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“Life on Horseback? A study of the “horse riding syndrome” in an Avar population of the 7th-8th century AD from Wien11-Csokorgasse”

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Table of Contents	Page
1 Introduction	6
2 Background information	7
2.1 Who were the Avars?	7
2.2 Avar horsemanship	10
2.3 The Biomechanics of Horse Riding	14
2.4 Morphological variations of the anterior proximal femur: Definitions & aetiology	18
2.5 The „Horse riding syndrome“: Definition & short summary of the state of research	22
3 Research questions	24
4 Hypotheses	26
4.1 Verification of the “horse riding syndrome”: Associations between different characteristics of the “Horse Riding Syndrome”	26
4.2 Differences between the sexes	27
4.3 Chronological Differences	28
4.4 Differences between socioeconomic groups	28
5 Material & Methods	29
5.1 Sample	29
5.2 Method for identification of the “Horse Riding Syndrome”	32
5.3 Statistical analyses	43
6 Results	44
6.1 Proximal Femur: Prevalence of non-metric traits of the anterior head-neck junction	44

6.1.1 “Poirier’s Facet”	44
6.1.1.1 Total adult population	
(male & female, all adult age groups)	44
6.1.1.2 Male adult population	
(all adult age groups)	45
6.1.1.3 Female adult population	
(all adult age groups)	47
6.1.2 Plaque	48
6.1.2.1 Total adult population	
(male & female, all adult age groups)	48
6.1.2.2 Male adult population	
(all adult age groups)	51
6.1.2.3 Female adult population	
(all adult age groups)	54
6.1.3 Cribriform changes	57
6.1.3.1 Total adult population	
(male & female, all adult age groups)	57
6.1.3.2 Male adult population	
(all adult age groups)	59
6.1.3.3 Female adult population	
(all adult age groups)	60
6.2 Index of Ovalization of Acetabulum (IOA)	62
6.2.1 Intra-observer reliability of	
VEAC and HOAC measurements	62
6.2.2 Associations between the characteristic traits of the	
“Horse Riding Syndrome” in the total adult population (Hypothesis 1)	63
6.2.3 Differences between the sexes (Hypothesis 2)	70

6.2.4 Chronological differences (Hypothesis 3)	72
6.2.5 Differences in IOA between socioeconomic groups ("Shallow" burials = low status vs. "deep" burials = high status; Hypothesis 4)	78
7 Discussion	82
7.1 Verification of the "Horse Riding Syndrome" and prevalence of non-metric traits of the anterior femoral head-neck junction	82
7.2 Differences between the sexes	89
7.3 Chronological differences	91
7.4 Socioeconomic differences	92
8 Conclusions	96
References	99
Abstract	104
Zusammenfassung	105

1 Introduction

The “horse riding syndrome” comprises a number of changes on the human skeleton which, if found in association, could indicate that the individual in question practiced horse riding as a habitual activity during his or her lifetime. In the bioarchaeological literature, “Poirier’s Facet” (*Reiterfacette*) has been referred to as one characteristic trait of the “horse riding syndrome”. Therefore, in archaeological contexts, individuals where “Poirier’s Facet” (*Reiterfacette*) is present on one or both femurs could be expected to exhibit a higher prevalence of other characteristics of the “horse riding syndrome”. The majority of traits belonging to this syndrome is non-metric (Anđelinović et al, 2015, Radi et al. 2013, Lawrence et al. 2018). However, the “Index of Ovalization (IOA)” developed by Berthon et al. (2018) is a useful, simple tool for quantifying what may be one of the major characteristics of the “horse riding syndrome”: The vertical elongation (=“ovalization”) of the acetabulum.

In this context, a key question is whether non-metric variations of the femoral head-neck junction other than typical “Poirier’s Facets” (= slight facets, different types of plaque and cribriform variations; according to the recent classification by Radi et al. 2013) may also be associated with the “horse riding syndrome”. Recent research by Radi et al. (2013) and Lawrence et al. (2018) suggests that plaque in the head-neck junction of the proximal femur is very common in some populations. Therefore, it is unlikely that it can be associated with specific activities such as horse riding.

Firstly, the aim of this thesis is to contribute to methodological research on the “horse riding syndrome”, by testing possible associations between different characteristics within the adult population of an Avar cemetery of the 7th-8th century AD from Eastern Austria (Wien-Csokorgasse). Avar populations are ideally suited for methodological research on the “horse riding syndrome”, because – according to historical sources – the Avars were accomplished mounted warriors. There is no information on the training of young Avars for mounted combat: However, historical and ethnographic analogies suggest that training must have begun at an early age and must have been quite intense, in order to reach a suitable level in late adolescence – the “normal” age for participation in battle in protohistoric warrior societies.

Secondly, the aim of this thesis is to identify possible differences in the prevalence of the “horse riding syndrome” between different groups within the adult population of the Avar cemetery Wien11-Csokorgasse. This research is expected to contribute to existing knowledge regarding the “way of life” and habitual activities of Avar populations in Eastern Austria. For example, the results could add a new perspective to research on the phenomenon of an increased occurrence of “equestrian graves” in the region along the north-western border of the Avar Empire, in particular in the final phases of the Avar period.

2 Background information

2.1 Who were the Avars?

The Avars, a nomadic people of Central Asian origin, were present in eastern central Europe from the year 568 to around 800 AD (Anke et al. 2008, Daim 1987, Daim 2003, Pohl 1988). According to the historical sources, the Avars were accomplished mounted warriors: Their outstanding skills in mounted archery, but also in fighting with a range of different weapons on horseback, appear to have been a major factor for their military success, especially when they first arrived in Europe in the late sixth and early seventh century AD. The archaeological sources (at present: a total of more than 60,000 graves from the Avar period in the Carpathian Basin) complement this picture: A considerable proportion of men’s graves in Avar cemeteries is furnished with weapons (bow and arrow, lance-heads, sabres/ swords, axes) and multi-part belt-sets, which were also part of the Avar warrior’s equipment. Some graves also include horse-riding equipment, partial or even complete horse-burials (Bede 2012). With the help of the grave goods in Avar burials, archaeologists have established a relative and absolute chronology of the Avar period in eastern and central Europe and obtained information on various aspects of Avar society, including gender roles, social status and contacts with other cultures (= mobility of people, objects, resources and ideas). In this context, it is important to note that “Avar culture”, as we see it in Avar burials in the Carpathian Basin, is in fact a mixture of diverse cultural influences: These reflect the heterogeneous, multi-cultural population of the Avar Empire.

Due to a lack of written sources from within the Avar Empire, we have no information about many aspects of life in the Avar period. Historical records concerning the Avar Empire are all “external”, written by historiographers from neighbouring cultures, such as Byzantium, China or the Frankish Empire. The scarcity of relevant historical sources can make it difficult for archaeologists to decipher “the cultural code” inherent in Avar burials. This aspect is particularly relevant for issues such as identity, socioeconomic status and gender roles. Although we can assume that the grave goods and burial customs of Avar period burials are relevant for studying this aspect, their historical interpretation is quite complex. For example, Avar archaeologists have identified several indicators of “high socioeconomic status”, such as the presence of multi-part belt-sets and precious metal objects in Avar graves, as well as an above-average depth of the burial in question (see for example: Daim 1987). However, we have no historical sources describing the structure of Avar society. Hence, the exact implications of wearing a multi-part belt-set in the Avar period remain unclear. However, multi-part belt-sets are clearly an indicator of male high status, because they occur in above-average-depth burials and in association with other high-status grave goods. We should also assume that in the Avar period, much like today, people had more than one identity and that these identities may have overlapped. This makes the historical interpretation of grave goods and burial customs challenging. Furthermore, we cannot assume that an early medieval burial is actually a “mirror of real life”. However, burial customs and rituals presented an opportunity for the family of the deceased to consciously present and reinforce their status within their community. Therefore, protohistoric burial customs and rituals may reflect the position of the deceased, or at least his or her family, in society. Bioarchaeology can contribute to interdisciplinary research on “Avar identities” by providing information on the health, lifestyle and activity patterns of Avar populations, thus offering an important, additional perspective to traditional archaeological methods focusing on material culture.

Wien11-Csokorgasse is one of the largest cemeteries of the Avar period in present-day Austria, consisting of 755 burials (within 705 graves), including adults and non-adults of both sexes and all age groups. The archaeological finds are still unpublished. However, a preliminary catalogue (Streinz 1977) and a preliminary, chronological evaluation (Streinz & Daim 2018) is available and constitutes the “archaeological criteria” (chronological phase; socioeconomic status) used in this thesis. Some chronological information, based on archaeological data, is

also available in a recent, detailed archaeozoological study of this cemetery (Baron 2018). At present, the archaeological data suggest that the Avar cemetery in Wien11-Csokorgasse was in use over a considerable period of time (Streinz & Daim 2018), from the second quarter of the 7th century AD (Early Avar Period 2) to the final Third of the 8th century (Late Avar Period 3). The latest phase of the cemetery includes four “equestrian burials” (Grave Nos. 650, 690, 692 and 693; Streinz 1977; Baron 2018), where the deceased were buried with a horse (including equipment for riding), as well as with other animals, such as dogs, and rich grave goods, including weapons (bow and arrow, sword, sabre) and multi-part belt-sets. Although the “equestrian burials”, like many other rich burials in this cemetery, had been robbed of most valuable goods in antiquity, enough evidence remains of the grave goods present originally in order to verify that high-status individuals were buried in these graves. Similarly, all “equestrian burials” are characterised by the large size of the grave and by an above-average depth, which, in Avar burials, is also an indicator of the high socioeconomic status of the deceased (Daim 1987, 171).

Archaeological data and historical sources suggest that a number of fundamental changes took place within Avar populations in Central Europe after the middle of the seventh century AD, including the trend to establishing more permanent settlements and the transition to an economy based more on agriculture and less on herding and plundering (“war economy”). In this context, it is relevant that within the Avar cemetery in Wien11-Csokorgasse the percentage of male burials containing arrowheads and other weapons (bow, sword, sabre, and axe) decreased over time (Baron 2018). Similarly, previous bioarchaeological research on the Avar cemetery Wien-Csokorgasse is compatible with this theory: According to Großschmidt (1990, 341), the prevalence of general stress markers in the Avar population buried in the cemetery of Wien-Csokorgasse decreased from the late 7th century (Middle Avar Period) to the 8th century (Late Avar Period), suggesting that, in general, the living conditions improved. In the context of the “horse riding syndrome”, it is particularly relevant that Großschmidt (1990) also observed a decrease in the prevalence of spondylolysis of lumbar vertebrae, as well as the frequency of other degenerative traits of the spine, the hip and knee joints, from the late 7th century (Middle Avar Period) to the 8th century (Late Avar Period). Großschmidt (1990) concluded that this could be due to changes of lifestyle, such as a

decrease in habitual horse riding, within the Avar population who buried their deceased in the cemetery of Wien11-Csokorgasse.

2.2 Avar horsemanship

There is no doubt that the horse played a major role in Avar society, both from a practical and from a symbolic point of view. The phenomenon of “equestrian burials” (= burials of humans with horses) and other rituals involving horses and riding equipment as part of the burial custom in the Avar period is diverse, with considerable regional and chronological differences, which reflect a range of cultural traditions. Throughout the Avar period, equestrian burials constitute only a small proportion of all Avar period graves (10% on average; see Bede 2012). In addition to this, the abundance of valuable grave goods in such burials may indicate that, generally speaking, only high-ranking burials included horses and/ or horse riding equipment. It should be noted that, in the Late Avar Period, especially during its final phase (Late Avar Period III), there is an increased prevalence of „equestrian graves“ in border regions of the Avar Empire and that – unlike most „equestrian burials“ in earlier periods – in some cases, also women and children were buried with horses. This phenomenon occurs in the Late Avar (8th century AD) cemeteries at Komárno (Slovakia; see Trugly 1987), but also in some Avar cemeteries during the same period in the Vienna region, such as Wien11-Csokorgasse, Vösendorf and Wien23-Liesing (see Tarcsay 2013).

Avar populations are ideal for a bioarchaeological study of the “horse riding syndrome”, because according to the historical sources, the Avars were accomplished mounted warriors. In particular, they were famous for their outstanding skills in mounted archery. Although there are no historical sources from the Avar Empire, some information is present in Byzantine and Chinese historiography. The most detailed information on Avar mounted warriors is available in the so-called “Strategikon” (Dennis 1984), a Byzantine military handbook attributed to the Byzantine Emperor Maurice, who ruled the Byzantine Empire from 582 to 602. However, a high-ranking Byzantine commander may in fact have been the author of the “Strategikon”.

The “Strategikon” gives the following description of Avar mounted warriors in the late 6th century: *“They are **armed with mail, swords, bows, and lances**. In combat most of them attack*

*doubly armed; lances slung over their shoulders and holding bows in their hands, they make use of both as need requires. Not only do they wear armor themselves, but in addition the horses of their illustrious men are covered in front with iron or felt. **They give special attention to training in archery on horseback***" (Dennis 1984, 116). The Avars' preference for mounted archery is also apparent from their military strategies: *"They prefer battles fought at long range, ambushes, encircling their adversaries, simulated retreats and sudden returns, and wedge-shaped formations, that is, in scattered groups"* (Dennis 1984, 117).

The "Strategikon" also emphasizes the Avars' preference for mounted combat, and attributes the latter to their training and lifestyle: *"Also in the event of battle, **when opposed by an infantry force in close formation, they stay on their horses and do not dismount, for they do not last long fighting on foot. They have been brought up on horseback** and owing to their lack of exercise they simply cannot walk about on their own feet"* (Dennis 1984, 117-118). Despite the fact that the passage just cited includes a well-known "*topos*" of classical historiography regarding equestrian nomads of Central Asia, it may contain an element of truth, with respect to their traditions and "way of life", for instance in that, they would have avoided having to fight on foot. In order to reach the level of proficiency attested to Avar mounted warriors by the historical sources, we can assume that they must have begun their training at an early age and from then on, must have worked a considerable amount of time every day on perfecting their skills. Mounted archery, in particular, requires an extraordinary amount of training, because the technique of taking aim is "instinctive", which can only be effective if the archer acquires sufficient routine in shooting from horseback. For Avar mounted warriors, hunting from horseback was presumably one way of staying in training during long periods of peace. Hence, it is likely that hunting was an important part of the lifestyle of the Avar elite, also because it allowed the mounted warriors to train their fighting skills during times of peace. The "Strategikon" also discusses hunting as an additional way of training for battle during times of peace (Dennis 1984, 165-169).

In the "Strategikon" (see Dennis 1984), Maurice recommends several aspects of Avar equestrian training and equipment. Hence, it appears that for 6th-7th century Byzantine military commanders, the equipment and training of the Avar mounted warriors was exemplary in many respects, which is not surprising, given the military success of the Avars at

this time. For example, the “Strategikon” gives the following recommendations for training the individual soldier for mounted combat: *“He should be trained to shoot rapidly on foot, either in the Roman or the Persian manner. Speed is important in shaking the arrow loose and discharging it with force. This is essential and should also be practiced while mounted. In fact, even when the arrow is well aimed, firing slowly is useless. He should practice shooting rapidly on foot from a certain distance at a spear or some other target. He should also shoot rapidly mounted on his horse at a run, to the front, the rear, the right, the left. He should practice leaping onto the horse. On horseback at a run he should fire one or two arrows rapidly and put the strung bow in its case, if it is wide enough, or in a half-case designed for this purpose, and then he should grab the spear which he has been carrying on his back. With the strung bow in its case, he should hold the spear in his hand, then quickly replace it on his back, and grab the bow. It is a good idea for the soldiers to practice all this while mounted, on the march in their own country. For such exercises do not interfere with marching and do not wear out the horses”* (Dennis 1984, 11).

Certainly, warriors of all period and cultures, whether infantry or cavalry, must have invested a lot of time in perfecting their fighting skills, because, in the event of battle, excellent fighting skills were a matter of life and death. Furthermore, it is an advantage to begin this training as early as possible. In the medieval Mongolian Empire – according to Chinese historiographer Meng Hung – children were given small bows and arrows at age four to five, expected to ride and hunt as frequently as possible and could be conscripted for battle at the age of fifteen (Hyland 1996, 130). It is quite likely that also in other, pre- and protohistoric steppe cultures – such as the Avars – a mounted archer’s career followed a similar pattern. For the protohistoric Central Asian steppe culture Hiung-nu, a Chinese source reports that the children of the Hiung-nu rode sheep (Bálint 1989, 261). This is interesting in the context of Early Medieval Turkish burials from Central Asia, where young children were buried together with sheep in a similar way that adult warriors were buried with horses (Bálint 1989, 261, Abb. 128).

According to the current state of research, the Avars played an important role in the introduction of stirrups into European equestrian culture. Presumably, Avar mounted warriors were the first “cavalry” which used stirrups on a regular basis (Anke et al. 2008, Daim 2003).

However, many aspects of the process of transmission of this innovation – which had a considerable, long-term effect on the development of European horsemanship – still remain unclear. Stirrups occur in Avar burials from the Early Avar Period (late 6th-early 7th century AD) onward. In the Byzantine military handbook from the same period, the “Strategikon”, stirrups are also mentioned (Dennis 1984), but not as a typically “Avar” innovation (such as tents or particular types of mail for horses and warriors), nor in a context where there is mention of the Avars.

It is also difficult to say, with any degree of certainty, how important stirrups actually were for the Avars from a practical point of view: In principle, mounted combat is possible without stirrups (example: Roman cavalry, Hunnic mounted warriors), with treeless or “soft” saddle-like pads (example: Scythian mounted warriors) or even without saddles (example: Assyrian cavalry). However, from a practical point of view, stirrups have several advantages: They improve the rider’s stability on horseback, which can be an asset in many situations, for example when fighting with a lance. They can also facilitate mounting the horse. Stirrups also make it easier for the rider to stand up in the saddle. This is advantageous at high speed and when travelling over long distances at the trot (present-day “posting”) or canter (present-day “forward seat”). The use of stirrups can also be advantageous for horseback archery: If the horseback archer stands up slightly in the stirrups, especially if the saddle provides support for the pelvis, this can facilitate fast, precise shooting with bow and arrow. Modern “schools” of horseback archery tend to train beginners on a bareback horse and let them progress to mounted archery with a saddle and stirrups as soon as they have mastered the correct technique and start to participate in competitions. Junkelmann (2008) has identified two different traditions of saddle types and associated traditions of horsemanship: The first line of development, without stirrups, includes Scythian saddle pads and ends with the Roman “horned” saddle, which ensured stability on horseback despite the lack of stirrups. The second line of development, according to Junkelmann (2008), begins with early medieval equestrian culture, notably the Huns and the Avars.

The biomechanics of horse riding depends on three aspects, which are interconnected: The horse, the saddle and the rider. As discussed above, there are considerable differences between different pre- and protohistoric equestrian cultures regarding this system. Although

we can reconstruct many aspects of the equipment of the Avar horse, the exact construction of Avar saddles is still unknown, due to lack of preservation of organic materials. However, according to the current state of research, we can assume that they were of a similar type (Bálint 1989, Abb. 65/ 1) to those of other early medieval steppe cultures. For example, in Borodaevka (middle Volga/ Don area), the wooden construction of a saddle from the 7th century was found, which is of a similar type to saddles used in Central Asia during the same period (Balint 1989, Abb. 18 and Abb. 118). In this context, it is important to point out that Avar horses were of considerably smaller and slighter build (maximum around 140 cm) than modern sport horses (see for example: Baron 2018). From a biomechanical point of view, this could be relevant for the research topic of this thesis because very large horses and/ or those with a broad rump may put more strain on the hip joint than horses of slighter build. Presumably, Avar mounted warriors did not have this problem, because their horses were only the size of modern-day native ponies (comparable perhaps to present day Huzul ponies) and relatively slight in build.

2.3 The Biomechanics of Horse Riding

From a bioarchaeological point of view, any physical activity performed on a day-to-day basis since early childhood is likely to have had an effect on the skeleton of the individual in question. According to “Wolff’s Law”, bone tissue can respond to mechanical stress by growth and remodelling and the capacity for bone tissue to adapt to mechanical stress is greatest in non-adults (Pearson et al. 2004).

In the last few decades, bioarcheological research has taken a great interest in reconstructing the activity patterns of past human populations, with the help of osteological traits and in particular, musculo-skeletal stress markers (MSM) at entheses: Hence, the re-construction of human activity has been referred to as “the holy grail” of bioarchaeology (Jurmain et al. 2012). However, a number of methodological problems are associated with the study of musculoskeletal stress markers (MSM). Apart from problems regarding scoring methodology, the appearance of musculoskeletal stress markers (MSM) is dependent on a multitude of factors, including age, sex, mechanical loading and genetic factors. In general, musculoskeletal stress markers (MSM) are non-specific and it is problematic to associate them with particular

activities, especially if they are the only criteria. The bones of the lower limb and the pelvis are a case in point, because they are crucial for locomotion and hence, for most day-to-day activities performed by humans, past or present. On the other hand, sports medicine research on top-level athletes provides evidence of the effects which repetitive, long-term practice of the same physical activity may have on the musculoskeletal system of the human body. Hence, it may be possible to detect differences in activity patterns in past populations by combining MSM with other osteological criteria or with the archaeological context (see for example Havelková et al. 2013).

The shoulder and lower back region, as well as the lower extremities, are the areas of the human body most affected by overuse injuries in present-day equestrian athletes (Pugh & Bolin 2004, 302). However, the majority of biomechanical and medical research on equestrian sports has focused on the “English style” of horse riding and, in particular, on competitive dressage riders. This could be due to the fact that advanced-level dressage riders, who are aiming for an „invisible“ communication between rider and horse, are the equestrian athletes most interested in „fine-tuning“ their riding position and technique, as well as in perfecting the system “horse – saddle – rider“, which is crucial for the effective communication between rider and horse. Recently, this practical interest in the biomechanics of horse riding has led to the establishment of new training methods within equestrian sports, as well as to an increase in publications focusing on this subject (for example: Meyners 2016). Another bias of modern sports medicine research on equestrian sports is that, because the majority of equestrian athletes, in particular in dressage, are female, most of the data analysed within these studies were obtained from research on female equestrian athletes.

There are differences regarding the ideal rider position between the various gaits of the horse (for example: walk, trot, canter, gallop), as well as between riding styles (English or Western) and training disciplines (dressage, show jumping, long-distance riding, reining, polo, modern horseback archery). However, fundamental biomechanical principles remain the same for the system “horse – saddle – rider“, regardless of riding style or training discipline: *„The highest forces during riding are absorbed through the rider’s ischial tuberosities, pelvis, sacrum, and lumbar spine. Low back pain is a common complaint among riders and leads to countless missed riding days, competitions and training problems. Much of the communication between*

rider and horse occurs through the rider's seat. During dressage, the rider's seat always contacts the saddle. A supple lower back drives the horse forward, whereas a tightened, extended back can signal the horse to slow down or collect their gait into a controllable form. Hunter-jumper riders often sit lighter in the saddle to allow the horse to travel forward freely. (...) The rider's weight is supported by dropping her heels and allowing her weight to sink into the lower leg and remain stable during the jump (...) Minor weight shifts on the ischial tuberosities signal the horse to turn or shift weight. In more advanced levels, the rider uses very little pressure on the bit to guide her horse. Some horses can be ridden by seat and leg cues alone" (Pugh & Delmas 2004, 30).

