sex can be assessed at the threshold of 0.95

Appendix 6. (3/3)

Individual	Group	PUM R	SPU R	DCOX R	IIMT R	ISMM R	SCOX R	SS R	SA R	SIS R	VEAC R	Probability Male R
179	NRD	70.80	32.30	235.00		127.50		85.30		47.90	61.20	**1.000**
181	NRD	72.80	33.70	219.00		119.20		77.50	71.00	40.70	58.70	**1.000**
182	NRD			236.00	49.70	124.50		78.00	83.10	43.00	60.70	**0.993**
183	RD		33.70	211.00	43.00	109.30		65.80	69.00	35.70	54.40	**0.993**
185	NRD	75.00		225.00	46.73	126.30	158.00	73.00	77.00	39.90	62.60	**1.000**
186	NRD											
188	NRD	71.22	32.80	218.00	39.45	116.20	165.00	81.00	77.50	41.30	59.37	**1.000**
197	RD			214.00		109.80	155.00	68.40	72.40	31.20	53.00	0.629
201	NRD	67.20	30.40	226.00	48.30	121.40		75.30	70.80	38.80	61.60	**1.000**
206	NRD				47.00		166.00	84.00	85.80			**0.962**
213	RD											
218	NRD	69.60	30.70	218.00		116.20	162.00	77.60	81.50	41.30	57.60	**1.000**
219	NRD	74.90		225.00		114.10		75.10	76.50	41.90	58.50	**0.992**
228	NRD	66.30	29.00	208.00		114.30		71.10	67.80	36.50	59.10	**1.000**
230	NRD		28.60	225.00	51.60	118.50	154.00	76.10	75.30	37.00	57.20	**0.998**
231	NRD			228.00	44.20	123.60		81.10	75.30	36.00	63.30	**1.000**
232	NRD				45.00	118.40	173.00	75.40	77.50	39.90	60.60	**0.970**
240	NRD	71.10	27.50					70.30	74.60	36.90	56.70	0.865
245	RD				52.20	121.60	167.00	80.10	81.70	40.60	62.00	**0.994**
247	NRD				48.70	119.50		74.90	70.70	38.40	59.24	**0.992**
252	RD											
257	RD	75.50	31.90	232.00	49.00	121.80	174.00	78.20	79.60	42.80	62.30	**1.000**
259	RD				44.30	111.00		76.20	77.00	39.40	59.42	0.920
264	NRD	82.00				131.80		83.20	83.40		64.00	**1.000**

R, right; RD, riding deposit; NRD, no riding deposit; the probability of being a male is calculated with a minimum of 4 measurements; values in bold indicate that the sex can be assessed at the threshold of 0.95

Appendix 7. Results of the sex determination of the individuals from the cemetery of Sárrétudvari-Hízóföld, based on the Probabilistic Sex Diagnosis (DSP) (Murail et al., 2005; Bruzek et al., 2017), and the morphological visual method by Bruzek (Bruzek, 2002), with also the sex known from genetic data (Archaeogenetics Laboratory, University of Szeged) (1/2)

Individual	Group	Sex DSP	Sex Morpho	Sex DNA	Sex Final study
3	NRD	M	NP	M	M
5	RD	M	NP	-	M
9	NRD	M	NP	-	M
11	NRD	M	NO	-	M
14	NRD	M	NP	-	M
16	NRD	M	NP	-	M
20	NRD	NO	M	-	M
21	NRD	NO	M	M	M
29	RD	M	NP	M	M
34	NRD	M	NP	-	M
37	NRD	M	NP	-	M
39	NRD	M	NP	-	M
41	RD	M	NP	M	M
48	NRD	M	NP	-	M
49	NRD	M	NP	-	M
62	NRD	M	NP	-	M
65	NRD	M	NO	M	M
66	NRD	M	NP	M	M
71	NRD	M	NP	-	M
72	NRD	M	NP	-	M
74	NRD	M	NP	-	M
80	NRD	M	NP	M	M
81	RD	M	NP	M	M
87	RD	M	M	-	M
90	RD	M	NP	M	M
100	NRD	M	NP	-	M
105	NRD	M	NP	-	M
106	NRD	M	NP	M	M
108	RD	M	NP	-	M
111	NRD	M	I	-	M
116	NRD	M	NP	-	M
120	NRD	I	M	-	M
123	NRD	M	I	-	M

M, male; I, indeterminate; NO, not observable; NP, not performed (the morphological visual method was not systematically performed when the DSP already allowed a successful sex diagnosis)

Appendix 7. (2/2)