Obviously, the exact details of horse-riding technique in the Avar period are no longer accessible to us. However, as discussed before, some basic principles of the communication between rider and horse remain the same throughout the history of equestrianism – past or present. Similarly, much can be inferred about Avar horse-riding technique due to the necessities of horseback archery: For instance, we can safely assume that Avar horse-riding technique must have focused on controlling the horse effectively without reins, using only the rider's seat and legs, because this is crucial for horseback archery and other types of mounted combat. Other important aspects must have been efficiency and comfort when covering long distances at moderate to high speed. Hence, it is likely that the Avars used some kind of "forward seat" when cantering and galloping, possibly also „posting" when trotting, presumably with shortened stirrup straps. We cannot say for certain whether Avar horseback archers stood up in the saddle, with the help of stirrups, in order to shoot. However, ethnographic parallels (for example: contemporary Mongolian horse archers), as well as the techniques used by modern competitive horseback archers in Europe suggest that this was presumably the case. For example, being able to direct the horse without using the reins is a major pre-requisite for using any type of weapon on horseback, especially for horseback archery. In addition to this, for many tasks in the everyday work of riding herdsmen on horseback it is also an asset to be able to direct the horse only with the seat and legs (for example when using a „lasso", opening gates or separating individual animals from the herd). In addition to this, considering horse-riding technique within modern "schools" of horseback archery may be helpful in this context.

Hence, generally speaking, we can assume that the Avar horse-riding technique is comparable to that of present-day mounted herdsman and hunters, in particular in Central Asia. When compared with present-day equestrian sports, Avar horse-riding style is presumably, due to the practical necessities of mounted combat, closer in technique to modern long distance and hunter-jumper riders than to dressage riders. This is relevant because most modern biomechanical and sports medicine research is focused on (predominantly female) dressage riders. However, as stated previously, basic principles of horse-rider communication and biomechanics remain the same throughout the equestrian world and are therefore also relevant for research on Avar mounted warriors: **“A rider’s legs are a stabilizing and driving force. Strong calf muscles and adductors are essential to help support and balance the seat. The calf muscles drive the horse forward by squeezing inward on the horse’s sides. Using the legs independently can direct a horse to turn, move sideways, change canter leads, or perform difficult dressage movements. As with the rider’s arms, strength disparities in the legs can lead to miscommunication with the horse or cause balance problems in the horse and rider. Riding places the leg in an artificial genu varus position. The forces transmitted through the knee are not usually encountered in most other activities or sports (...) The natural position of the foot in the stirrup causes external rotation of the tibia. The stirrup should be positioned across the ball of the foot. The toe turns slightly outward so the calf and ankle are applied to the horse’s side (...). The ankle is also an area of stress during riding because the gravitational forces are absorbed through the heels. The rider’s weight should be pressed downward through the heel. The heel acts as a shock absorber so the leg and seat can remain stable and balanced (...). When the ankle is properly flexed and the rider’s weight is absorbed through the heels, the Achilles tendon is eccentrically loaded throughout the ride. Repetitive microtrauma can lead to Achilles tendinosis. In addition, riders wear heavy, hard-soled boots for long periods of time while working around the barn and this can also place strain on the ankle. Proper stretching of the gastrocnemius and soleus muscles is essential to preventing injury”** (Pugh & Delmas 2004, 302).

2.4 Morphological variations of the anterior proximal femur – Definitions & aetiology

Despite an abundance of anatomical literature on morphological variations of the proximal femur, there is still considerable debate regarding the terminology, interpretation and aetiology of these variations (see Radi 2013 and Mellado et al. 2014). According to Finnegan & Faust (1974), there are three types of morphological variation in the head-neck junction of the anterior proximal femur: These may all be summarised by the “reaction area” concept, which includes two “elevated” changes (Poirier’s Facet; Plaque) and one “excavated” change (Cribra) visible on the bone surface, as defined below. In rare cases, according to Finnegan & Faust (1974, 8) all three types of variation may occur together on the same femur. The first elevated variation is defined as follows (see Fig. 1 B): *“Poirier’s Facet is scored as present when there is a noticeable, however slight, bulging of the articular surface of the femoral head toward the anterior portion of the femoral neck. This facet is necessarily smooth and is not to be confused with plaque formation (...)”* (Finnegan & Faust 1974, 8). In contrast, the second elevated variation is characterised as follows (see Fig. 1 C): *“Plaque formation is scored as present when an overgrowth or bony scar can be defined as extending from the area of Poirier’s facet on the femoral head down onto the femoral neck which often surrounds or covers Allen’s fossa”* (Finnegan 1974 & Faust, 8). Finally, the following definition of the excavated type of variation is given (see Fig. 1 A): *“The Cervical Fossa (depression) of Allen, when present, is usually located near the anterior superior margin of the femoral neck close to the border of the head. It can vary from a small depression to a large eroded area one centimetre square where the cortical bone has been removed exposing underlying trabeculae. The border of this fossa may have a ridge of thickening around it reminiscent of an inflammatory response. To be scored as present, the underlying trabeculae must be seen (...)”* (Finnegan & Faust 1974, 7).

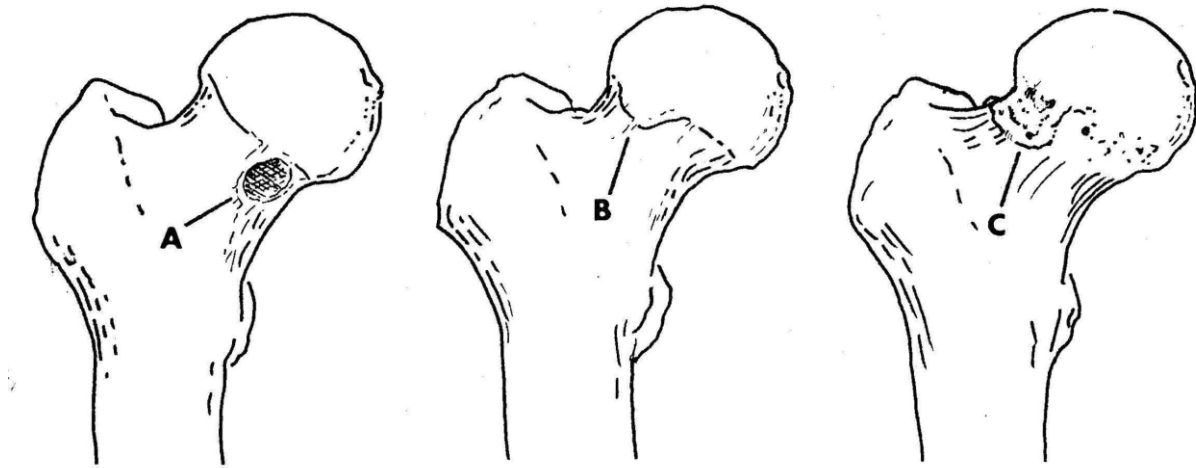


Fig. 1: Morphological variations of the anterior proximal femur: A = “Allen’s Fossa”, B = “Poirier’s Facet”, C = “Plaque” (Illustration from: Finnegan & Faust 1974, 7, Fig. 1)

According to White et al. 2012 (252), „*Allen’s fossa, Poirier’s facet, and plaque are all defects of the margin of the femoral head*“ and they suggest that, as interrelated features, these three traits should be scored together on a scale of 0 to 7. The differences in classification systems for morphological variations of the anterior proximal femur illustrate the problem of “categorizing” individual variation, which may in fact be continuous. Current medical research could facilitate the correct interpretation of osteological traits from bioarchaeological contexts. Unfortunately, clinical research focusing on the effects of sports on the morphology of the proximal human femur in living patients, in particular in professional horse riders, is not yet available. Nevertheless, recent work by Mellado et al. (2014) on the proximal femoral region of living humans of different age groups, using 64-slice multi-detector computed tomography (MDCT) is helpful for the interpretation of morphological variations of the proximal femur on dry bone. A considerable number of the variations identified by Mellado et al. (2014) in living individuals correspond to traits, which occur on the proximal region of human femora from archaeological contexts. The classification system for morphological variations of the anterior femoral head-neck Mellado et al. (2014, 49, Fig. 14) has identified 8 variations, which deviate from standard anatomy (absence of traits): This includes the variation “slight accessory facet”, which is not as pronounced as the typical “Poirier’s Facet”. Hence, “slight facets” were also taken into consideration in the research carried out in this thesis (see ch. 6.1).

As discussed above, the “reaction area” concept includes both elevated and excavated variations of the anterior head-neck junction of the femur. Multiple detector computed tomography (MDCT) of the anterior femoral head neck junction in adults (Mellado et al. 2014) has confirmed that the “reaction area” may include both elevated (“Plaque”) and excavated (“Cribra”) changes on the bone surface. In addition to this, medical/ radiological research using MDCT has also provided evidence linking these osteological traits to increased physical activity and/ or advanced age: *“At the medial aspect of the eminentia articularis a **roughened area** is commonly seen (...). This variable trait, probably exercise-related, has been found to show greater development in vigorous athletes. It has been termed “reaction area”. It lies close to the rim of the articular surface, just above the Poirier’s facet site. It may get ulcerated, originating a herniation pit. When the pit collapses or gets exposed, an Allen’s fossa may arise. The concave space between a sharp articular ridge and the articular rim is also termed Allen’s fossa. In summary, the “reaction area” concept would encompass both exostosis-like projections (including some CAM-type bumps) and excavated variants. In young adults, the reaction area shows a smooth, slightly elevated contour at the anterior neck (...). It is hard to identify on axial-oblique MDCT views (...) and preserves the anterior head-neck offset. (...) The reaction area becomes significantly rough and prominent in the elderly, originating a grossly evident plaque (...), which can be identified on volume-rendered and oblique-axial (superior, middle, inferior) views. In these cases, histological evaluation reveals thickened exposed trabeculae and rests of fibrocartilage, but no hyaline cartilage. (...) A large herniation pit may be found in symptomatic individuals. Although traditionally considered a normal variation, its potential association with femoroacetabular impingement has been extensively debated (...). MDCT optimally depicts the very common association of a plaque-like reaction area with a herniation pit (...), typically found at the most anterosuperior and medial aspect of the femoral neck. These associated traits have been termed “fibrocystic changes” in the radiology literature, although they probably belong to the spectrum of the “reaction area” concept, which is commonly found in non-osteoarthritic hips”* (Mellado 2014, 21-23).

Based on MDCT-research of the femoral head-neck junction of living adults, Mellado et al. (2014) describe “Poirier’s facet” as follows: *“The anterior aspect of the articular surface typically shows a gently convex contour. However, a **common extension of the articular surface into the neck** may be found, which is known as **Poirier’s facet** (...). In these cases, the*

articular surface is limited by two concave margins (...), above and below the medial aspect of the eminentia articularis (...). The Poirier's facet may extend into the femoral neck for as much as 1.5 cm. **The Poirier's facet is smooth and typically covered by hyaline cartilage.** On oblique-axial views, **the Poirier's facet is prominent and pointed, showing no reactive sclerosis.** According to classic anatomical descriptions and MDCT appearance, **the Poirier's facet may be a constitutional cause of CAM-type bump**" (Mellado et al. 2014, 19).

Apart from "Poirier's facet" at the femoral head-neck junction, two other osteological variations of the proximal femur, which, according to some researchers, are part of the "horse riding syndrome" (see ch. 5.2), have recently been studied in living adult patients. The first of these variations is an exostosis ("spicules"; see fig. 16) in the trochanteric fossa: *"The trochanteric fossa (...) is a deep extra-articular depression medial and posterior to the tip of the greater trochanter (...). It may contain a little bony spur of no clinical significance, which represents the **site of insertion of the obturator externus muscle**"* (Mellado 2014, 29). The second variation is an "overhanging" of the greater trochanter's tip over the trochanteric fossa ("curved trochanter"; see fig. 16): *"The posterior tip of the superior border of the greater trochanter may show slightly variable configuration. Most commonly, the posterior aspect of the greater trochanter shows slight medial projection, and stays away from the trochanteric fossa. However, when the posterior aspect of the greater trochanter projects medially, it overhangs over the trochanteric fossa"* (Mellado 2014, 30).

Functional hypotheses have interpreted variations of the anterior, femoral head-neck junction as "stress markers", by associating them with specific types of physical activities, which habitually cause considerable pressure or traction in the hip joint. Recently, a considerable proportion of research on proximal femur variability has focused on the femoral impingement syndrome. Indeed, research on FAI can make an important contribution to the interpretation of anatomical variations of the proximal femur (see for example: Villotte & Knüsel 2009). The results of current research medical and radiological research suggest that some, but by no means all, variations of the anterior head-neck junction may cause cam-type femoroacetabular impingement (FAI): Both "Poirier's Facet" and Plaque type A could contribute to causing FAI and thus, ultimately, constitute a cause of osteoarthritis of the hip joint (Mellado et al. 2014, Lawrence 2018).

At present, the synthesis of current radiological research on living patients with traditional osteological research (dry bone samples from reference collections and archaeological contexts) suggests that plaque and cribriform lesions in the anterior head-neck junction of the human femur could be associated phenomena in the context of the “reaction area concept” with, possibly, a common aetiology. According to Mellado et al. (2014), a relatively uniform, elevated bone surface change in the “reaction area” of the anterior proximal femur (“Plaque”) appears to be characteristic for young adults with a particularly active lifestyle (athletes). In older adults, however, according to Mellado et al. (2014), the appearance of the “reaction area” of the anterior proximal femur is normally more heterogeneous, with a combination of elevated and excavated bone surface changes. In this context, it is possible that the “herniation pits” observed by radiologists in living patients are the equivalent of the cribriform changes observed on dry bone.

On the other hand, the synthesis of current radiological research on living patients with traditional osteological research (dry bone samples from reference collections and archaeological contexts) suggests that “Poiriers facets” could be a distinct phenomenon, which is not associated with the reaction area concept.

2.5 The „Horse riding syndrome“ – Definition & short summary of the state of research

The so-called „horse riding syndrome“ (Anđelinović et al. 2015; Baillif-Ducros 2012; Baillif-Ducros & McGlynn 2013; Berthon et al. 2018; Belcastro et al. 2001; Larentis 2017) refers to an ensemble of changes on the human skeleton which, if found in association, may indicate that the individual in question practiced horse riding as a habitual activity during his or her lifetime. From a methodological point of view, the identification of specific activities in a bioarchaeological context is encumbered by serious limitations (see for example: Jurmain et al. 2012, Foster et al. 2012). However, recent research relevant to the “horse riding syndrome” is quite promising (Anđelinović et al. 2015; Baillif-Ducros 2012; Baillif-Ducros & McGlynn 2013; Berthon et al. 2018; Belcastro et al. 2001; Larentis 2017). The characteristic traits of the “horse riding syndrome” occur predominantly on the bones of the lower limb, the pelvis and the

spine. This particular set of osteological markers is also referred to as „knight syndrome“ by some authors (Larentis 2017), which may be derived from the French terminology for this syndrome („syndrome de cavalier“ – Baillif-Ducros 2012). Surprisingly, the number of systematic, bioarchaeological studies on the „horse riding syndrome“ is less extensive than expected (see Berthon et al. 2018; Larentis 2017 and Andelinovic et al. 2015 for an overview of literature on the topic). However, the characteristic traits of this syndrome frequently appear in bioarchaeological literature as an argument that a particular individual was a „horse rider“.

The trait most frequently cited in the bioarchaeological literature as an indicator of habitual horse riding activity is the so-called „Reiterfacette“ („riders facet“), which refers to characteristic changes in the area of transition between the *caput femoris* and the *collum femoris*. For example, Anđelinović et al. (2015, 714, Table 3) list the “Poirier’s facets” as one of the characteristic traits of the „horse riding syndrome“. However, there appear to be some inconsistencies regarding the terminology and its usage in bioarchaeological literature. As the issue of the aetiology of this non-metric trait is not yet resolved, it is certainly preferable to use the term “Poirier’s facet”, because it is more neutral than “rider’s facet”. Therefore, the term “Poirier’s facet” is used throughout this thesis. It is interesting that in the modern population (Certosa cemetery, Bologna, Italy first half of 20th century) studied by Radi (2013), “Poirier’s Facets” were extremely rare.

A key question is whether non-metric variations of the femoral head-neck junction other than typical “Poirier’s Facets” (for example: Slight facets, different types of plaque and cribriform variations; according to the recent classification by Radi et al. 2013) may also be associated with the “horse riding syndrome”. Recent research by Radi et al. (2013) and Lawrence et al. (2018) suggests that plaque in the head-neck junction of the proximal femur is very common in some populations. Therefore, it is unlikely that it can be associated with specific activities such as horse riding. According to Belcastro et al. (2006, 324-325), while biomechanical stress on the hip joint in flexion and extension may be a major factor in causing morphological variations of the femoral head-neck junction, other factors such as hormonal and metabolic levels may also influence the prevalence and appearance of these variations. Hence, biomechanical stress on the hip joint may cause differential adaptive effects, for example in

different age groups, as well as in males and females: *“Therefore, the Allen’s fossa and iliac imprint could indicate a common aetiology (postural mechanical stress related to flexion/extension of the hip joint) that is influenced by age, causing different effects; age-related changes in hormonal and metabolic levels of a bone subjected to biomechanical stress may cause differential adaptive effects”* (Belcastro et al. 2006, 325). According to Belcastro et al. 2006, the continuity between the femoral head and neck is an important criterion for the presence of Poirier’s facet (hyaline/ articular cartilage), while for the iliac imprint (Plaque) this is not the case.

Recently, Baillif-Ducros & Mc Glynn (2013) added another osteological marker to the characteristic changes associated with the “horse riding syndrome”: This is the presence of osteoarthritis on the upper outline of the patellar surface, as an indication of possible stirrup use. This particular trait is especially relevant in the study of Avar populations, which are, from a historical-archaeological point of view, traditionally assumed to have played an important role in technological change in equestrian cultures, by bringing the stirrup from Asia to Europe.

Another osteological change frequently associated with habitual horse riding in the bioarchaeological literature is a change in the shape („ovalization“) of the acetabulum (Larsen 1997, Erickson et al. 2000; Bailliff-Ducros 2012; Larentis 2017). In this context, the “Index of Ovalization (IOA)” introduced by Berthon et al. (2018) is a useful, simple tool for quantifying what may be one of the major characteristics of the “horse riding syndrome”: The vertical elongation (Ovalization) of the acetabulum.

3 Research questions

On the one hand, the purpose of this thesis is to contribute to methodological research on the “horse riding syndrome”, by examining whether specific morphological variations of the anterior femoral head-neck junction (“Poirier’s Facet”, “Plaque” and “Cribra”, according to the recent classification by Radi et al. 2013) associate with other potential characteristics of the “horse riding syndrome”. Avar populations are ideally suited for methodological research on the “horse riding syndrome”, because, due to the historical context, it is likely that Avar adult

populations include a considerable number of individuals who had spent much time on horseback.

Hypothesis 1 (= Sub-Hypotheses 1a to 1h) examines possible associations between the Index of Ovalization of Acetabulum (IOA), which is a metric trait (Berthon et al. 2018) and each of eight other criteria of the “horse riding syndrome” suggested by previous research (see Ch. 2.5 and 5.2). Seven of these eight criteria are non-metric (Hypotheses 1a to 1g; see Ch. 4.1, below) and the T-test is used in each case, given normal distribution, in order to test for significant differences in IOA between the groups with presence vs. absence of the trait in question. The assumption that “Poirier’s Facet” is the only morphological variation of the femoral head-neck junction, which is a part of the “horse riding syndrome”, constitutes the basis for Hypothesis 1a (below). However, one of these eight criteria (Hypothesis 1h) is a metric trait, like the IOA. Hence, given normal distribution, the relationship between these two metric traits is explored, using Pearson’s correlation coefficient.

On the other hand, this thesis intends to identify possible differences in habitual horse riding activity between different groups within the adult Avar population of Wien 11-Csokorgasse (Hypothesis 2-4; consisting of two sub-hypotheses, in each case). The basis for these hypotheses is the current state of research on the prevalence of horse riding in Avar society in the seventh and eighth centuries AD. Archaeological data and historical sources suggest that a number of fundamental changes took place within the Avar populations in Central Europe after the middle of the seventh century AD, including the trend to establishing more permanent settlements and the transition to an economy based more on agriculture and less on herding and plundering (“war economy”). The aim of this thesis is to investigate to what extent the prevalence of the traits in question is dependent on the sex (Hypothesis 2), chronological position (Hypothesis 3) and socioeconomic status (Hypothesis 4) of the adult population of an Avar cemetery of the 7th and 8th centuries AD (Wien 11-Csokorgasse). The evaluation of Hypothesis 2 takes place with the help of two major characteristics of the “horse riding syndrome” – “Poirier’s Facet” and the Index of Ovalization of Acetabulum (IOA). However, the evaluation of Hypotheses 3 and 4 takes place with the help of only a single, but major criterion of the “horse riding syndrome”, the Index of Ovalization of Acetabulum (IOA). It was not possible to use more criteria for testing Hypothesis 2, 3 and 4, due to sample size,

because of the insufficient state of preservation of the human osteological material from this site.

4 Hypotheses

4.1 Verification of the “Horse Riding Syndrome”: Associations between different characteristics of the “Horse Riding Syndrome”

Hypothesis 1

There are associations between different characteristics of the “Horse Riding Syndrome”.

Hypothesis 1 was tested via eight sub-hypotheses (Sub-hypothesis 1a to 1h, below): Seven of these sub-hypotheses each test for significant differences regarding the ovalization of the acetabulum (via differences in a metric trait, the IOA) in adults with the presence or absence of a given non-metric characteristic of the “horse riding syndrome” (see Hypothesis 1a to 1g, below). Hypothesis 1 h tests for a significant correlation between two metric traits of the “horse riding syndrome”: The IOA and the average entheses robusticity score for the lower limbs.

Sub-hypothesis 1a

The mean Index of Ovalization of Acetabulum (IOA) is significantly higher for adults with a “Poiriers Facet” on the same side *Os femoris* than for adults without this trait.

Sub-hypothesis 1b

The mean Index of Ovalization of Acetabulum (IOA) is significantly higher for adults with pronounced gluteal entheses on the same side *Os coxae* than than for adults without this trait.

Sub-hypothesis 1c

The mean Index of Ovalization of Acetabulum (IOA) is significantly higher for adults with a pronounced *Linea aspera* on the (same side) *Os femoris* than for than for adults without this trait.

Sub-hypothesis 1d

The mean Index of Ovalization of Acetabulum (IOA) is significantly higher for adults with a curved *Trochanter major* on the (same side) *Os femoris* than for adults without this trait.

Sub-hypothesis 1e

The mean Index of Ovalization of Acetabulum (IOA) is significantly higher for adults with exostosis (“spicules”) in the *Fossa trochanterica* on the (same side) *Os femoris* than for adults without this trait.

Sub-hypothesis 1f

The mean Index of Ovalization of Acetabulum (IOA) is significantly higher for adults with exostosis (“spicules”) in the *Fovea capitis* on the (same side) *Os femoris* than for adults without this trait.

Sub-hypothesis 1g

The mean Index of Ovalization of Acetabulum (IOA) is significantly higher for adults with osteoarthritis on the upper outline of the patellar surface on the (same side) *Os femoris* than for adults without this trait.

Sub-hypothesis 1h

In the total adult population, there is a positive correlation between the IOA and the entheses robusticity scores of the lower limbs of an individual.

4.2 Differences between the sexes

Hypothesis 2

The prevalence of one or more characteristic traits of the “Horse Riding Syndrome” is significantly higher in the adult male population than in the adult female population buried in the Avar cemetery Wien-Csokorgasse.

Sub-hypothesis 2a

The prevalence of “Poiriers Facet” is significantly higher in the adult male population than in the adult female population buried in the Avar cemetery Wien-Csokorgasse.

Sub-hypothesis 2b

The average Index of Ovalization of Acetabulum (IOA) is significantly higher in the adult male population than in the adult female population buried in the Avar cemetery Wien-Csokorgasse.

4.3 Chronological Differences

Hypothesis 3

The prevalence of one or more characteristic traits of the “Horse Riding Syndrome” is significantly higher in the early phases than in the later phases of the Avar cemetery Wien-Csokorgasse and this difference could be especially relevant for the female adult population.

Sub-hypothesis 3a

The average Index of Ovalization of Acetabulum (IOA) in the total adult population is significantly higher in the early phases than in the later phases of the Avar cemetery Wien-Csokorgasse.

Sub-hypothesis 3b

The average Index of Ovalization of Acetabulum (IOA) in the adult female population is significantly higher in the early phases than in the later phases of the Avar cemetery Wien-Csokorgasse.

4.4 Differences between socioeconomic groups

Hypothesis 4

The prevalence of one or more characteristic traits of the “Horse Riding Syndrome” is significantly higher in adults with “high socioeconomic status” than in adults with “low socioeconomic status” and this could be especially relevant for the male adult population.

Sub-hypothesis 4 a

The mean IOA of total adult individuals with “high socioeconomic status” (proxy: burial in “deep” graves = grave depth 1.00 m or more) is significantly higher than the mean IOA of total adult individuals with “low socioeconomic status” (proxy: burial in “shallow” graves = grave depth less than 1.00 m).

Sub-hypothesis 4 b

The mean IOA of male adult individuals with “high socioeconomic status” (proxy: burial in “deep” graves = grave depth 1.00 m or more) is significantly higher than the mean IOA of male adult individuals with “low socioeconomic status” (proxy: burial in “shallow” graves = grave depth less than 1.00 m).

5 Material & Methods

5.1 Sample

The sample for this study was taken from the adult population of the Avar cemetery of Wien 11-Csokorgasse (Streinz 1977, Großschmidt 1990): This was advantageous because the osteological material is easily accessible at the Institute of Anthropology and the age and sex determination, as well as valuable paleopathological observations have already been published (Großschmidt 1990). The chronological information and other archaeological data (presence of weapons and multi-part belt sets as grave goods; the depth of graves) used in this thesis are derived from the preliminary catalogue (Streinz 1977), the preliminary, chronological evaluation (Streinz & Daim 2018) and from a recent, zooarchaeological study of this cemetery (Baron 2018). In order to obtain a suitable sample size, the six phases of this cemetery were transformed into three chronological groups (early/ middle/ late phase, by combining two phases in each case). Multi-part belt sets and deep graves were chosen as a proxy for high socioeconomic status: The average depth for burials with multi part belt sets is 0.96 m (Baron 2018, 302), therefore 1.00 m was taken as the limit between the two groups with shallow and deep graves, respectively.

In preparation for this research, all individuals of the age groups adult and older (according to Großschmidt 1990) from the Avar cemetery Wien 11-Csokorgasse, which are currently accessible in the collection of the Institute of Evolutionary Anthropology – a total of around 300 individuals – were subjected to a preliminary examination. The purpose of this first round of research was to determine whether the state of preservation of the individuals in question was sufficient for inclusion in the sample for this thesis. Sub-adults were not included in the sample, given the assumption that it would be more difficult to assess the presence of the non-metric traits of the proximal femur in individuals with incomplete fusion of the epiphysis of the femoral head.

This thesis focuses on three main types of non-metric traits of the proximal femur (facets, plaque and cribriform changes) and their possible relevance for the so-called “horse riding syndrome“. Hence, only individuals of the age groups adult and older (according to Großschmidt 1990) with at least one proximal femur sufficiently well preserved for scoring these three main types of non-metric traits (facets, plaque and cribriform changes) were included in the sample. The total sample consists of 149 individuals – 60 individuals with both proximal femora well-preserved and 89 with either the left or the right proximal femur sufficiently well-preserved to record the traits in question.

As Fig. 2 illustrates, approximately half of the 149 individuals in our sample were identified as women, the other as men. All data regarding the age and sex of the individuals included in our sample were adopted from the dissertation of Großschmidt (1990).

In terms of chronology, the sample is evenly distributed, as can be seen from Fig. 4: One third belongs to the early, middle and late phases of the cemetery, respectively. However, concerning age-groups, young adults constitute the majority in the sample (see Fig. 3).

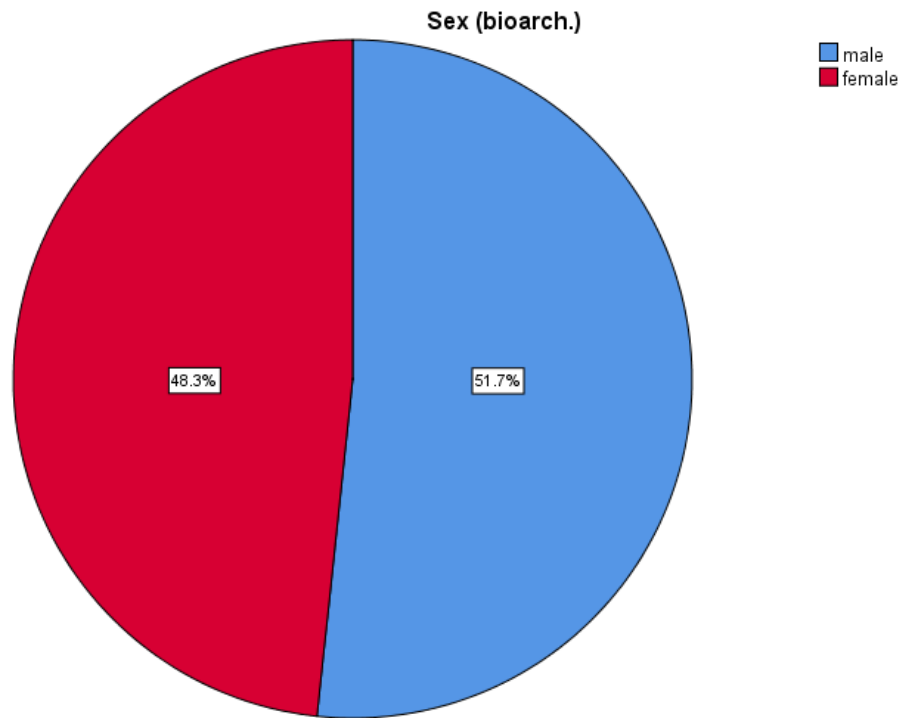


Fig. 2: Frequency of male and female adult individuals in the sample (n = 149)

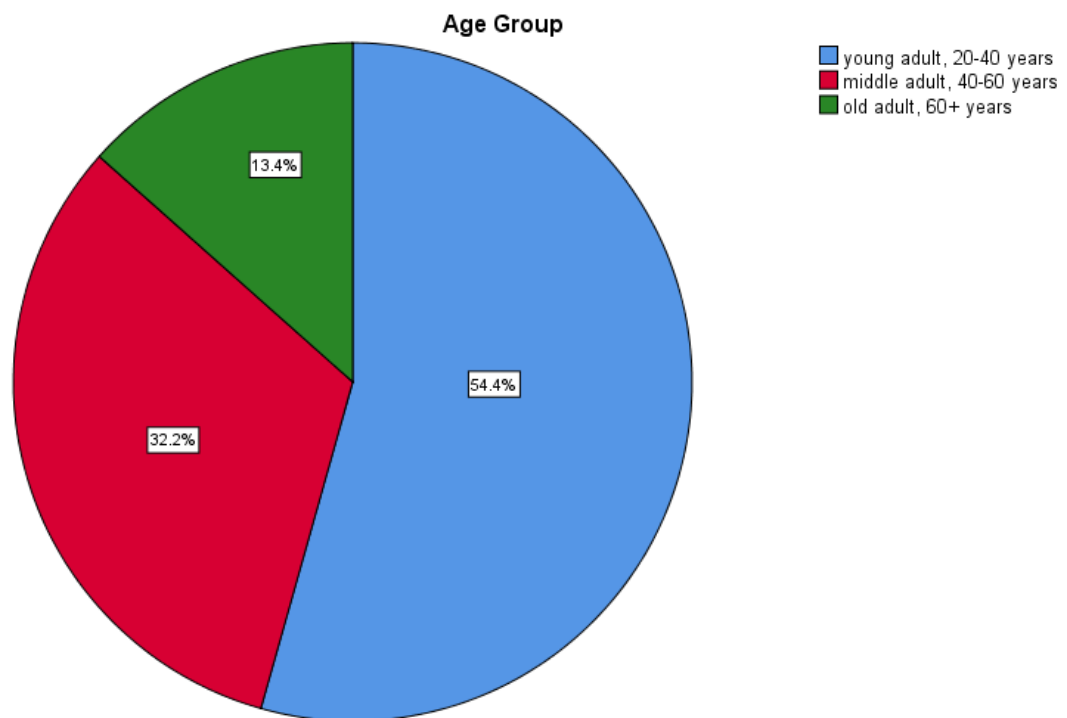


Fig. 3: Frequency of adult age groups in the sample (n = 149)

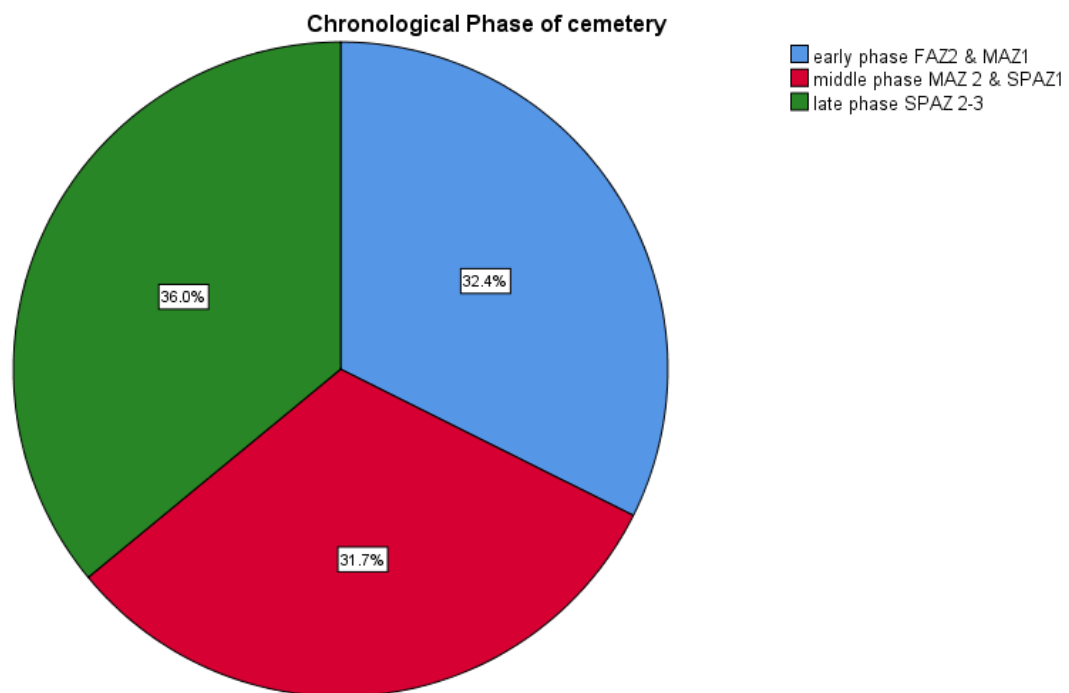


Fig. 4: Chronological distribution of the sample (n = 149)

5.2 Method for identification of the “Horse Riding Syndrome”

The following selection of potential characteristics of the “Horse Riding Syndrome” were examined on the osteological sample for this thesis – adult individuals (n= 149) from the Avar cemetery Wien11-Csokorgasse. Traits were scored as non-recordable if 50% of the surface was damaged.

“Horse Riding Syndrome” – Osteological traits included in this study:

Os femoris:

- **1. Collum femoris: „Poirier’s facets“** (according to: Anđelinović et al. 2015) **and associated traits** (“Allen’s fossa”/ Cribra, plaque etc.; see: White et al. 2012, Lawrence 2018, Radi 2013) – Definitions and Scoring System according to Radi et al. 2013

Qualitative traits:

The following six qualitative traits (2-7a) were scored as present/ absent (five traits on *Os femoris* and one trait on the *Os coxae*):

- **2. Pronounced *Linea aspera* on *Os femoris*;** (according to: Anđelinović et al. 2015)

- **3. Curved, pronounced Trochanter major on *Os femoris*;** (according to: Anđelinović et al. 2015)
- **4. Exostosis (“spicules”) in Fossa trochanterica on *Os femoris*;** (according to: Anđelinović et al. 2015)
- **5. Exostosis (“spicules”) in Fovea capitis on *Os femoris*;** (according to: Anđelinović et al. 2015)
- **6. Presence of osteoarthritis on the upper outline of the patellar surface on *Os femoris*;** (as an indication of possible stirrup use; according to Baillif-Ducros & Mc Glynn 2013)

Os coxae:

- **7a. Pronounced entheses (of gluteal muscles) on *Os coxae*;** (according to: Anđelinović et al. 2015)

Quantitative traits

- **7b. Entheses of lower limb** – Scoring system according to Mariotti et al. (2007): Entheses robusticity score calculated from a maximum of 7 entheses for left and right side = max. 3 entheses per side on the femur, max. 2 entheses per side on the tibia, max. 1 entheses per side on the patella and max. 1 entheses per side on the calcaneus.
- **8. Acetabulum (*Os coxae*): „Index of Ovalization“ (IOA)** – according to Berthon et al. (2018).

Scoring the non-metric variations of the proximal femur (specifically: the anterior area of the femoral head-neck junction) took place according to the classification system developed by Radi et al. (2013). The latter was chosen as a basis for this thesis not only because it is the most recent classification system, but also because it is the classification system on which crucial new research on variations of the anterior area of the femoral head-neck junction in living patients is based (Mellado et al. 2014). Similarly, recent bioarchaeological research on non-metric variations of the proximal femur in an early medieval population from Kulubnarti, Nubia (Lawrence et al. 2018), also uses the classification system developed by Radi et al. (2013). Hence, it is advantageous to use the same system, in order to facilitate comparing the results of Lawrence et al. (2018) with the results on the Avar population from Wien 11-Csokorgasse. The classification system by Radi et al. (2013) considers facets, plaque and cribra as independent descriptors, although they are known to co-exist quite frequently.

According to Radi et al. (2013, 262, Table 1), the characteristics of Poirier’s facet are as follows:

1. The expansion surface on the femoral neck is continuous with the articular surface of the femoral head.

2. The expansion surface on the femoral neck is on the same plane as the femoral head.

3. The expansion surface on the femoral neck is smooth.

In contrast, a rough surface is characteristic for plaque. Hence, plaque is visible as a structure that is distinct from the smooth surface of the femoral head (Radi et al. 2013, 262, Table 1), as compared to Poirier's facet, where the expansion surface is smooth and thus continuous with the femoral head.

Radi et al. (2013, 262, Table 1) have distinguished between three types of plaque:

- Type A is located on the same plane as the femoral head.
- Type B is located on an intermediate plane between the surfaces of the femoral head and neck.
- Type C is located (completely or partly) below the plane of the femoral neck.

According to Radi et al. (2013) Cribra type 1 is present when there are only small holes (max. 1mm diameter) on the bone surface, while Cribra type 2 is scored only for substantial perforations, where the underlying trabeculae are apparent.



Fig. 5: Grave 348 (middle adult, male), right proximal femur, ventral view – “Poirier’s Facet”



Fig. 6: Grave 487 (old adult, female), left proximal femur, ventral view – Plaque type A



Fig. 7: Grave 256 (young adult, male), left proximal femur, ventral view – Plaque type B



Fig. 8: Grave 139 (young adult, female), left proximal femur, ventral view – Plaque type C and Cribra type 1



Fig. 9: Grave 30/1 (young adult, male), left proximal femur, ventral view – Plaque type C and Cribra type 2



Fig. 10: Grave 217 (young adult, female), right proximal femur – Plaque type C and Cribra type 2

The index of ovalization of acetabulum (IOA) is a simple measurement method developed by Berthon et al. (2018), in order to facilitate detection of the “vertical elongation of the acetabulum” (“Ovalization”) in quantitative terms, without having to resort to more complex morphometric methods, such as the Fourier analysis used by Erickson et al. (2000).

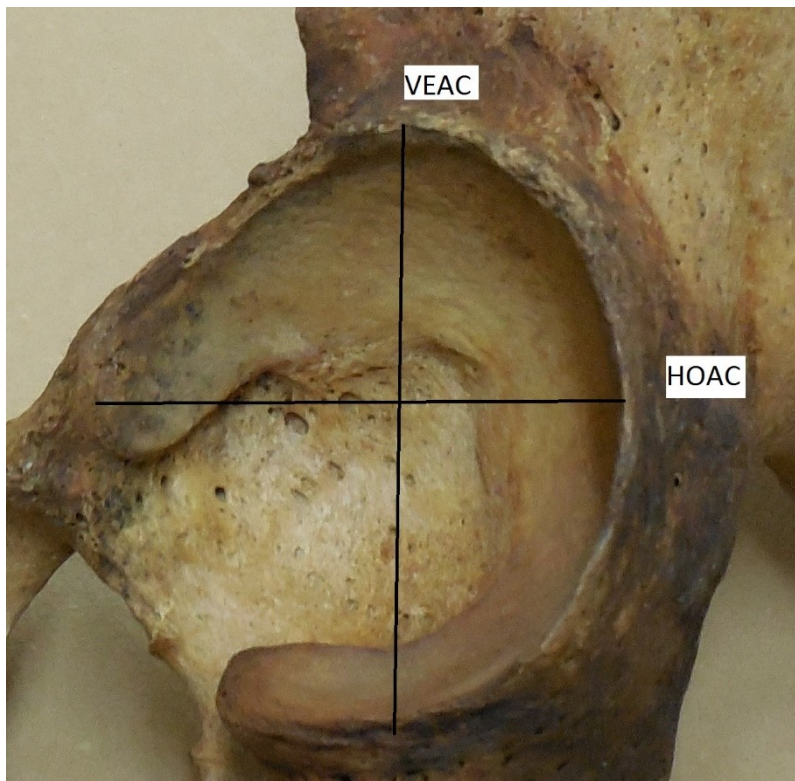


Fig. 11: Grave 21 (young adult, male), left acetabulum with noticeable “Ovalization” (vertical elongation) – showing the measurements VEAC (maximum vertical diameter of acetabulum) and HOAC (maximum horizontal diameter of acetabulum)

The IOA is defined as $VEAC / HOAC$, where VEAC is the “maximum vertical diameter of acetabulum” and HOAC is the “maximum horizontal diameter of acetabulum”, measured on the rim of the acetabulum in each case (see Fig. 11). The measurements were carried out with a digital caliper, in mm, to 1 decimal. For each VEAC or HOAC, 2 measurements were carried out on the same day and the arithmetic mean was used in order to calculate the IOA.

Intra-observer reliability was measured by carrying out a third round of measurements in a separate session after several months, on a random sample of 10 individuals with 20 femora. The correlation coefficients (non-parametric, Spearman-Rho) for these measurements are shown in Table 1 (Ch. 6.2.1).

Entheses robusticity was scored according to Mariotti et al. (2007) for the 7 entheses of the lower limb on a scale of 0 (absence) to 3 (very pronounced): For each individual, the average entheses robusticity score was calculated from a maximum of 7 entheses, separately for the left and right side. These 7 entheses are: max. 3 entheses per side on the femur (*M. gluteus maximus*, *M. vastus medialis*, *M. iliopsoas*), max. 2 entheses per side on the tibia (Quadriceps tendon; *M. soleus*), max. 1 enthesis per side on the patella (Quadriceps tendon) and max. 1 enthesis per side on the calcaneus (Achilles tendon).



Fig. 12: Grave 21 (young adult, male), left femur, ventral view – slight “Poirier’s Facet” on head-neck junction & slight osteoarthritis on upper edge of patellar surface



Fig. 13: Grave 21 (young adult, male), left femur, dorsal view – pronounced Linea aspera & pronounced, curved trochanter major



Fig. 14: Grave 21 (young adult, male), left os coxae, ventral view – pronounced entheses of gluteal muscles & ovalization (vertical elongation) of acetabulum



Fig. 15: Grave 315 (old adult, female), distal right femur – Patellar surface with pronounced osteoarthritis along the upper edge



Fig. 16: Grave 266 (middle adult, male), left proximal femur, dorsal view – curved, pronounced trochanter major; exostosis in fossa troch. & fovea capitis; moderately pronounced entheses

5.3 Statistical analysis

All statistics with were carried out with SPSS 25. After verifying normal distribution using the Kolmogorov-Smirnov test, the hypotheses were tested with the help of the independent-sample T-test, one-way ANOVA and Pearson's correlation coefficient. Results were considered significant when $p = 0.05$ and highly significant when $p = 0.001$. Pie charts were constructed in order to illustrate the prevalence of the different types of morphological variations of the anterior head-neck junction of the femur in the total adult population, as well as in adult males and adult females. In addition to this, box-plots were constructed in order to illustrate variations in IOA within the adult population of the Avar cemetery Wien-Csokorgasse.