Individual	Group	Sex DSP	Sex Morpho	Sex DNA	Sex Final study
124	NRD	M	NO	-	M
128	NRD	M	M	-	M
145	NRD	M	NP	-	M
146	RD	M	NP	-	M
149	NRD	M	NP	-	M
160	RD	M	NP	-	M
169	NRD	M	NP	-	M
171	RD	M	NP	-	M
172	NRD	M	NP	-	M
178	NRD	M	NP	-	M
179	NRD	M	NP	-	M
181	NRD	M	NP	-	M
182	NRD	M	NP	M	M
183	RD	M	NP	-	M
185	NRD	M	NP	-	M
186	NRD	M	NP	-	M
188	NRD	M	NP	-	M
197	RD	M	M	M	M
201	NRD	M	NP	-	M
206	NRD	M	M	-	M
213	RD	M	NO	-	M
218	NRD	M	NP	-	M
219	NRD	M	NP	-	M
228	NRD	M	NP	-	M
230	NRD	M	NP	-	M
231	NRD	M	NP	-	M
232	NRD	M	NP	-	M
240	NRD	M	I	-	M
245	RD	M	NP	M	M
247	NRD	M	NP	-	M
252	RD	NO	M	-	M
257	RD	M	NP	-	M
259	RD	I	M	M	M
264	NRD	M	NP	M	M

M, male; I, indeterminate; NO, not observable; NP, not performed (the morphological visual method was not systematically performed when the DSP already allowed a successful sex diagnosis)

Appendix 8. Results of the age estimation of the adult individuals from the cemetery of Sárrétudvari-Hízóföld based on the changes at the sacropelvic surface of the ilium (Schmitt, 2005), and observation of the bone maturation (sternal extremity of the clavicle and iliac crest of the coxal bone) to distinguish the young adults (see Chapter 2, I.B.3) (1/3)

Individual	Group	SSPIA L	SSPIB L	SSPIC L	SSPID L	Age L	SSPIA R	SSPIB R	SSPIC R	SSPID R	Age R	Age Final	Bone maturation
3	NRD	2	1	1	N		2	1	1	2	20-49	20-49	
5	RD	2	1	1	1	20-39	2	1	1	1	20-39	20-39	
9	NRD	2	N	2	N		2	N	2	N		>20	
11	NRD	N	1	2	N		N	N	N	N		>20	
14	NRD	1	1	1	1	20-29	1	1	1	1	20-29	20-29	20-29
16	NRD	N	N	N	N		2	1	2	1	20-49	20-49	
20	NRD	1	1	1	1	20-29	N	N	N	N		20-29	20-29
21	NRD	2	1	1	1	20-39	2	1	1	N		20-39	
29	RD	2	2	1	2	>30	2	2	1	2	>30	>30	
34	NRD	2	1	1	1	20-39	2	1	1	1	20-39	20-39	
37	NRD	2	2	2	N	>30	2	2	N	N		>30	
39	NRD	2	3	2	2	>60	2	2	2	N		>60	
41	RD	2	2	1	1	20-49	2	2	1	1	20-49	20-49	
48	NRD	2	1	1	1	20-39	2	1	N	1		20-39	
49	NRD	2	N	1	1	>20	2	N	1	1	>20	>20	
62	NRD	2	1	1	1	20-39	2	1	1	1	20-39	20-39	
65	NRD	2	1	2	1	20-49	2	1	N	1		20-49	
66	NRD	N	2	1	N		N	2	1	1	20-49	20-49	
71	NRD	2	2	2	2	>40	2	2	2	2	>40	>40	
72	NRD	2	1	1	1	20-39	2	1	1	1	20-39	20-39	
74	NRD	2	2	1	2	>30	2	2	1	2	>30	>30	

L, left; R, right; RD, riding deposit; NRD, no riding deposit; N, not observable; SSPIA, transverse organization; SSPIB, surface modification; SSPIC, apical modification; SSPID, modification of the iliac tuberosity; bone maturation based on the observation of the sternal extremity of the clavicle and the iliac crest of the coxal bone

Appendix 8. (2/3)

Individual	Group	SSPIA L	SSPIB L	SSPIC L	SSPID L	Age L	SSPIA R	SSPIB R	SSPIC R	SSPID R	Age R	Age Final	Bone maturation
80	NRD	2	2	1	1	20-49	2	2	1	1	20-49	20-49	
81	RD	2	2	2	2	>40	N	N	1	N		>40	
87	RD	2	2	N	1	>20	2	2	N	1	>20	>20	
90	RD	N	N	N	N		N	N	1	N		>20	
100	NRD	2	2	N	1		2	2	2	1	>30	>30	
105	NRD	2	2	1	1	20-49	N	N	N	N		20-49	
106	NRD	2	1	2	N		2	1	2	2	30-59	30-59	
108	RD	N	1	1	1	20-39	N	1	1	1	20-39	20-39	20-29
111	NRD	2	2	1	1	20-49	N	N	N	N		20-49	
116	NRD	2	2	1	1	20-49	2	2	1	N		20-49	
120	NRD	2	2	1	1	20-49	2	2	N	N		20-49	
123	NRD	2	N	1	N		2	1	1	1	20-39	20-39	
124	NRD	2	2	2	2	>40	N	N	N	N		>40	
128	NRD	N	N	N	1		1	1	1	1	20-29	20-29	20-29
145	NRD	2	1	1	1	20-39	N	1	1	N		20-39	
146	RD	1	1	1	1	20-29	1	1	1	1	20-29	20-29	20-29
149	NRD	2	3	2	N	>50	N	N	N	N		>50	
160	RD	2	2	N	2		2	2	2	2	>40	>40	
169	NRD	2	1	1	1	20-39	2	1	1	1	20-39	20-39	
171	RD	N	N	1	N		N	N	1	N		>20	
172	NRD	2	N	N	N		2	1	1	N	20-49	20-49	
178	NRD	2	2	1	N		2	2	1	2	>30	>30	