6 Results

6.1 Proximal Femur: Prevalence of non-metric traits of the anterior head-neck junction

6.1.1 “Poirier’s Facet”

6.1.1.1 Total adult population (male & female, all adult age groups)

As Fig. 17 and 18 demonstrate, a characteristic “Poirier’s Facet” was present in 15.4% (18/117) of the total adult individuals with an observable left proximal femur and in 20.4% (19/93) of the total adult individuals with an observable right proximal femur. In addition to this, a “slight facet” was present in 9.4% (11/117) of the total adult individuals with an observable left proximal femur and in 7.5% (7/93) of the total adult individuals with an observable right proximal femur. When combining these two categories – which could be advisable due to variations in scoring systems for morphological variations of the femoral head-neck junction – facets would be present in 24.8% (29/117) of the total adult individuals with an observable left proximal femur and in 27.9% (26/93) of the total adult individuals with an observable right proximal femur.

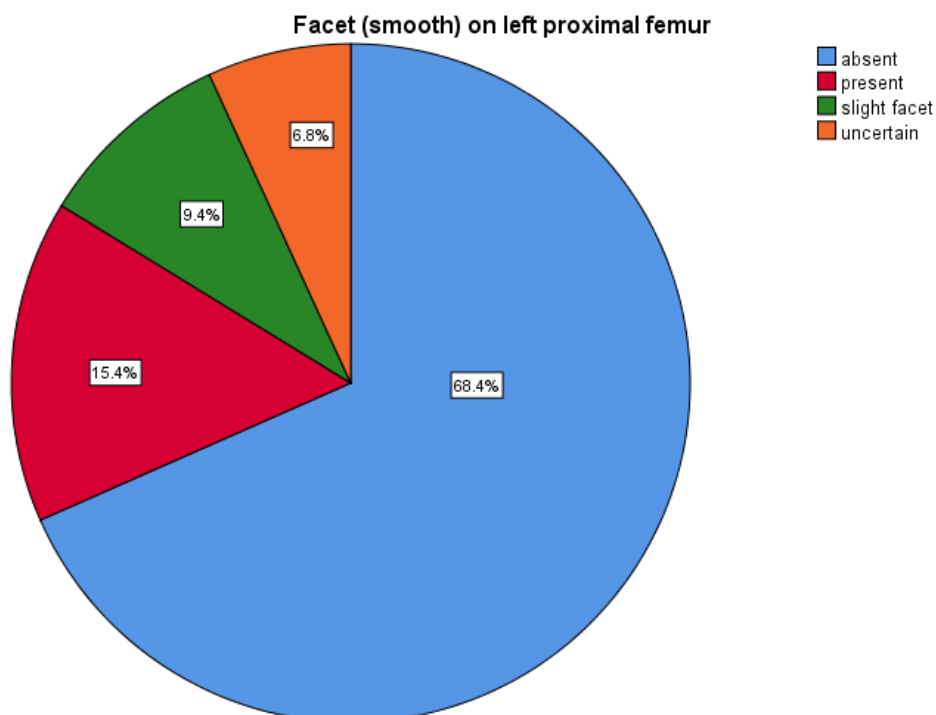


Fig. 17: Prevalence of “Poirier’s Facet” in the total adult population of the Avar cemetery Wien-Csokorgasse (left proximal femur, n = 117)

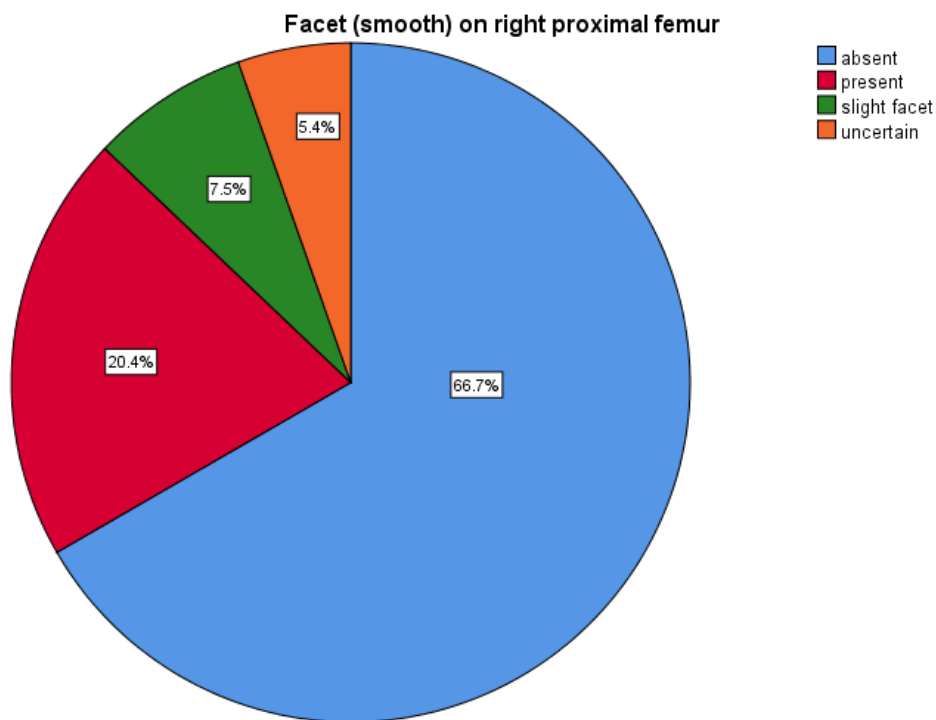


Fig. 18: Prevalence of “Poirier’s Facet” in the total adult population of the Avar cemetery Wien-Csokorgasse (right proximal femur, n = 93)

6.1.1.2 Male adult population (all adult age groups)

Fig. 19 and 20 illustrate that a typical “Poirier’s Facet” was present in 22.8% (13/57) of the adult male individuals with an observable left proximal femur and in 32.6% (15/46) of the male individuals with an observable right proximal femur. In addition to this, a “slight facet” was present in 12.3% (7/57) of the male individuals with an observable left proximal femur and in 2.2% (1/46) of the male individuals with an observable right proximal femur. As above, a combination of these two separate categories would mean that facets would be present in 35.1% (20/57) of the male individuals with an observable left proximal femur and in 34.8% (16/46) of the male individuals with an observable right proximal femur.

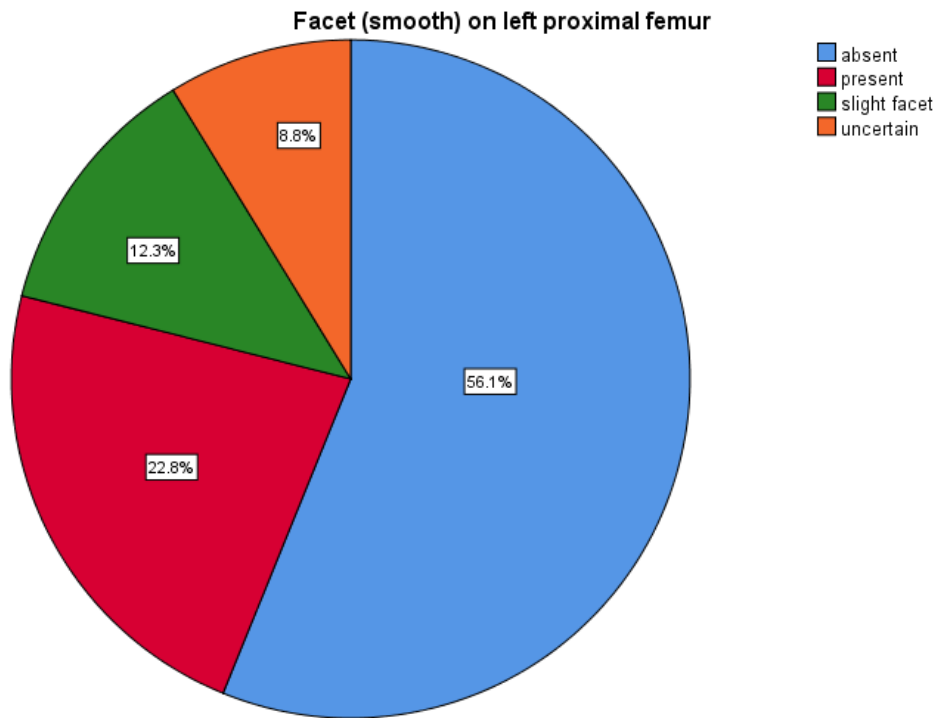


Fig. 19: Prevalence of “Poirier’s Facet” in the male adult population of the Avar cemetery Wien-Csokorgasse (left proximal femur, n = 57)

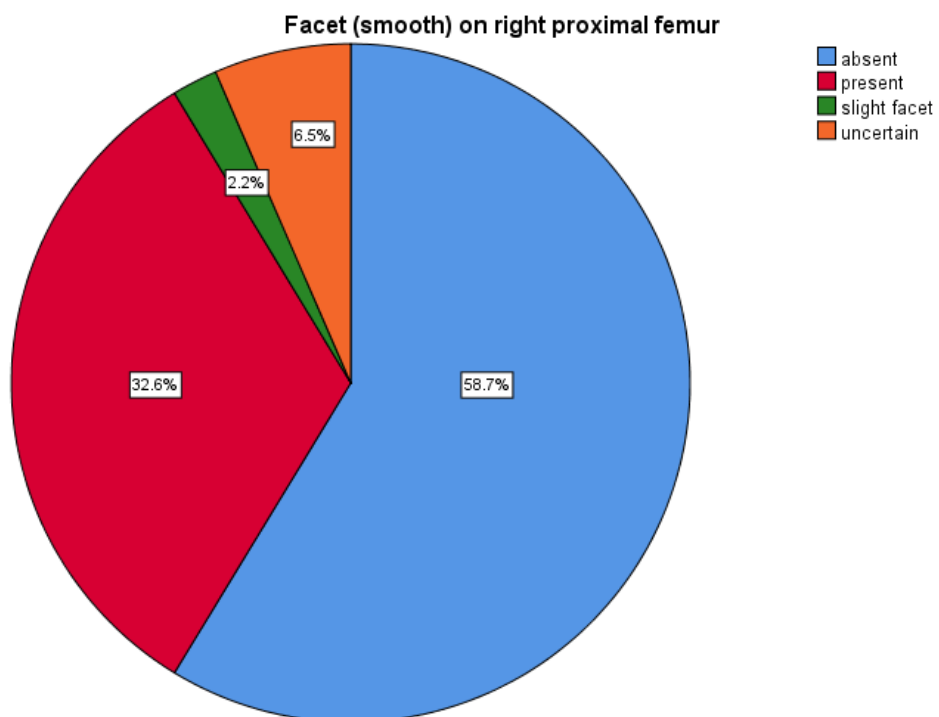


Fig. 20: Prevalence of “Poirier’s Facet” in the male adult population of the Avar cemetery Wien-Csokorgasse (right proximal femur, n = 46)

6.1.1.3 Female adult population (all adult age groups)

Fig. 21 and 22 indicate that a characteristic “Poirier’s Facet” was present in 8.3% (5/60) of the female individuals with an observable left proximal femur and in 8.5% (4/47) of the female individuals with an observable right proximal femur. In addition to this, a “slight facet” was present in 6.7% (4/60) of the female individuals with an observable left proximal femur and in 12.8% (6/47) of the female individuals with an observable right proximal femur. Again, a combination of these two groups would mean that facets would be present in 15.0% (9/60) of the female individuals with an observable left proximal femur and in 21.3% (10/47) of the female individuals with an observable right proximal femur.

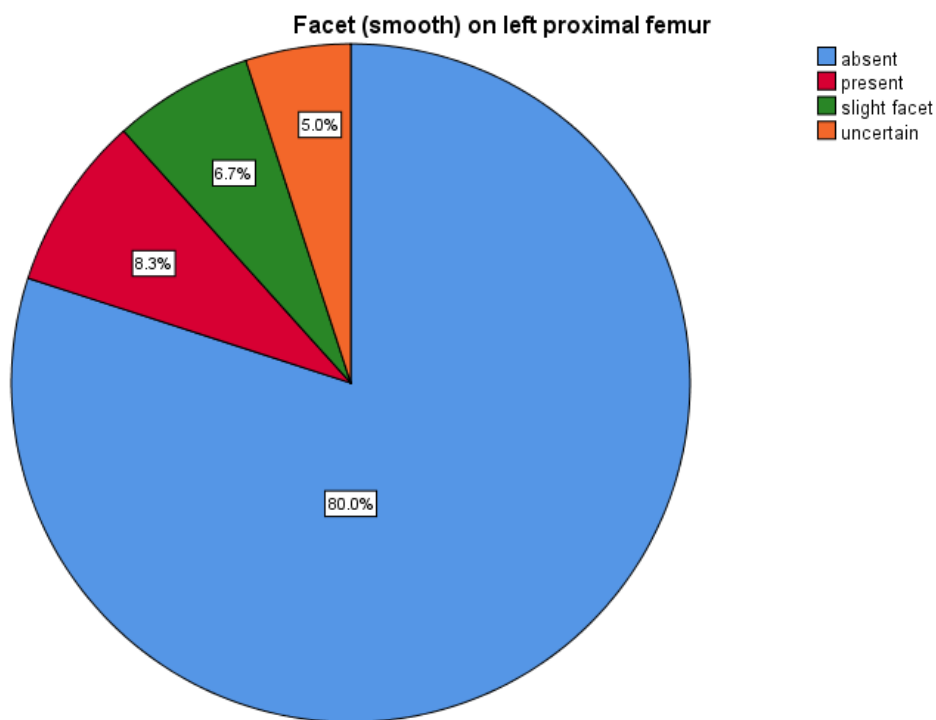


Fig. 21: Prevalence of “Poirier’s Facet” in the female adult population of the Avar cemetery Wien-Csokorgasse (left proximal femur, n = 60)

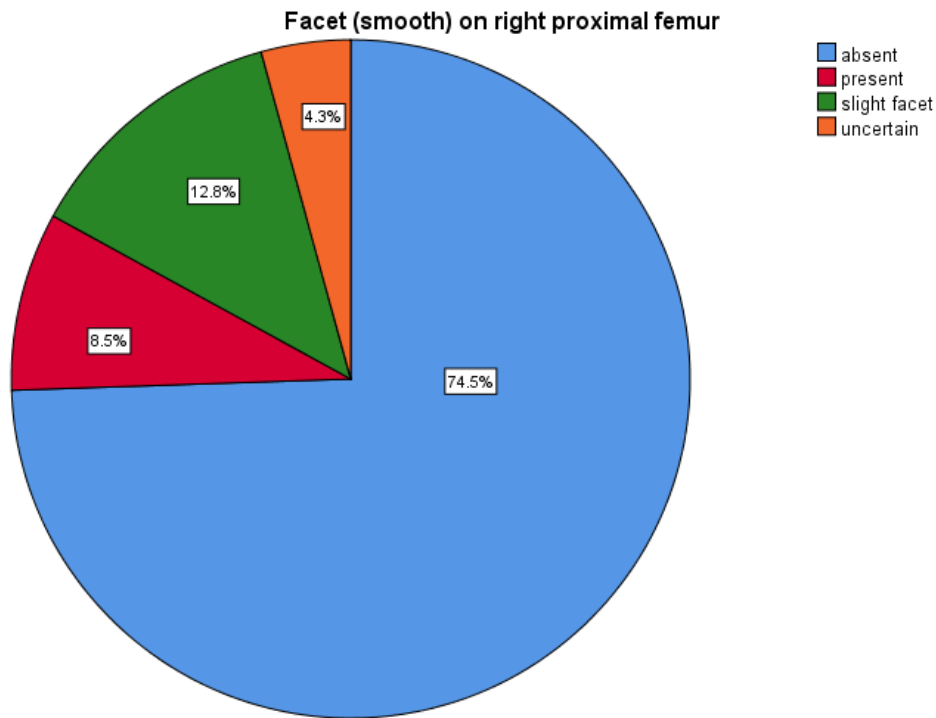


Fig. 22: Prevalence of “Poirier’s Facet” in the female adult population of the Avar cemetery Wien-Csokorgasse (right proximal femur, n = 47)

6.1.2 Plaque

6.1.2.1 Total adult population (male & female, all adult age groups)

Fig. 23 and 24 demonstrate that plaque was present in 48.7% (57/117) of the total adult individuals with an observable left proximal femur and in 45.2% (42/93) of the total adult individuals with an observable right proximal femur.

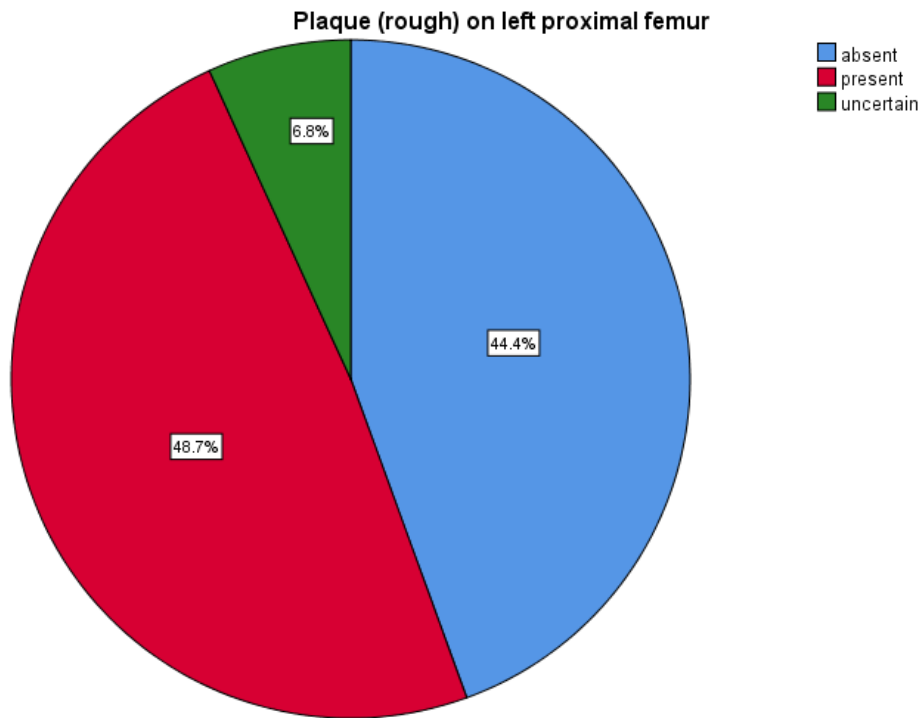


Fig. 23: Prevalence of plaque in the total adult population of the Avar cemetery Wien-Csokorgasse (left proximal femur, n = 117)

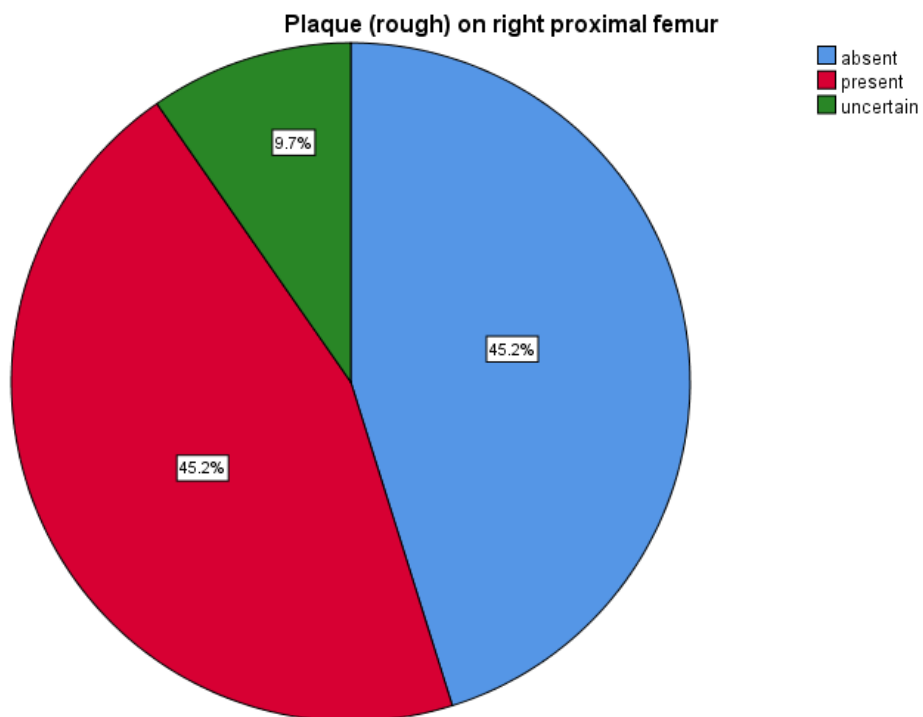


Fig. 24: Prevalence of plaque in the total adult population of the Avar cemetery Wien-Csokorgasse (right proximal femur, n = 93)

As Fig. 25 and 26 indicate, plaque type A was present in 5.1% (6/117) of the total adult individuals with an observable left proximal femur and in 6.5% (6/93) of the total adult individuals with an observable right proximal femur. Fig. 25 and 26 also show that plaque type B was present in 19.7% (23/117) of the total adult individuals with an observable left proximal femur and in 16.1% (15/93) of the total adult individuals with an observable right proximal femur. Similarly, fig. 25 and 26 demonstrate that plaque type C was present in 23.1% (27/117) of the total adult individuals with an observable left proximal femur and in 22.6% (21/93) of the total adult individuals with an observable right proximal femur.