L, left; R, right; RD, riding deposit; NRD, no riding deposit; N, not observable; SSPIA, transverse organization; SSPIB, surface modification; SSPIC, apical modification; SSPID, modification of the iliac tuberosity; bone maturation based on the observation of the sternal extremity of the clavicle and the iliac crest of the coxal bone

Appendix 8. (3/3)

Individual	Group	SSPIA L	SSPIB L	SSPIC L	SSPID L	Age L	SSPIA R	SSPIB R	SSPIC R	SSPID R	Age R	Age Final	Bone maturation
179	NRD	N	N	N	N		N	N	N	N		>20	
181	NRD	2	2	2	N		2	2	2	2	>40	>40	
182	NRD	N	N	N	N		N	N	N	N		>20	
183	RD	2	2	1	1	20-49	2	2	1	1	20-49	20-49	
185	NRD	2	2	N	2		2	2	2	2	>40	>40	
186	NRD	2	2	1	1	20-49	2	2	1	N		20-49	
188	NRD	2	1	1	1	20-39	2	1	1	1	20-39	20-39	
197	RD	1	1	1	1	20-29	1	1	1	1	20-29	20-29	20-29
201	NRD	2	1	1	1	20-39	2	1	1	2	20-49	20-49	
206	NRD	2	1	1	1	20-39	2	1	1	1	20-39	20-39	
213	RD	2	2	1	1	20-49	N	N	N	N		20-49	
218	NRD	2	2	1	1	20-49	2	2	1	1	20-49	20-49	
219	NRD	N	N	N	N		2	2	2	N	>30	>30	
228	NRD	2	1	1	1	20-39	2	1	1	1	20-39	20-39	
230	NRD	2	2	2	1	>30	2	2	2	1	>30	>30	
231	NRD	2	2	2	2	>40	2	2	2	2	>40	>40	
232	NRD	2	1	1	1	20-39	2	1	1	1	20-39	20-39	
240	NRD	2	1	1	N	20-49	N	1	N	1		20-49	
245	RD	2	2	N	2	>30	2	2	N	2	>30	>30	
247	NRD	2	2	2	2	>40	2	2	N	2		>40	
252	RD	N	N	N	N		N	N	N	N		>20	
257	RD	2	2	N	2		2	2	1	2	>30	>30	
259	RD	N	N	N	N		2	2	N	2	>30	>30	
264	NRD	2	1	N	1		2	1	1	1	20-39	20-39	

L, left; R, right; RD, riding deposit; NRD, no riding deposit; N, not observable; SSPIA, transverse organization; SSPIB, surface modification; SSPIC, apical modification; SSPID, modification of the iliac tuberosity; bone maturation based on the observation of the sternal extremity of the clavicle and the iliac crest of the coxal bone

RÉSUMÉ

Certains changements observés sur les os humains permettent de reconstituer les activités des populations anciennes, comme l'équitation. Pour identifier des indicateurs osseux fiables pour cette pratique, nous avons étudié des populations de la période de la Conquête hongroise (10e siècle), connues pour leurs cavaliers-archers. Le mobilier archéologique retrouvé dans les cimetières de la période confirme la présence de cavaliers. Nous avons analysé les différences morphologiques et pathologiques entre individus avec et sans mobilier et avec des non-cavaliers modernes, et avons identifié plusieurs types de modifications osseuses sur les os du bassin, le fémur, les vertèbres ou le pied, qui semblent liées à l'équitation. Nous avons aussi observé que des méthodes modernes comme la microtomographie et les reconstructions 3D peuvent améliorer l'identification de certaines activités. Nos recherches apportent un nouvel éclairage à la reconstruction des modes de vie des populations du passé.

MOTS CLÉS

Anthropologie biologique, Bioarchéologie, Paléopathologie, Marqueurs osseux d’activité, Pratique cavalière, Période de la Conquête hongroise

ABSTRACT

Some changes observed on human bones can help to reconstruct past populations’ activities, such as horse riding. To identify reliable skeletal indicators for this practice, we relied on populations from the Hungarian Conquest period (10th century), who were known for their powerful mounted archers. In many cemeteries from that period, horse riding equipment and horse bones associated with the individuals in the graves confirm the presence of riders. We analyzed morphological and pathological differences between the individuals with and without riding deposit, and with modern presumed non-riders, and we identified several types of skeletal changes on the hip bone, femur, vertebrae, or the foot that could be related to horse riding. We also observed that the use of modern methods like microtomography and 3D reconstructions could help with the identification of some activities. Our research sheds new light on the reconstruction of the lifestyles of past populations.

KEYWORDS

Biological anthropology, Bioarchaeology, Paleopathology, Activity-related skeletal changes, Horse riding, Hungarian Conquest period