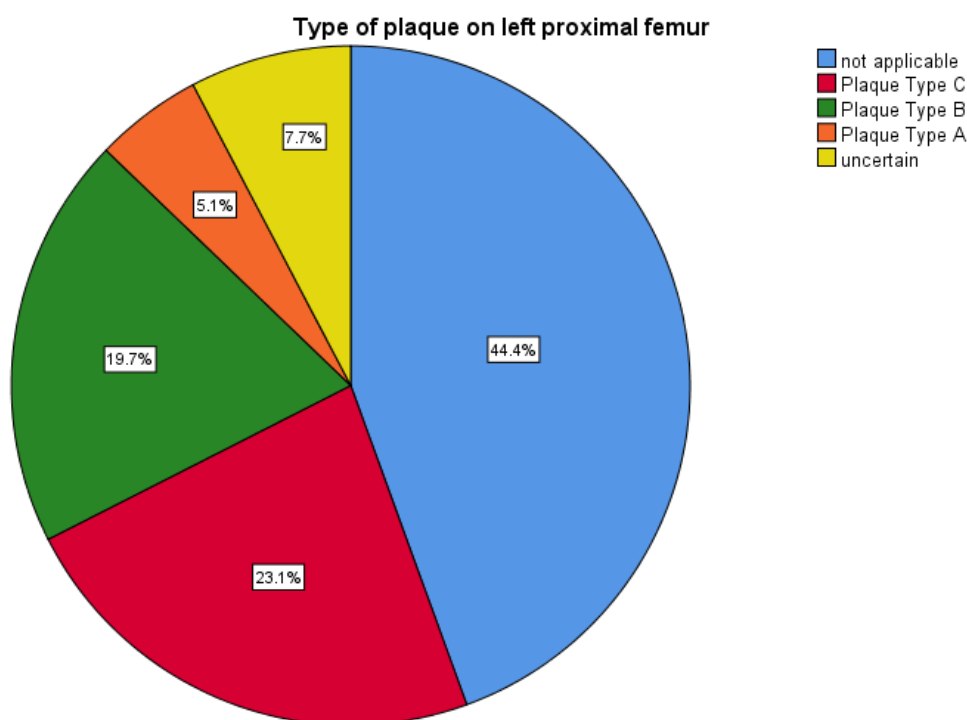


Fig. 25: Prevalence of different types of plaque in the total adult population of the Avar cemetery Wien-Csokorgasse (left proximal femur, n = 117)

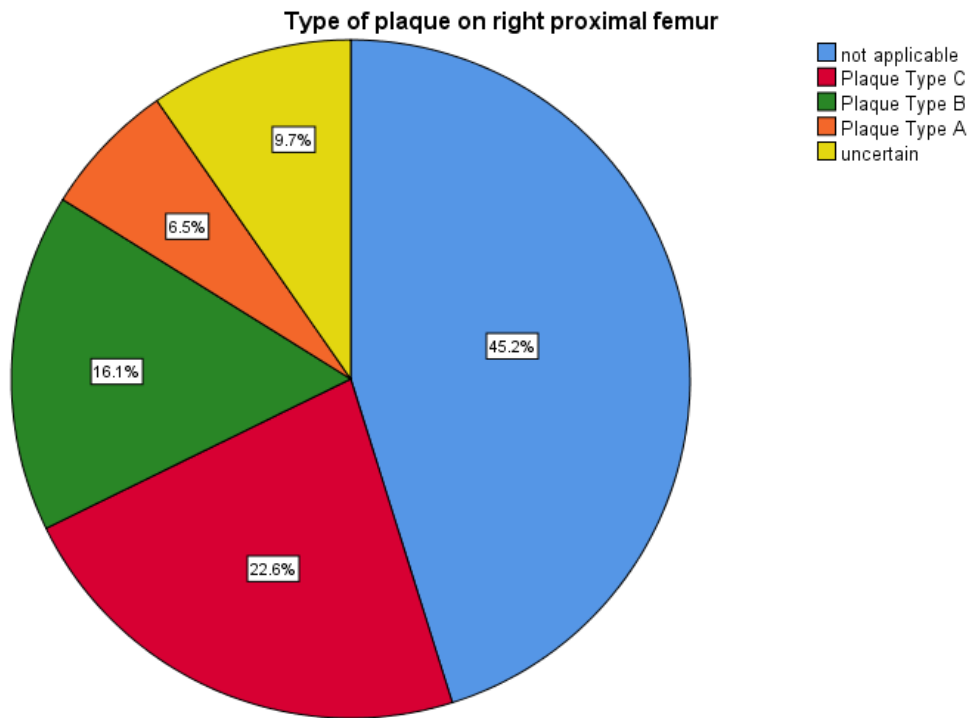


Fig. 26: Prevalence of different types of plaque in the total adult population of the Avar cemetery Wien-Csokorgasse (right proximal femur, n = 93)

6.1.2.2 Male adult population (all adult age groups)

Fig. 27 and 28 show that plaque was present in 50.9 % (29/57) of the adult male individuals with an observable left proximal femur and in 50.0 % (23/46) of the adult male individuals with an observable right proximal femur.

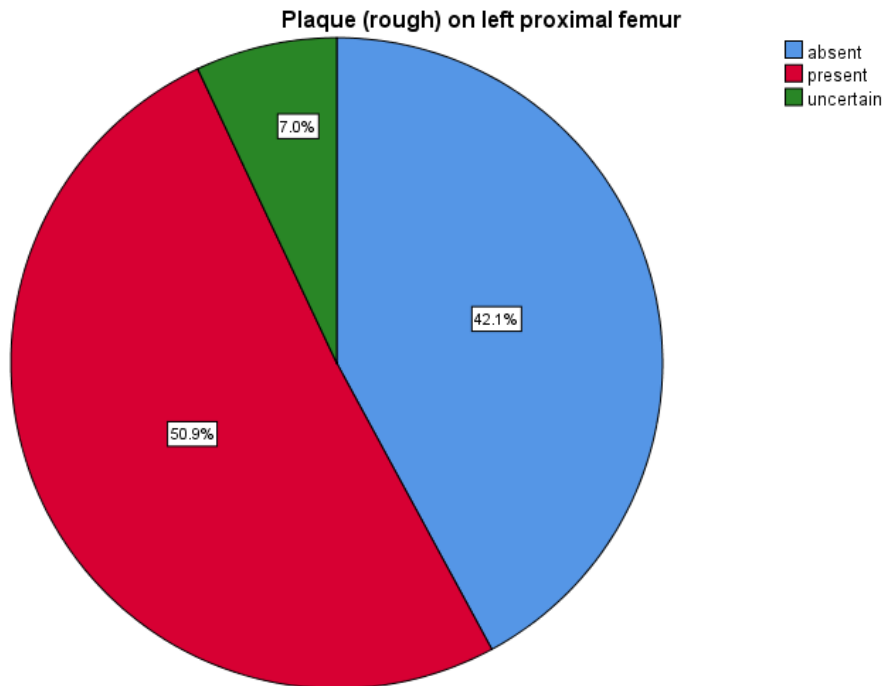


Fig. 27: Prevalence of plaque in the male adult population of the Avar cemetery Wien-Csokorgasse (left proximal femur, n = 57)

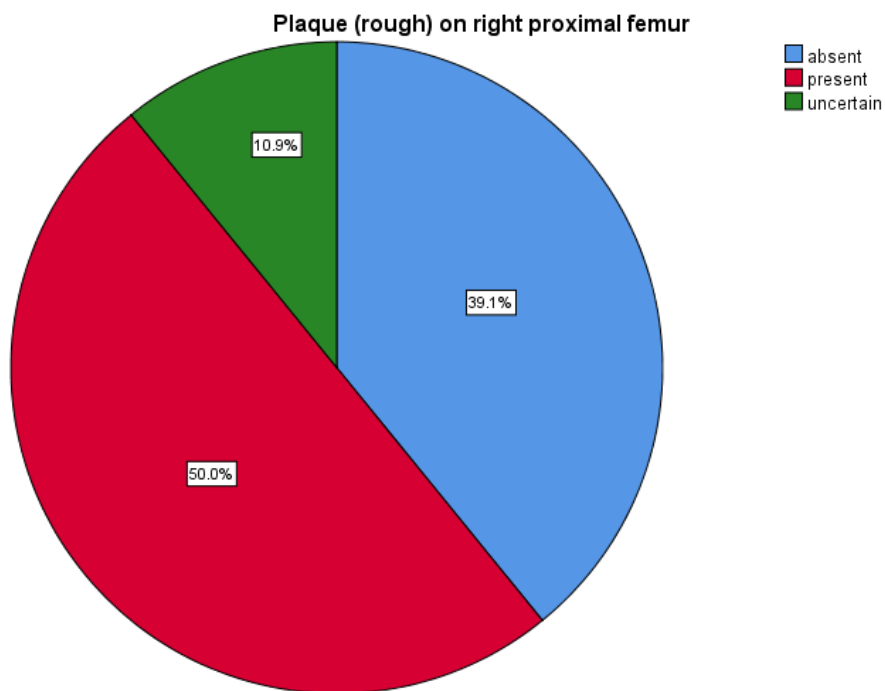


Fig. 28: Prevalence of plaque in the male adult population of the Avar cemetery Wien-Csokorgasse (right proximal femur, n = 46)

As indicated by Fig. 29 and 30, plaque type A was present in 5.3% (3/57) of the adult male individuals with an observable left proximal femur and in 8.7% (4/46) of the adult male individuals with an observable right proximal femur. Similarly, fig. 29 and 30 demonstrate that

plaque type B was present in 22.8% (13/57) of the adult male individuals with an observable left proximal femur and in 17.4% (8/46) of the adult male individuals with an observable right proximal femur. Fig. 29 and 30 also show that plaque type C was present in 19.3% (11/57) of the adult male individuals with an observable left proximal femur and in 21.7% (10/46) of the adult male individuals with an observable right proximal femur.

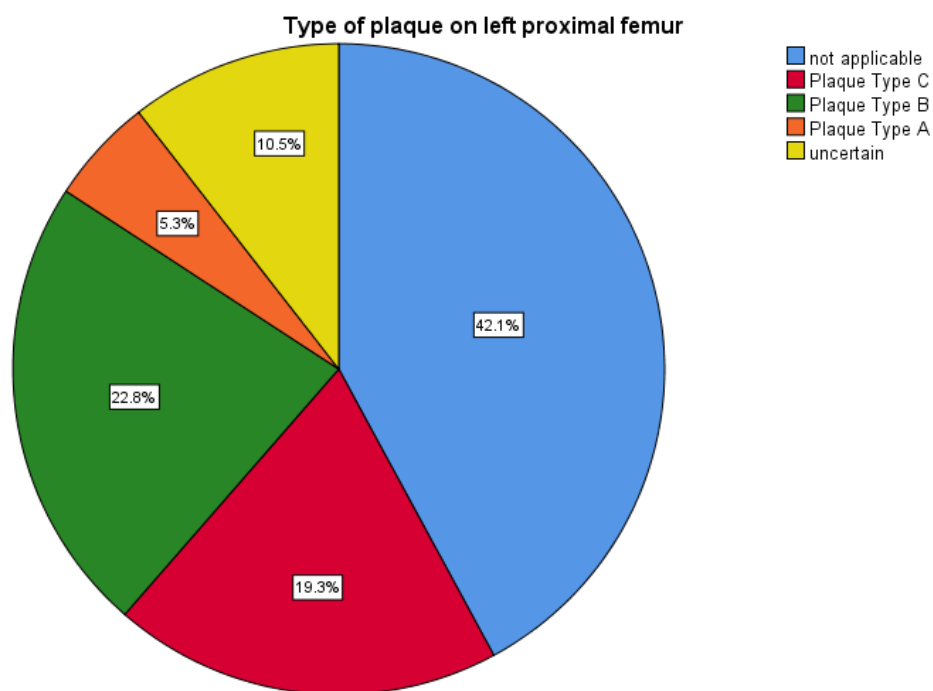


Fig. 29: Prevalence of different types of plaque in the male adult population of the Avar cemetery Wien-Csokorgasse (left proximal femur, n = 57)

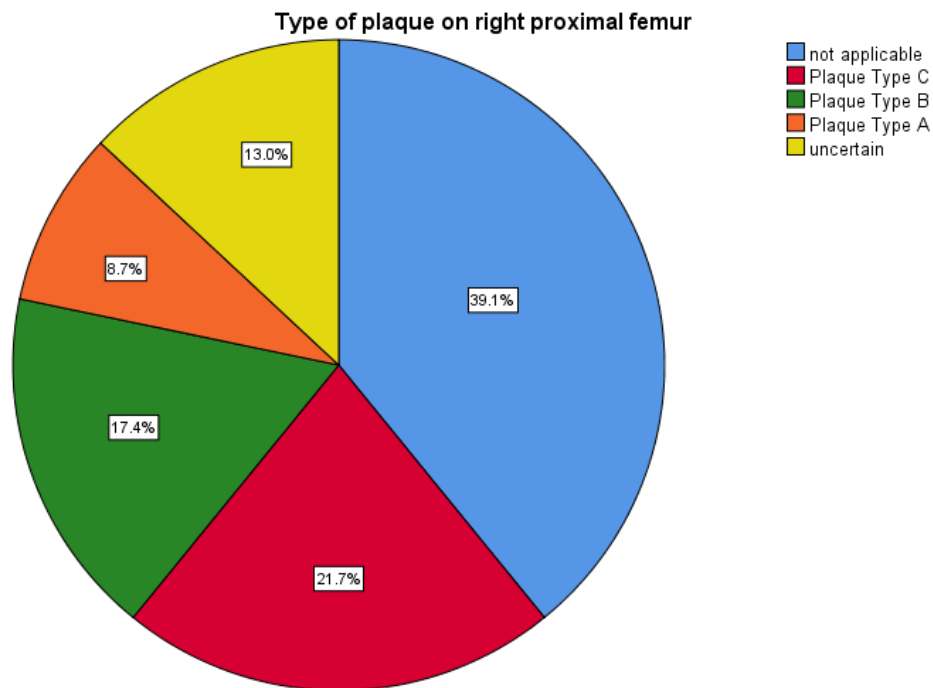


Fig. 30: Prevalence of different types of plaque in the male adult population of the Avar cemetery Wien-Csokorgasse (right proximal femur, n = 46)

6.1.2.3 Female adult population (all adult age groups)

Fig. 31 and 32 show that plaque was present in 46.7 % (28/60) of the adult female individuals with an observable left proximal femur and in 40.4 % (19/47) of the adult female individuals with an observable right proximal femur.

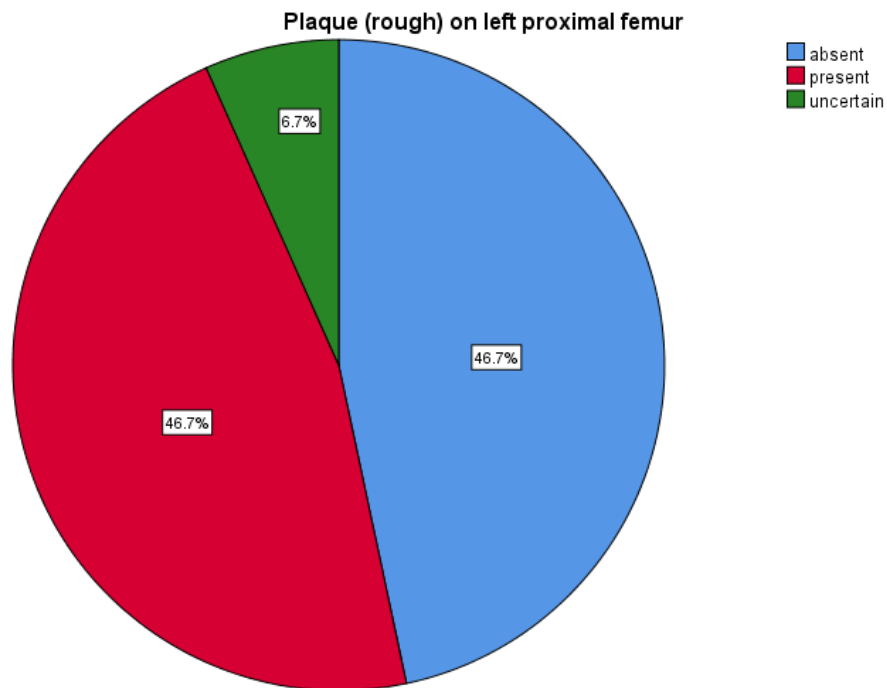


Fig. 31: Prevalence of plaque in the female adult population of the Avar cemetery Wien-Csokorgasse (left proximal femur, n = 60)

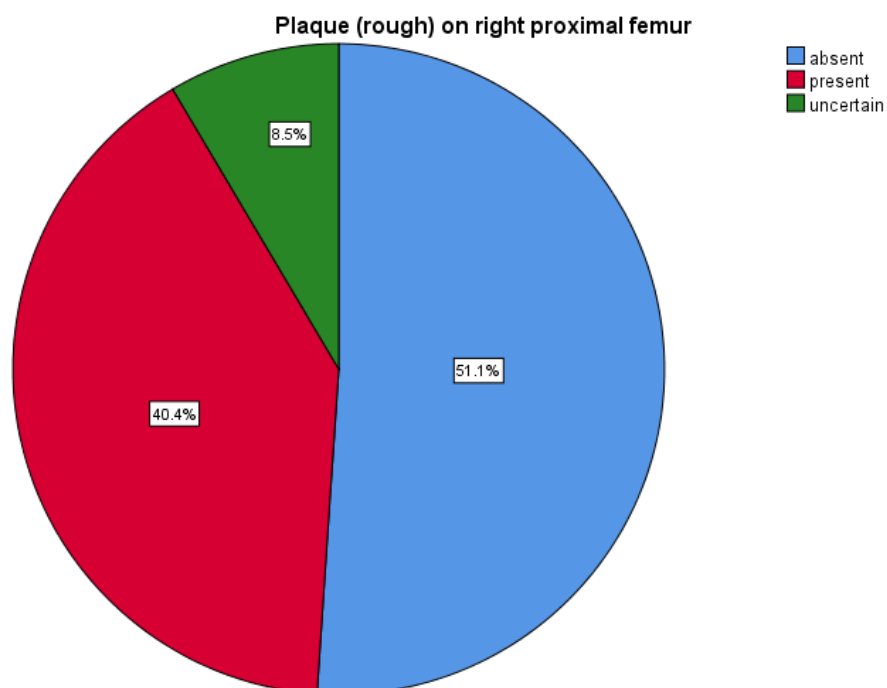


Fig. 32: Prevalence of plaque in the female adult population of the Avar cemetery Wien-Csokorgasse (right proximal femur, n = 47)

Fig. 33 and 34 demonstrate that plaque type A was present in 5.0% (3/60) of the adult female individuals with an observable left proximal femur and in 4.3% (2/47) of the adult female

individuals with an observable right proximal femur. Fig. 33 and 34 also show that Plaque type B was present in 16.7% (10/60) of the adult female individuals with an observable left proximal femur and in 14.9% (7/47) of the adult female individuals with an observable right proximal femur. Similarly, fig. 33 and 34 indicate that plaque type C was present in 26.7% (16/60) of the adult female individuals with an observable left proximal femur and in 23.4% (11/47) of the adult female individuals with an observable right proximal femur.

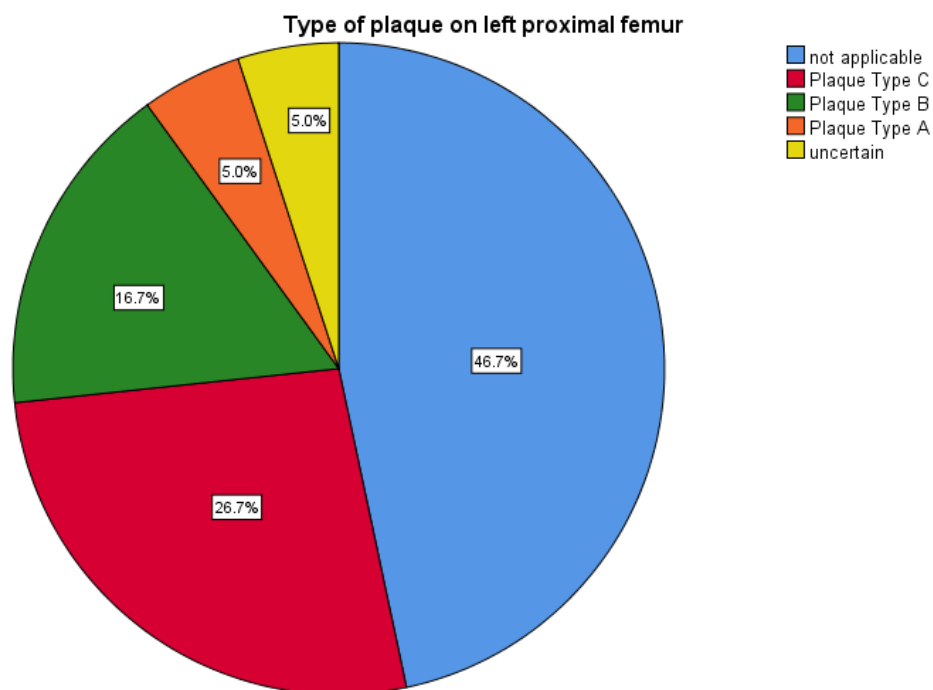


Fig. 33: Prevalence of different types of plaque in the female adult population of the Avar cemetery Wien-Csokorgasse (left proximal femur, n = 60)

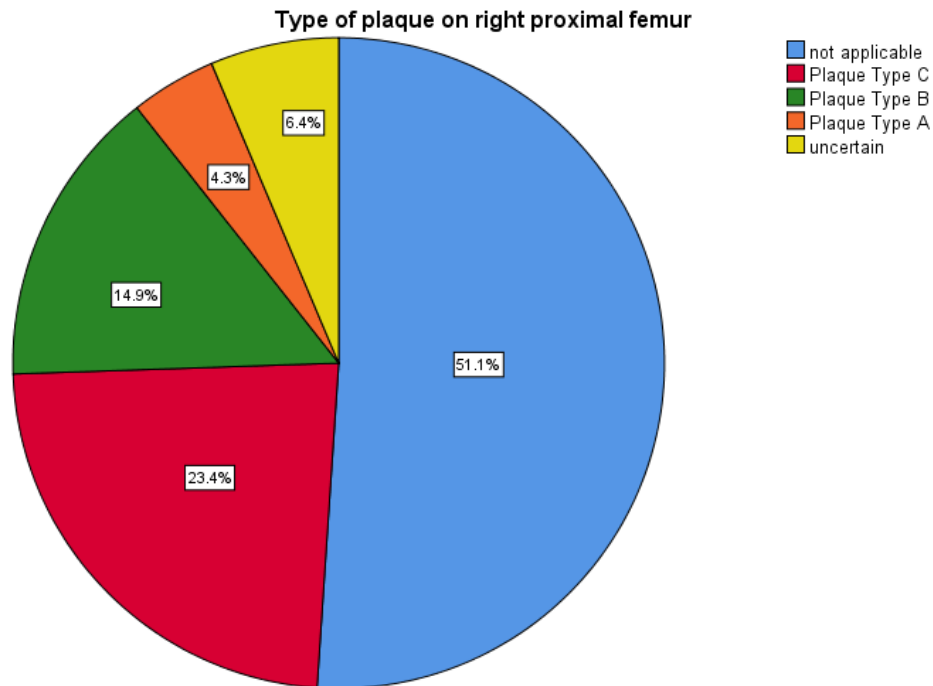


Fig. 34: Prevalence of different types of plaque in the female population of the Avar cemetery Wien-Csokorgasse (right proximal femur, n = 47)

6.1.3 Cribriform changes

6.1.3.1 Total adult population (male & female, all adult age groups)

Fig. 35 and 36 show that cribriform changes type 1 were present in 49.2% (58/117) of the total adult individuals with an observable left proximal femur and in 51.6% (48/93) of the total adult individuals with an observable right proximal femur. Fig. 35 and 36 also indicate that cribriform changes type 2 were present in 24.6% (29/117) of the total adult individuals with an observable left proximal femur and in 19.4% (18/93) of the total adult individuals with an observable right proximal femur.

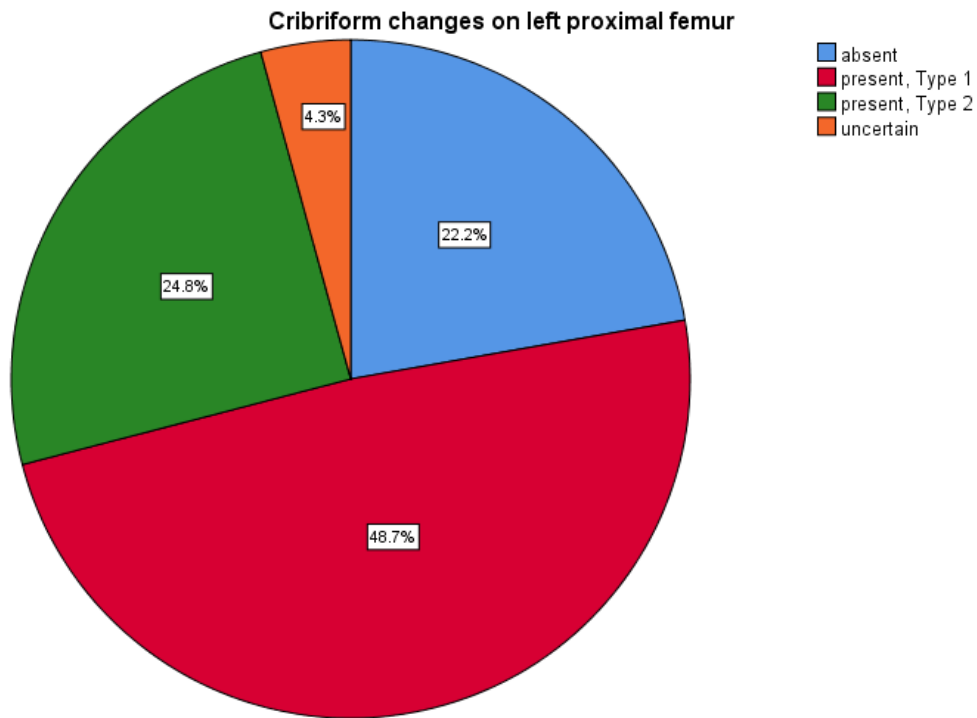


Fig. 35: Prevalence of different types of cribriform changes in the total adult population of the Avar cemetery Wien-Csokorgasse (left proximal femur, n = 117)

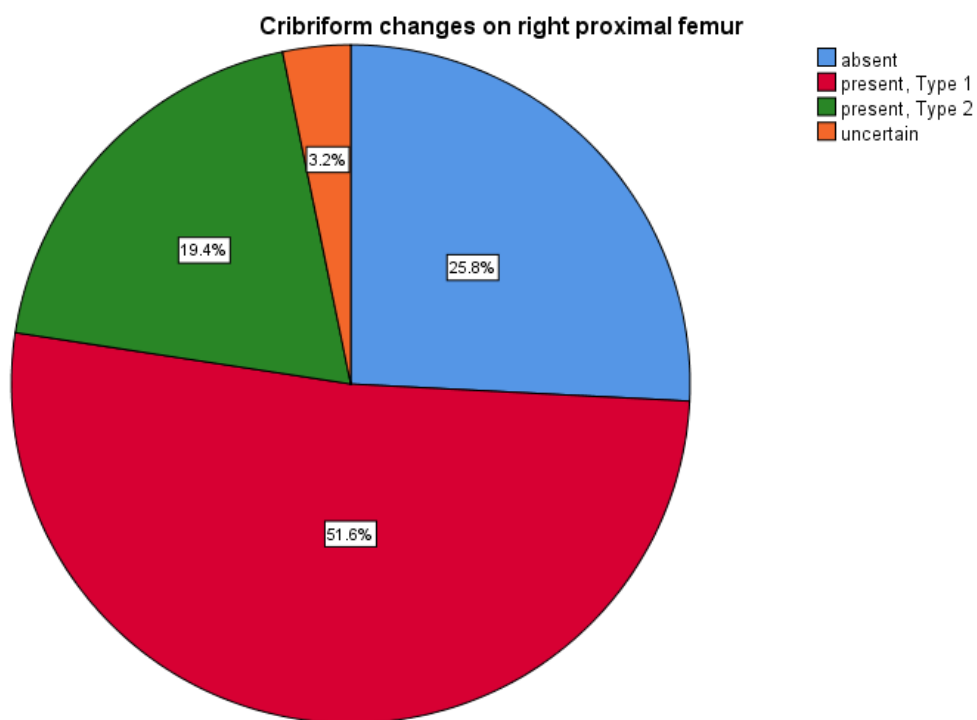


Fig. 36: Prevalence of different types of cribriform changes in the total adult population of the Avar cemetery Wien-Csokorgasse (right proximal femur, n = 93)

6.1.3.2 Male adult population (all adult age groups)

Fig. 37 and 38 demonstrate that cribriform changes type 1 were present in 54.4% (31/57) of the adult male individuals with an observable left proximal femur and in 58.7% (27/46) of the adult male individuals with an observable right proximal femur. Fig. 37 and 38 also indicate that cribriform changes type 2 were present in 10.5% (6/57) of the adult male individuals with an observable left proximal femur and in 6.5% (3/46) of the adult male individuals with an observable right proximal femur.

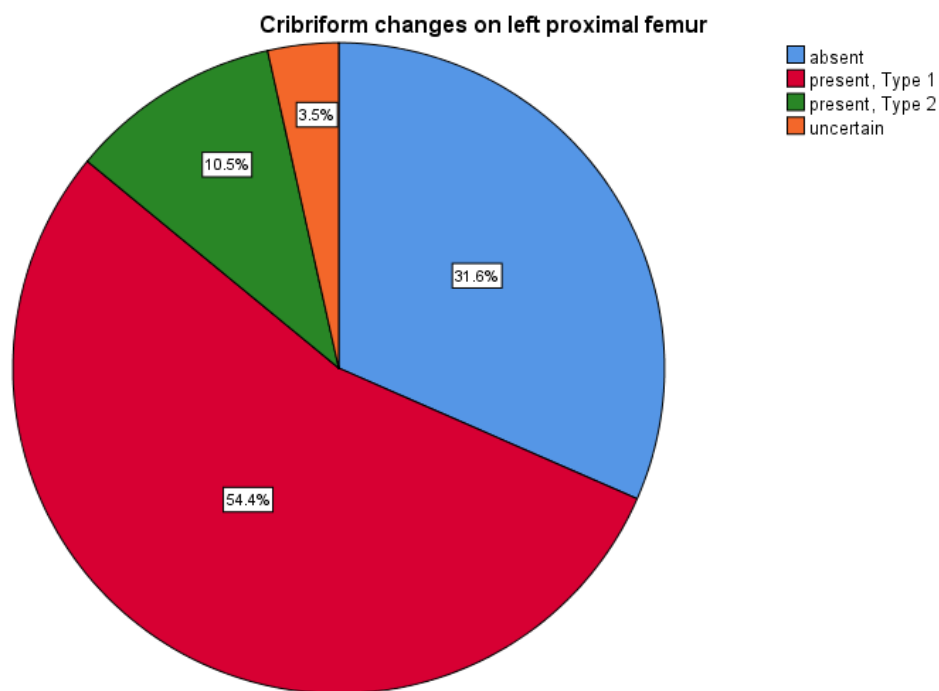


Fig. 37: Prevalence of different types of cribriform changes in the adult male population of the Avar cemetery Wien-Csokorgasse (left proximal femur, n = 57)

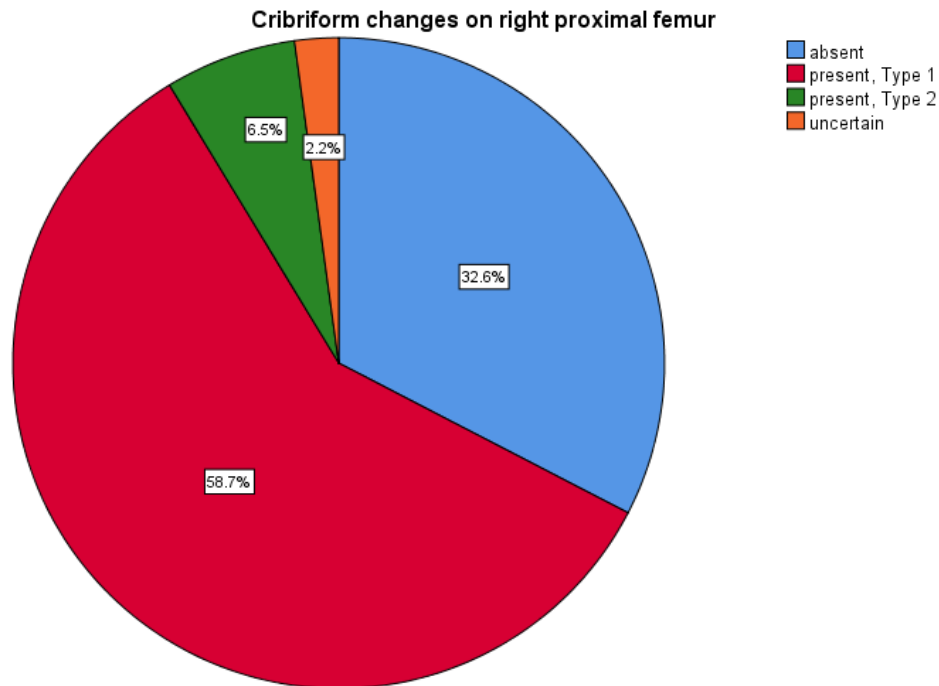


Fig. 38: Prevalence of different types of cribriform changes in the adult male population of the Avar cemetery Wien-Csokorgasse (right proximal femur, n = 46)

6.1.3.3 Female adult population (all adult age groups)

As indicated by Fig. 39 and 40, cribriform changes type 1 were present in 43.3% (26/60) of the total adult female individuals with an observable left proximal femur and in 44.7% (21/47) of the adult female individuals with an observable right proximal femur. Fig. 39 and 40 also show that cribriform changes type 2 were present in 38.3% (23/60) of the adult female individuals with an observable left proximal femur and in 31.9% (15/47) of the adult female individuals with an observable right proximal femur.

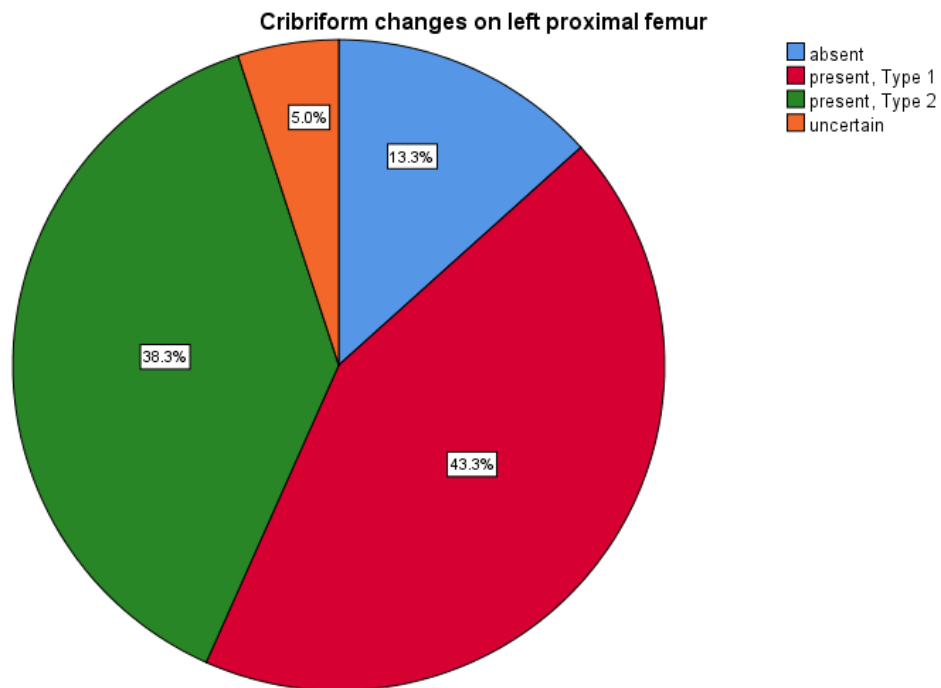


Fig. 39: Prevalence of different types of cribriform changes in the adult female population of the Avar cemetery Wien-Csokorgasse (left proximal femur, n = 60)

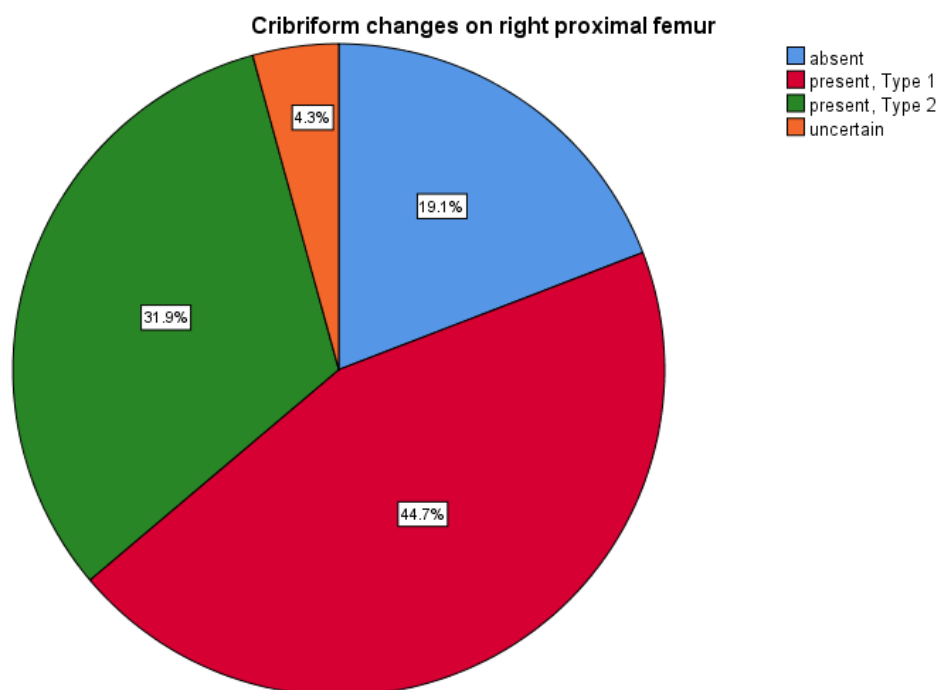


Fig. 40: Prevalence of different types of cribriform changes in the adult female population of the Avar cemetery Wien-Csokorgasse (right proximal femur, n = 47)

6.2 Index of Ovalization of Acetabulum (IOA)

6.2.1 Intra-observer reliability of VEAC and HOAC measurements

Measurements 1 and 2 were taken for all individuals, on the same day, and were utilized to calculate the arithmetic mean VEAC/ HOAC, which was then used to calculate the IOA.

Measurement 3 was taken for 10 randomly selected individuals, in a separate measurement session several months after the session for measurement 1 & 2.

Spearman-Rho Correlation Coefficient	VEAC of left acetabulum	HOAC of left acetabulum	VEAC of right acetabulum	HOAC of right acetabulum
Measurement 1 vs. measurement 2	0.999 (N = 78; $p = 0.000$)	0.998 (N = 78; $p = 0.000$)	0.998 (N = 80; $p = 0.000$)	0.997 (N = 80; $p = 0.000$)
Arithmetic mean of measurement 1 and 2 vs. measurement 3	0.997 (N = 10; $p = 0.000$)	1.000 (N = 10; $p = 0.000$)	0.976 (N = 10; $p = 0.000$)	0.985 (N = 10; $p = 0.000$)

Table 1: Overview of intra-observer reliability of VEAC and HOAC measurements

Table 1 shows that the correlation coefficient is in all cases well above 0.900, which can be considered satisfactory.

The correlation coefficient of the randomly selected control measurements taken in a separate session (measurement 3; $n = 10$) with the average of the same-day measurements (measurement 1 and 2) is in the range of 1.000 to 0.976.

Although the range is larger, this is not much lower than the correlation coefficient for measurements 1 and 2, which is 0.999 to 0.997.

6.2.2 Associations between the characteristic traits of the “Horse Riding Syndrome” in the total adult population (Hypothesis 1)

Hypothesis 1

There are associations between different characteristics of the “Horse Riding Syndrome” – *partly verified*.

Sub-hypothesis 1a

The mean Index of Ovalization of Acetabulum (IOA) is significantly higher for adults with a “Poiriers Facet” on the same side *Os femoris* than for adults without this trait – *partly verified*.

Fig. 41 and 42 demonstrate that for both the left and the right acetabulum, the mean Index of Ovalization of Acetabulum (IOA) is higher for adults with a “Poirier’s Facet” on the same-side proximal femur than for those without a “Poirier’s Facet”.

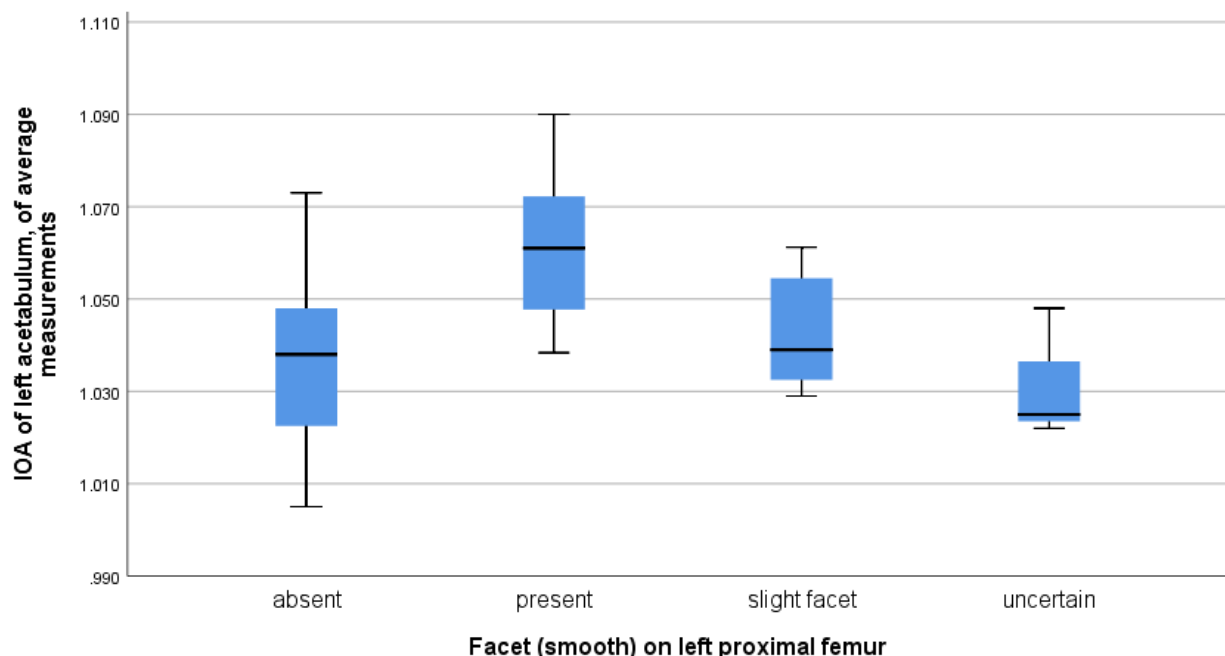


Fig. 41: Mean Index of Ovalization (IOA) of the left acetabulum in individuals without/ with „Poirier’s Facet“ on the left proximal femur in the total adult population of the Avar cemetery Wien-Csokorgasse (n = 117)

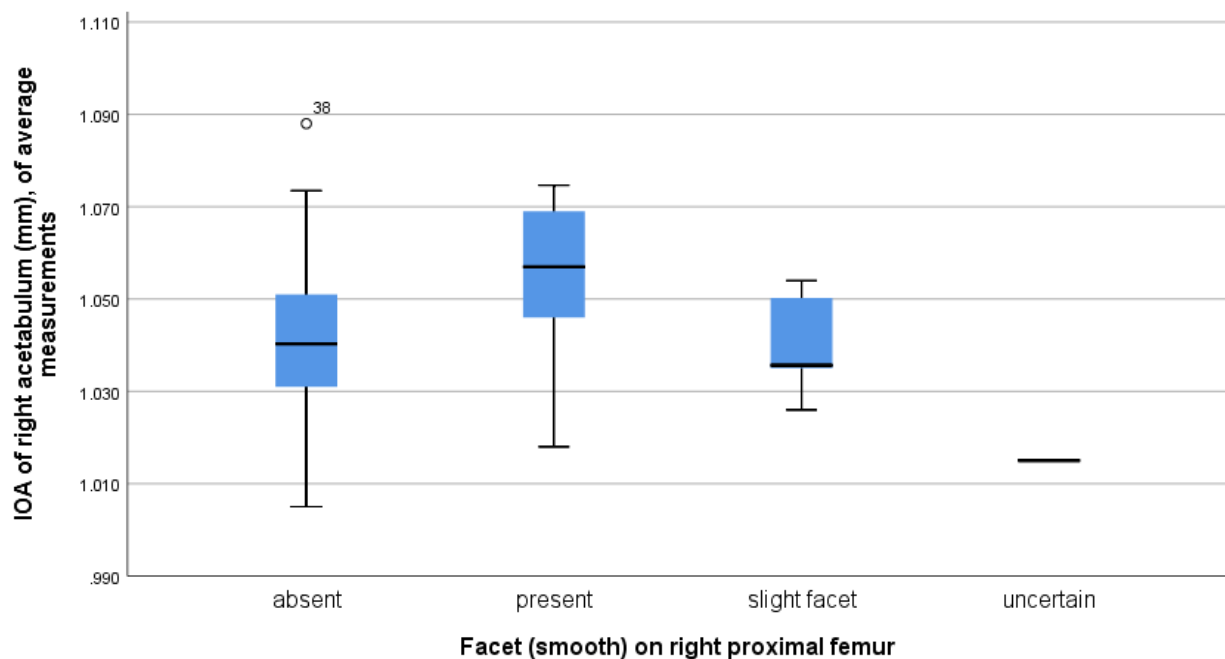


Fig. 42: Mean Index of Ovalization (IOA) of the right acetabulum in individuals without/ with „Poirier’s Facet“ on the right proximal femur in the total adult population of the Avar cemetery Wien-Csokorgasse (n = 93)

This observation suggests an association between these two characteristics of the “horse riding syndrom” – “Poirier’s Facet” and the “Ovalization” (= vertical elongation) of the Acetabulum.

This possible association was tested using the independent-sample T-test:

The mean Index of Ovalization of Acetabulum (IOA) for the left acetabulum was much higher for adults (male and female together; all adult age groups) with a Poiriers Facet on the left proximal femur ($M = 1.061$, $SD = 0.015$, $n = 14$) than for those without a Poiriers Facet on the left proximal femur ($M = 1.037$, $SD = 0.019$, $n = 47$). The results of the independent-sample T-test were highly significant ($t(59) = -4.332$, $p = 0.000$).

The mean Index of Ovalization of Acetabulum (IOA) for the right acetabulum was also higher for adults with a Poiriers Facet on the right proximal femur ($M = 1.053$, $SD = 0.018$, $n = 10$) than for those without a Poiriers Facet on the right proximal femur ($M = 1.042$, $SD = 0.020$, $n = 29$). However, the results of the independent-sample T-test were not significant ($t(37) = -1.489$, $p = 0.145$).

Hence, sub-hypothesis 1a was partly verified: It can be accepted for the left side only, while for the right side the null-hypothesis must be accepted.

Sub-hypothesis 1b

The mean Index of Ovalization of Acetabulum (IOA) is significantly higher for adults with pronounced gluteal entheses on the same side *Os coxae* than than for adults without this trait – verified.

The T-test was also used to identify a possible association between the vertical elongation of the acetabulum and the presence of pronounced gluteal entheses on the same *Os coxae*:

The mean Index of Ovalization of Acetabulum (IOA) for the left acetabulum was clearly higher for adults with pronounced gluteal entheses on the left *Os coxae* ($M = 1.045$, $SD = 0.020$, $n = 54$) than for those without pronounced gluteal entheses on the left *Os coxae* ($M = 1.033$, $SD = 0.015$, $n = 17$). The results of the independent-sample T-test were significant ($t(69) = -2.221$, $p = 0.030$).

Similarly, the mean Index of Ovalization of Acetabulum (IOA) for the right acetabulum was noticeably higher for adults with pronounced gluteal entheses on the right *Os coxae* ($M = 1.046$, $SD = 0.021$, $n = 57$) than for those without pronounced gluteal entheses on the right *Os coxae* ($M = 1.031$, $SD = 0.016$, $n = 16$). The independent-sample T-test was also significant ($t(71) = -2.596$, $p = 0.011$).

Thus, sub-hypothesis 1b was verified for both sides.

Sub-hypothesis 1c

The mean Index of Ovalization of Acetabulum (IOA) is significantly higher for adults with a pronounced *Linea aspera* on the (same side) *Os femoris* than for than for adults without this trait – falsified.

The mean Index of Ovalization of Acetabulum (IOA) for the left acetabulum was only minimally higher for adults (male and female; all adult age groups) with a pronounced Linea Aspera on

the left proximal femur ($M = 1.044$, $SD = 0.020$, $n = 57$) than for those without a pronounced Linea Aspera on the left proximal femur ($M = 1.042$, $SD = 0.018$, $n = 6$). Clearly, the results of the independent-sample T-test were not significant ($t(61) = -0.216$, $p = 0.830$).

The mean Index of Ovalization of Acetabulum (IOA) for the right acetabulum was higher for adults with a pronounced Linea Aspera on the right proximal femur ($M = 1.048$, $SD = 0.021$, $n = 40$) than for those without a pronounced Linea Aspera on the right proximal femur ($M = 1.033$, $SD = 0.006$, $n = 3$). However, the results of the independent-sample T-test were not significant ($t(41) = -1.215$, $p = 0.231$).

Thus, sub-hypothesis 1c was falsified for both sides and the null-hypothesis must be accepted.

Sub-hypothesis 1d

The mean Index of Ovalization of Acetabulum (IOA) is significantly higher for adults with a curved *Trochanter major* on the (same side) *Os femoris* than for adults without this trait – falsified.

The mean Index of Ovalization of Acetabulum (IOA) for the left acetabulum was only slightly higher for adults (male and female; all adult age groups) with a curved *Trochanter major* on the left proximal femur ($M = 1.044$, $SD = 0.020$, $n = 42$) than for those without a curved *Trochanter major* on the left proximal femur ($M = 1.040$, $SD = 0.021$, $n = 14$). Clearly, the results of the independent-sample T-test were not significant ($t(54) = -0.667$, $p = 0.508$).

The mean Index of Ovalization of Acetabulum (IOA) for the right acetabulum was not higher for adults with a curved *Trochanter major* on the right proximal femur ($M = 1.045$, $SD = 0.018$, $n = 16$) than for those without a curved *Trochanter major* on the right proximal femur ($M = 1.045$, $SD = 0.017$, $n = 17$). In this case, the mean values were similar for the two groups with presence/ absence of this particular trait. Hence, the results of the independent-sample T-test were not significant ($t(31) = -0.082$, $p = 0.935$).

Therefore, sub-hypothesis 1d was falsified for both sides and the null-hypothesis must be accepted.

Sub-hypothesis 1e

The mean Index of Ovalization of Acetabulum (IOA) is significantly higher for adults with exostosis (“spicules”) in the *Fossa trochanterica* on the (same side) *Os femoris* than for adults without this trait – falsified.

The mean Index of Ovalization of Acetabulum (IOA) for the left acetabulum was not higher for adults (male and female; all adult age groups) with an exostosis in the *Fossa trochanterica* on the left proximal femur ($M = 1.041$, $SD = 0.020$, $n = 46$) than for those without an exostosis in the *Fossa trochanterica* on the left proximal femur ($M = 1.041$, $SD = 0.017$, $n = 21$). In fact, the mean values for the two groups were identical. Therefore, the results of the independent-sample T-test were not significant ($t(65) = -0.162$, $p = 0.871$).

The mean Index of Ovalization of Acetabulum (IOA) for the right acetabulum was noticeably higher for adults with a curved *Trochanter major* on the right proximal femur ($M = 1.046$, $SD = 0.019$, $n = 22$) than for those without a curved *Trochanter major* on the right proximal femur ($M = 1.039$, $SD = 0.016$, $n = 17$). However, the results of the independent-sample T-test were not significant ($t(37) = -1.349$, $p = 0.186$).

Hence, sub-hypothesis 1e was falsified for both sides and the null-hypothesis must be accepted.

Sub-hypothesis 1f

The mean Index of Ovalization of Acetabulum (IOA) is significantly higher for adults with exostosis (“spicules”) in the *Fovea capitis* on the (same side) *Os femoris* than for adults without this trait – falsified.

The mean Index of Ovalization of Acetabulum (IOA) for the left acetabulum was only minimally higher for adults (male and female; all adult age groups) with an exostosis of the *Fovea capitis* on the left proximal femur ($M = 1.045$, $SD = 0.021$, $n = 26$) than for those without an exostosis of the *Fovea capitis* on the left proximal femur ($M = 1.043$, $SD = 0.018$, $n = 37$). Clearly, the results of the independent-sample T-test were not significant ($t(61) = -0.509$, $p = 0.613$).

The mean Index of Ovalization of Acetabulum (IOA) for the right acetabulum was not higher for adults with an exostosis of the *Fovea capitis* on the right proximal femur ($M = 1.042$, $SD = 0.023$, $n = 20$) than for those without an exostosis of the *Fovea capitis* on the right proximal femur ($M = 1.044$, $SD = 0.019$, $n = 24$). In fact, in the group with absence of this trait the mean IOA was even minimally higher than in the group with presence of the trait. The results of the T-test were not significant ($t(42) = 0.289$, $p = 0.774$).

Thus, sub-hypothesis 1f was falsified for both sides and the null-hypothesis must be accepted.

Sub-hypothesis 1g

The mean Index of Ovalization of Acetabulum (IOA) is significantly higher for adults with osteoarthritis on the upper outline of the patellar surface on the (same side) *Os femoris* than for adults without this trait – falsified.

The mean Index of Ovalization of Acetabulum (IOA) for the left acetabulum was noticeably higher for adults (male and female; all adult age groups) with osteoarthritis along the upper edge of the patellar surface of the left proximal femur ($M = 1.044$, $SD = 0.017$, $n = 38$) than for those without osteoarthritis along the upper edge of the patellar surface of the left proximal femur ($M = 1.037$, $SD = 0.020$, $n = 17$). However, the results of the independent-sample T-test were not significant ($t(53) = -1.288$, $p = 0.203$).

The mean Index of Ovalization of Acetabulum (IOA) for the right acetabulum was clearly higher for adults with osteoarthritis along the upper edge of the patellar surface of the right proximal femur ($M = 1.050$, $SD = 0.019$, $n = 20$) than for those without osteoarthritis along the upper edge of the patellar surface of the right proximal femur ($M = 1.039$, $SD = 0.018$, $n = 14$). However, the results of the independent-sample T-test were not significant ($t(32) = -1.622$, $p = 0.115$).

Thus, sub-hypothesis 1g was falsified for both sides and the null-hypothesis must be accepted.

Sub-hypothesis 1h

In the total adult population, there is a positive correlation between the IOA and the entheses robusticity scores of the lower limbs of an individual – *partly verified*.

In the total adult population, the mean IOA of the left acetabulum and the mean entheses robusticity score for the left lower limb are significantly, weakly positively correlated $r(76) = 0.243, p = 0.033$.

In the total adult population, the mean IOA of the left acetabulum and the mean entheses robusticity score for the right lower limb are highly significantly, moderately positively correlated $r(70) = 0.326, p = 0.005$.

In the total adult population, the mean IOA of the right acetabulum and the mean entheses robusticity score for the left lower limb are also weakly positively correlated, but this correlation is not significant, $r(78) = 0.136, p = 0.234$.

In the total adult population, the mean IOA of the right acetabulum and the mean entheses robusticity score for the right lower limb are also weakly positively correlated, but this correlation is not significant, $r(75) = 0.164, p = 0.156$.

Hence, hypothesis 1h was partially verified, for the left side only: For the left acetabulum and both lower limbs, significant positive, weak to moderate correlations between the Index of Ovalization of Acetabulum (IOA) and lower limb entheses robusticity score suggest an association between these two traits (traits 1 and 3.2). However, for the right acetabulum and both lower limbs, the null hypothesis must be accepted.

In conclusion, Hypothesis 1 is partially true: While sub-hypothesis 1b was verified for both sides, sub-hypotheses 1a and 1h were both partly verified (for the left side only).

On the other hand, sub-hypotheses 1c, 1d, 1e, 1f and 1g were shown to be false for both the left and the right side in the total adult population. Thus, for the five other non-metric traits of the “horse riding syndrome” which were taken into consideration as part of this study, the differences regarding the mean Index of Ovalization of Acetabulum (IOA) between adults with

presence/ absence of the trait in question were relatively small and/ or the independent-sample T-test between these groups was not significant. Hence, for the five traits in question, the hypothesis that there is an association with the ovalization of the acetabulum could not be verified. Hence, the null hypothesis must be accepted for each of these five traits. Therefore, the results suggest that – at least in the sample investigated in this thesis – the five traits in question cannot be regarded as specific characteristics of the “horse riding syndrome”. However, this could be due to the small size of the sample, as a consequence of the insufficient state of preservation of the osteological material in question.

6.2.3 Differences between the sexes (Hypothesis 2)

Hypothesis 2

The prevalence of one or more characteristic traits of the “Horse Riding Syndrome” is significantly higher in the adult male population than in the adult female population buried in the Avar cemetery Wien-Csokorgasse – *verified*.

Sub-hypothesis 2a

The prevalence of “Poiriers Facet” is significantly higher in the adult male population than in the adult female population buried in the Avar cemetery Wien-Csokorgasse – *verified*.

Sub-hypothesis 2b

The average Index of Ovalization of Acetabulum (IOA) is significantly higher in the adult male population than in the adult female population buried in the Avar cemetery Wien-Csokorgasse - *verified*.

The Chi-square test was used to investigate the relation between the sex of an adult individual in this Avar population and the presence of “Poiriers Facet” in the femoral head-neck junction. The relation between these variables was significant for both the left proximal femur $\chi^2(3, n = 117) = 8.002, p = 0.046$ and for the right proximal femur $\chi^2(3, n = 93) = 11.163, p = 0.011$.

Hence, hypothesis 2a was verified for both the left and the right side. In the Avar population in question, adult men were more likely to have a “Poiriers Facet” in the femoral head-neck junction than adult women.

Figs. 43 and 44 illustrate that in the adult population (= all adult age groups and all chronological phases) the mean IOA of the left acetabulum and the mean IOA of the right acetabulum is noticeably higher for males than for females.

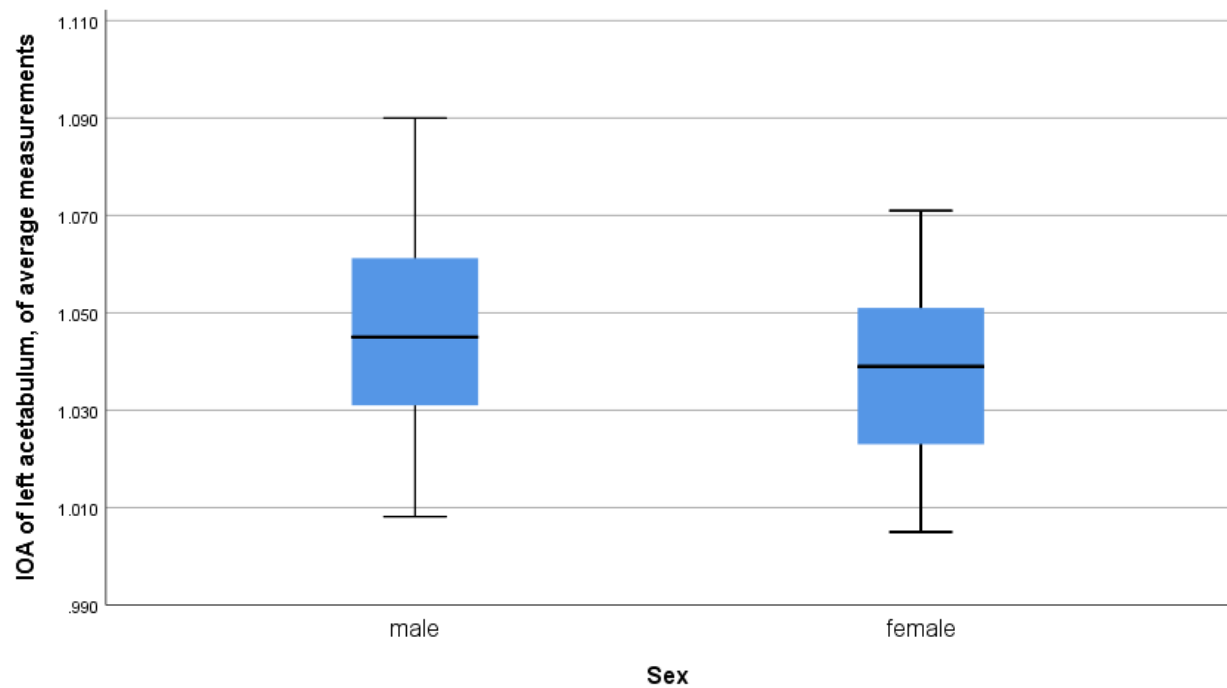


Fig. 43: Mean Index of Ovalization (IOA) of the left acetabulum in adult males and adult females of the Avar cemetery Wien-Csokorgasse (n = 78)

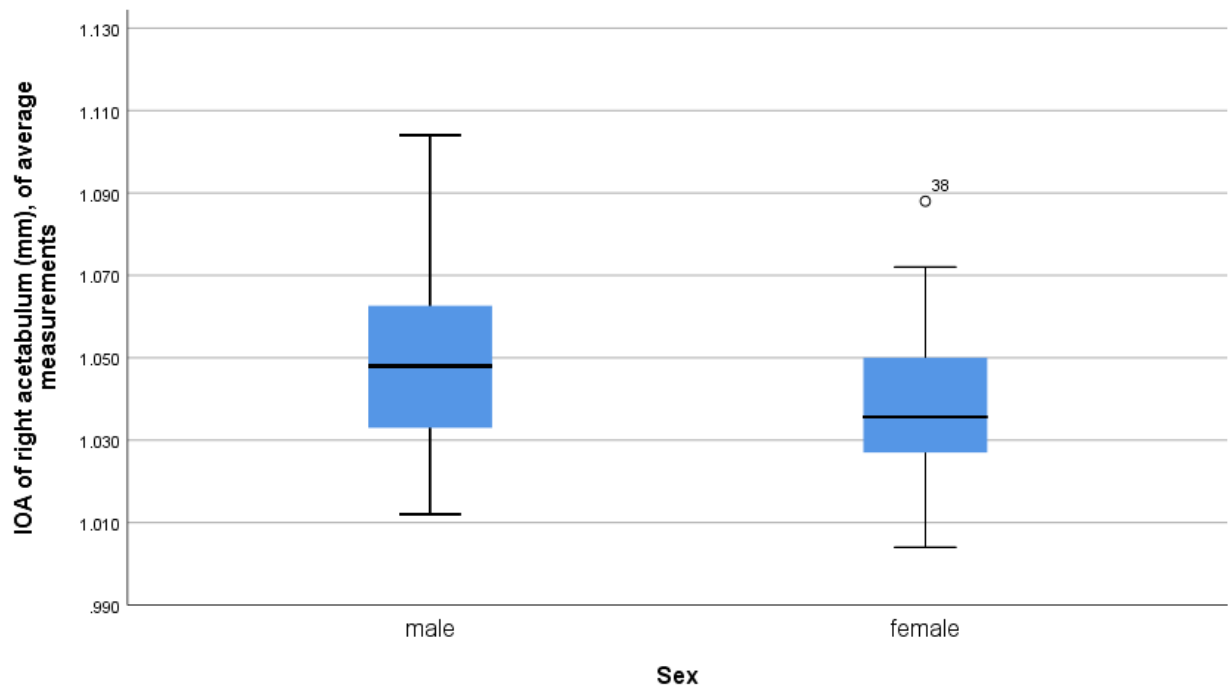


Fig. 44: Mean Index of Ovalization (IOA) of the right acetabulum in adult males and adult females of the Avar cemetery Wien-Csokorgasse (n = 80)

Hypothesis 2b was tested using the independent-sample T-test. For the left acetabulum, the mean IOA was higher in adult males ($M = 1.047$, $SD = 0.020$, $n = 37$) than in adult females ($M = 1.038$, $SD = 0.018$, $n = 41$). The results of the independent-sample T-test were significant, $t(76) = 2.121$, $p = 0.037$.

For the right acetabulum, the mean IOA was higher in adult males ($M = 1.048$, $SD = 0.021$, $n = 39$) than in adult females ($M = 1.037$, $SD = 0.019$, $n = 41$). The results of the independent-sample T-test were significant, $t(78) = 2.386$, $p = 0.019$.

Hence, hypothesis 2b is true for both the left and the right side.

6.2.4 Chronological differences (Hypothesis 3)

Hypothesis 3

The prevalence of one or more characteristic traits of the “Horse Riding Syndrome” is significantly higher in the early phases than in the later phases of the Avar cemetery Wien-

Csokorgasse (= *falsified*) and this difference could be especially relevant for the female adult population (= *partly verified*).

Sub-hypothesis 3a

The average Index of Ovalization of Acetabulum (IOA) in the total adult population is significantly higher in the early phases than in the later phases of the Avar cemetery Wien-Csokorgasse – *falsified*.

Sub-hypothesis 3b

The average Index of Ovalization of Acetabulum (IOA) in the adult female population is significantly higher in the early phases than in the later phases of the Avar cemetery Wien-Csokorgasse – *partly verified*.

Fig. 45 demonstrates that in the total adult population, the mean IOA of the left acetabulum was slightly higher in the early phase ($M = 1.048$, $SD = 0.016$, $n = 21$) than in the middle phase ($M = 1.039$, $SD = 0.020$, $n = 28$) and the late phase ($M = 1.043$, $SD = 0.021$, $n = 27$).

However, as illustrated by fig. 46, for the right acetabulum in the total adult population, there are no substantial differences in mean IOA between the early phase ($M = 1.043$, $SD = 0.015$, $n = 22$), the middle phase ($M = 1.045$, $SD = 0.023$, $n = 27$) and the late phase ($M = 1.041$, $SD = 0.023$, $n = 29$).

The results of the one-way ANOVA are in accordance with these observations:

In the total adult population, the mean index of acetabulum (IOA) of the left acetabulum did not differ significantly between the three chronological phases (early/ middle/ late) of the cemetery, $F(2, 73) = 1.307$, $p = 0.277$.

Similarly, in the total adult population, the mean index of acetabulum (IOA) of the right acetabulum did not differ significantly between the three chronological phases (early/ middle/ late) of the cemetery, $F(2, 75) = 0.230$, $p = 0.795$.

Hence, in the total adult population, hypothesis 3a is false for both the left and right acetabulum: Therefore, for both sides, the null hypothesis is true: In the total adult

population, there is no significant difference in mean IOA between the three chronological phases of this Avar cemetery.

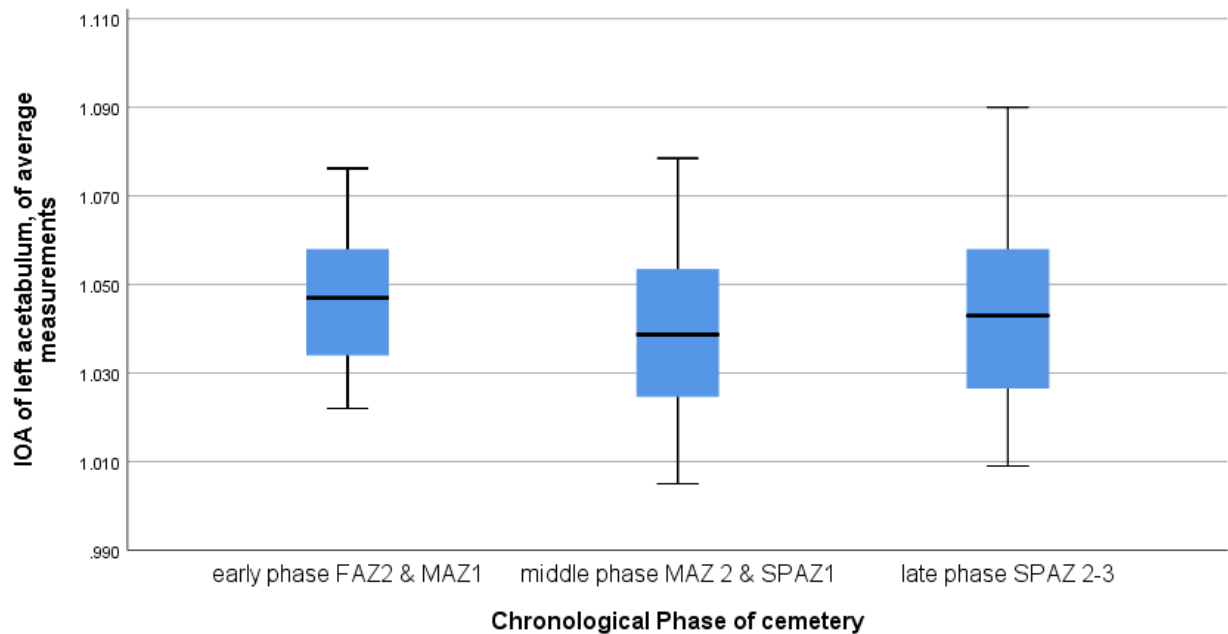


Fig. 45: Mean Index of Ovalization (IOA) of the left acetabulum in the three chronological phases of the Avar cemetery Wien-Csokorgasse; total adult population (n = 117)

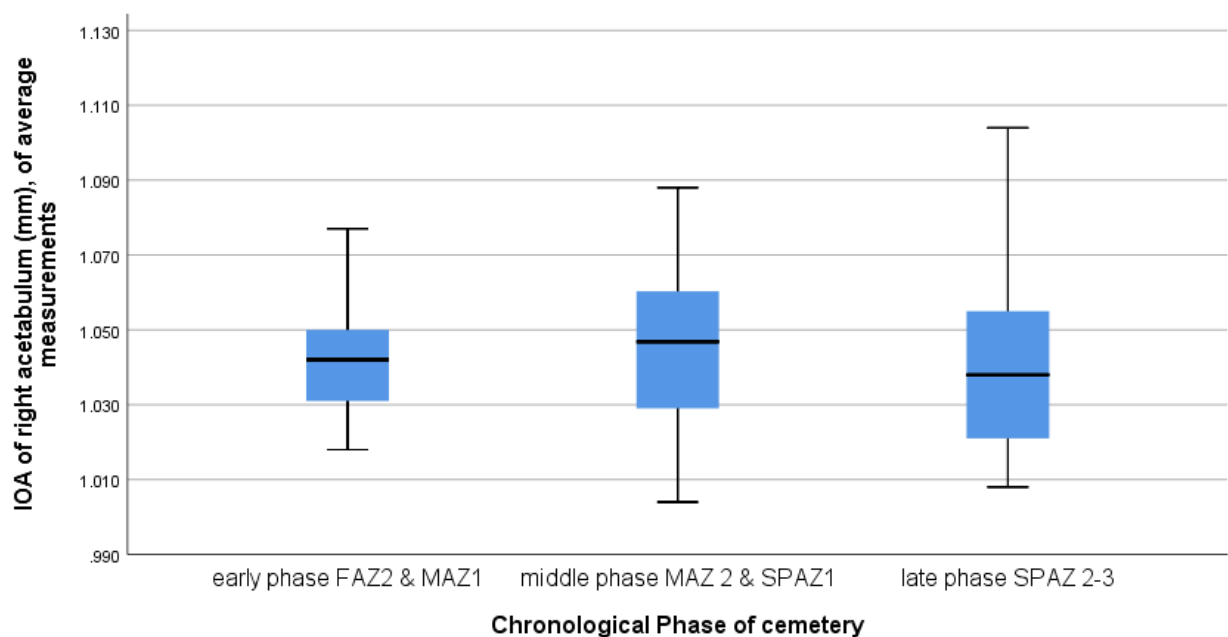


Fig. 46: Mean Index of Ovalization (IOA) of the right acetabulum in the three chronological phases; total adult population of the Avar cemetery Wien-Csokorgasse (n = 93)

For the adult male population, there is no clear pattern, although the mean IOA is somewhat higher in the middle phase than in the early and late phases, especially on the right side (see fig. 47 and 48, below).

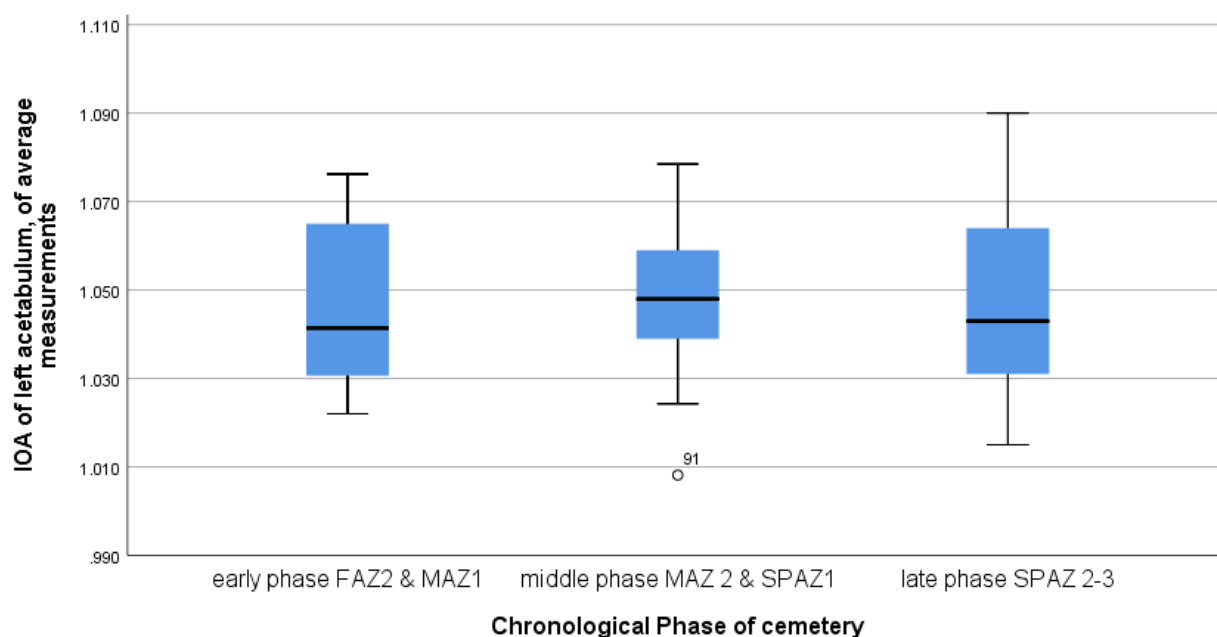


Fig. 47: Mean Index of Ovalization (IOA) of the left acetabulum in the three chronological phases of the Avar cemetery Wien-Csokorgasse; male adult population (n = 57)

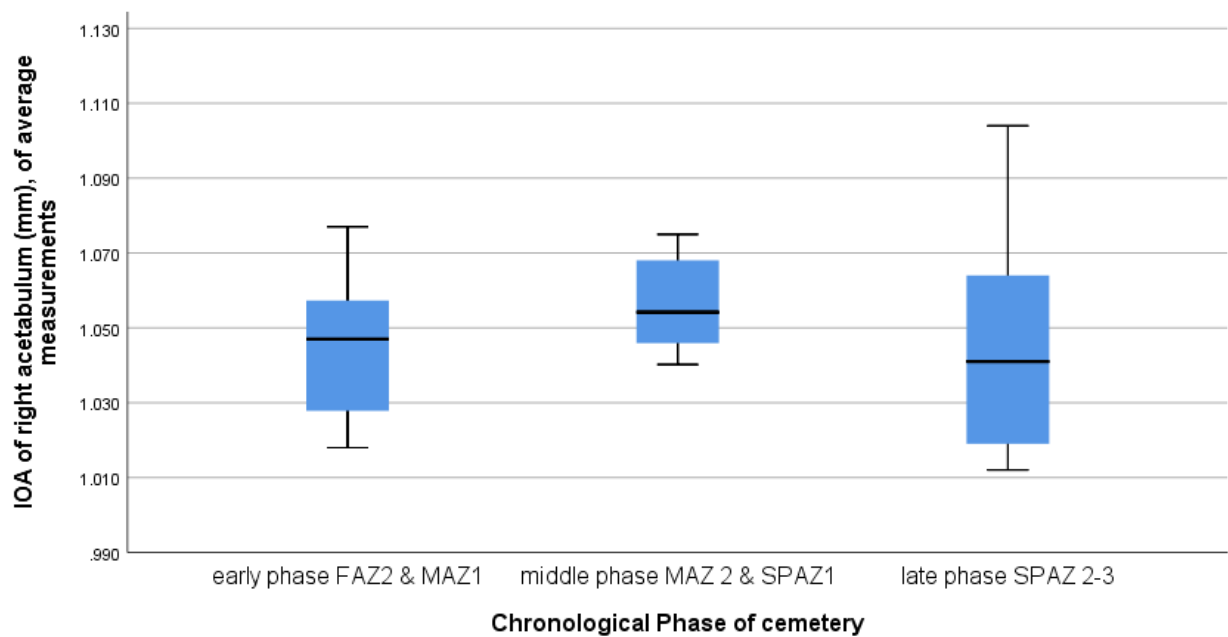


Fig. 48: Mean Index of Ovalization (IOA) of the right acetabulum in the three chronological phases of the Avar cemetery Wien-Csokorgasse; male adult population (n = 46)

However, for the female adult population, a clear trend was apparent (see fig. 49 and 50), in particular for the left acetabulum:

The mean IOA of the left acetabulum of women buried during the early phase ($M = 1.049$, $SD = 0.009$, $n = 10$) of the Avar cemetery Wien-Csokorgasse was noticeably higher than the IOA of women buried during the middle phase ($M = 1.030$, $SD = 0.018$, $n = 15$) and the late phase ($M = 1.040$, $SD = 0.020$, $n = 14$).

For the right acetabulum, however, the differences in mean IOA of women buried during the early phase ($M = 1.040$, $SD = 0.009$, $n = 10$), middle phase ($M = 1.036$, $SD = 0.026$, $n = 15$) and late phase ($M = 1.038$, $SD = 0.016$, $n = 14$) is only minimal, although the mean IOA is highest in the early phase.

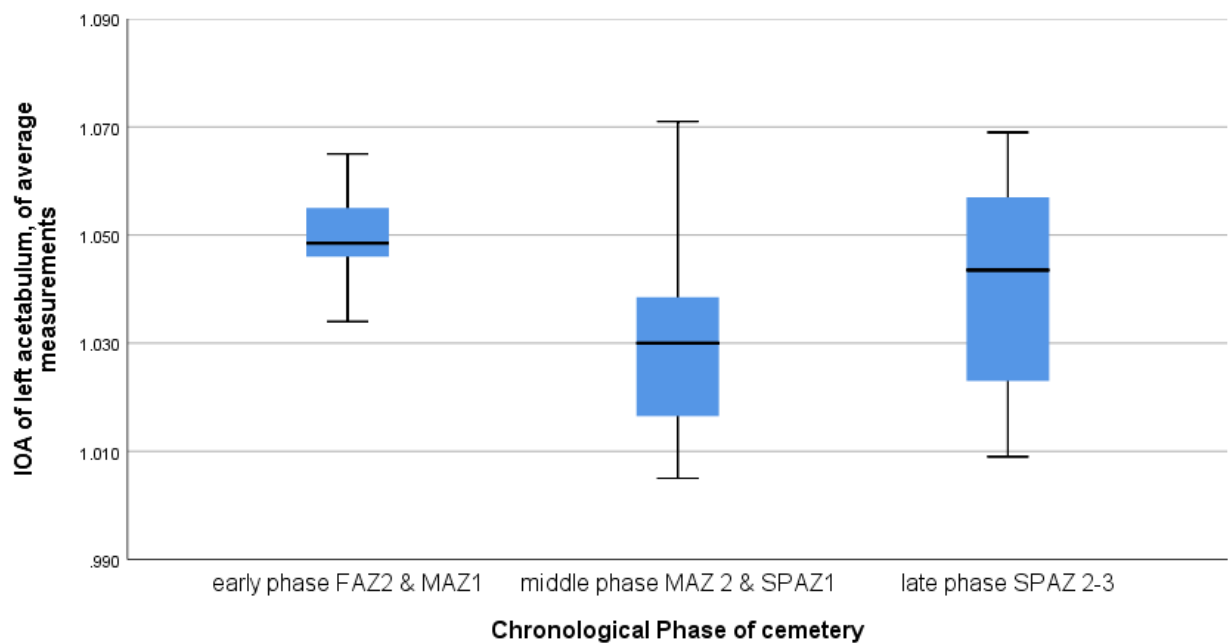


Fig. 49: Mean Index of Ovalization (IOA) of the left acetabulum in the three chronological phases of the Avar cemetery Wien-Csokorgasse; female adult population (n = 60)

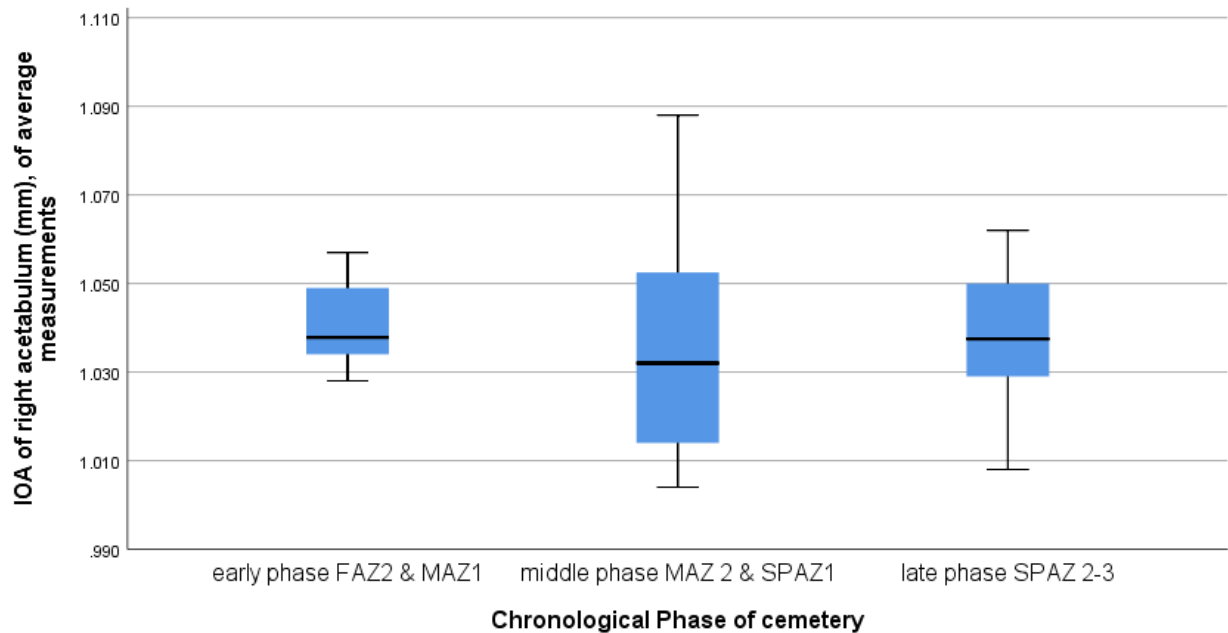


Fig. 50: Mean Index of Ovalization (IOA) of the right acetabulum in the three chronological phases of the Avar cemetery Wien-Csokorgasse; female adult population (n = 47)

The results of a one-way ANOVA support these observations: In the female adult population, the mean index of acetabulum (IOA) of the left acetabulum differed significantly between the three chronological phases (early/ middle/ late) of the cemetery, $F(2, 36) = 3.909$, $p = 0.029$. On the other hand, also in the female adult population, the mean index of acetabulum (IOA) of the right acetabulum did not differ significantly between the three chronological phases (early/ middle/ late) of the cemetery, $F(2, 36) = 0.162$, $p = 0.851$.

Hence, in the female adult population, hypothesis 3b was partially verified: It is true for the left acetabulum only, but not for the right acetabulum.

6.2.5 Differences in IOA between socioeconomic groups (“Shallow” burials = low status vs. “deep” burials = high status; Hypothesis 4)

Hypothesis 4

The prevalence of one or more characteristic traits of the “Horse Riding Syndrome” is significantly higher in adults with “high socioeconomic status” than in adults with “low socioeconomic status” (= *partly verified*) and this could be especially relevant for the male adult population (= *verified*).

Sub-hypothesis 4 a

The mean IOA of total adult individuals with “high socioeconomic status” (proxy: burial in “deep” graves = grave depth 1.00 m or more) is significantly higher than the mean IOA of total adult individuals with “low socioeconomic status” (proxy: burial in “shallow” graves = grave depth less than 1.00 m) – *partly verified*.

Sub-hypothesis 4 b

The mean IOA of male adult individuals with “high socioeconomic status” (proxy: burial in “deep” graves = grave depth 1.00 m or more) is significantly higher than the mean IOA of male adult individuals with “low socioeconomic status” (proxy: burial in “shallow” graves = grave depth less than 1.00 m) – *verified*.

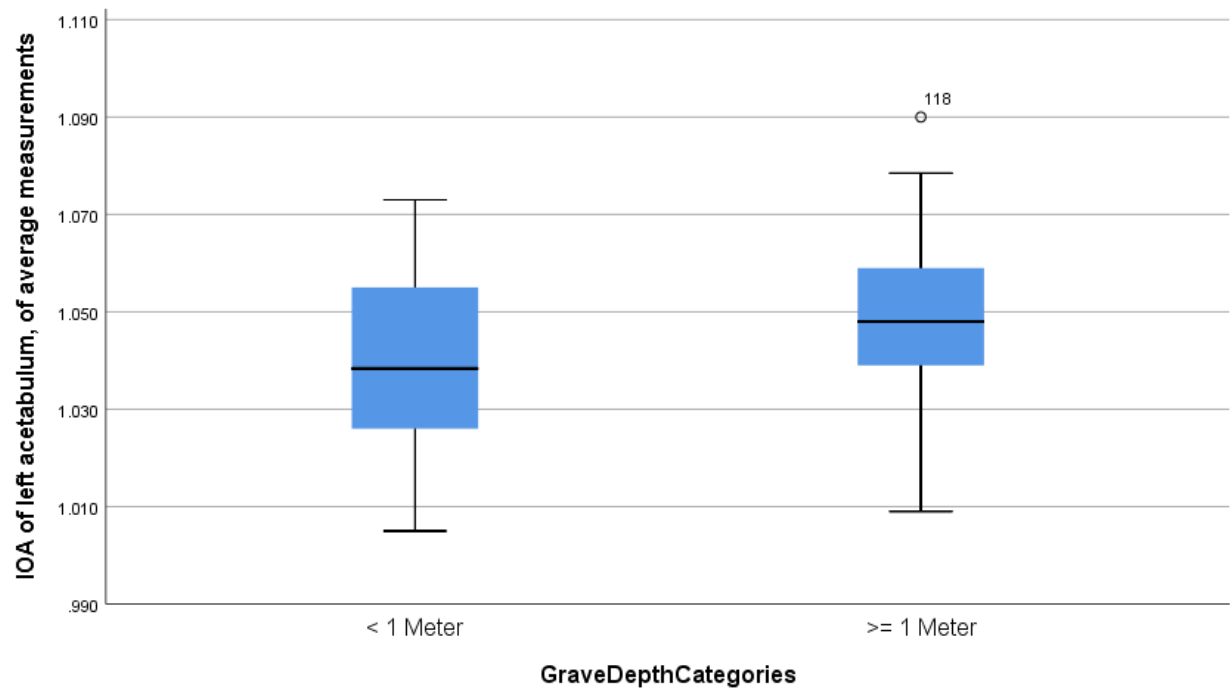


Fig. 51: Mean Index of Ovalization (IOA) of the left acetabulum in “shallow” and “deep” burials; total adult population of the Avar cemetery Wien-Csokorgasse (n = 78)

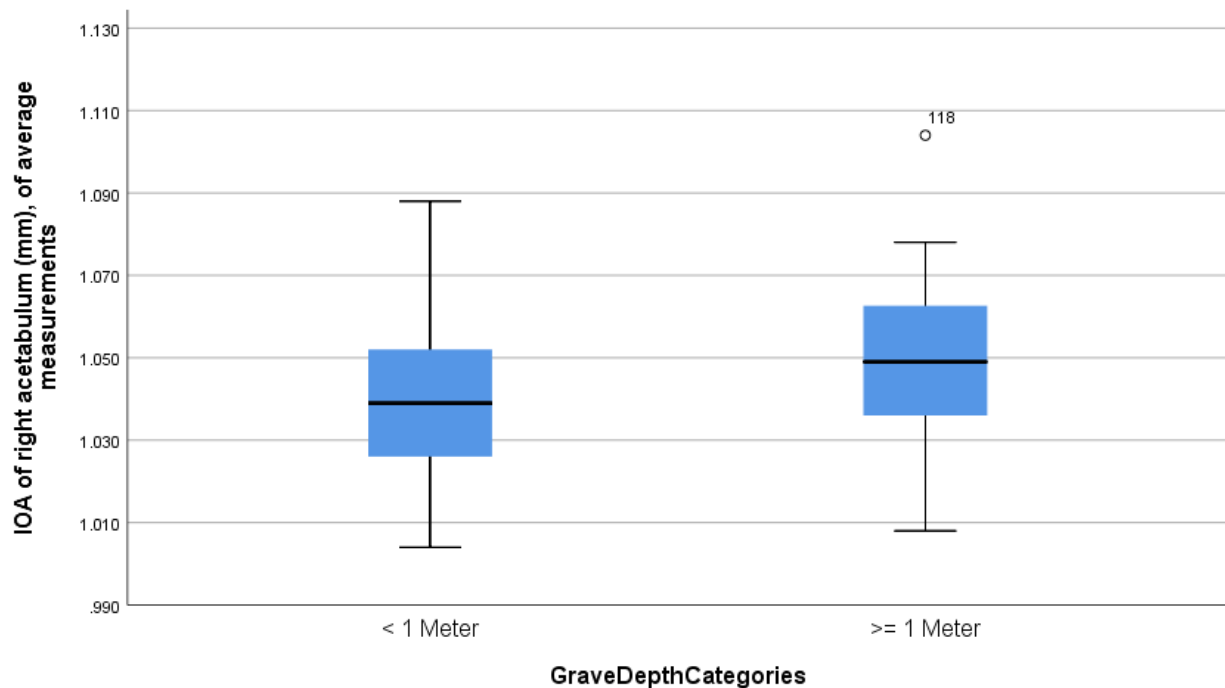


Fig. 52: Mean Index of Ovalization (IOA) of the right acetabulum in “shallow” and “deep” burials; total adult population of the Avar cemetery Wien-Csokorgasse (n = 80)

As Fig. 51-54 show, a similar trend is apparent both for the total adult population and for the adult male population. However, the differences between the socioeconomic groups are much clearer in the adult male population (Fig. 53-54) than in the total adult population (Fig. 51-52).

For the right acetabulum, the mean IOA was higher for all adults (men and women of all adult age groups; see Fig. 52) buried at a depth of 1.00 m or more ($M = 1.050$, $SD = 0.021$, $n = 26$) than for adults buried at a depth of less than 1.00 m ($M = 1.039$, $SD = 0.020$, $n = 54$). The results of the independent-sample T-test were significant, $t(78) = -2.151$, $p = 0.035$.

For the left acetabulum, the mean IOA was also noticeably higher for all adults (men and women of all adult age groups; see Fig. 51) buried at a depth of 1.00 m or more ($M = 1.048$, $SD = 0.021$, $n = 25$) than for adults buried at a depth of less than 1.00 m ($M = 1.039$, $SD = 0.019$, $n = 53$). However, the results of the independent-sample T-test were not significant, $t(76) = -1.782$, $p = 0.079$.

Hence, hypothesis 4a was partly verified (for the right side only).

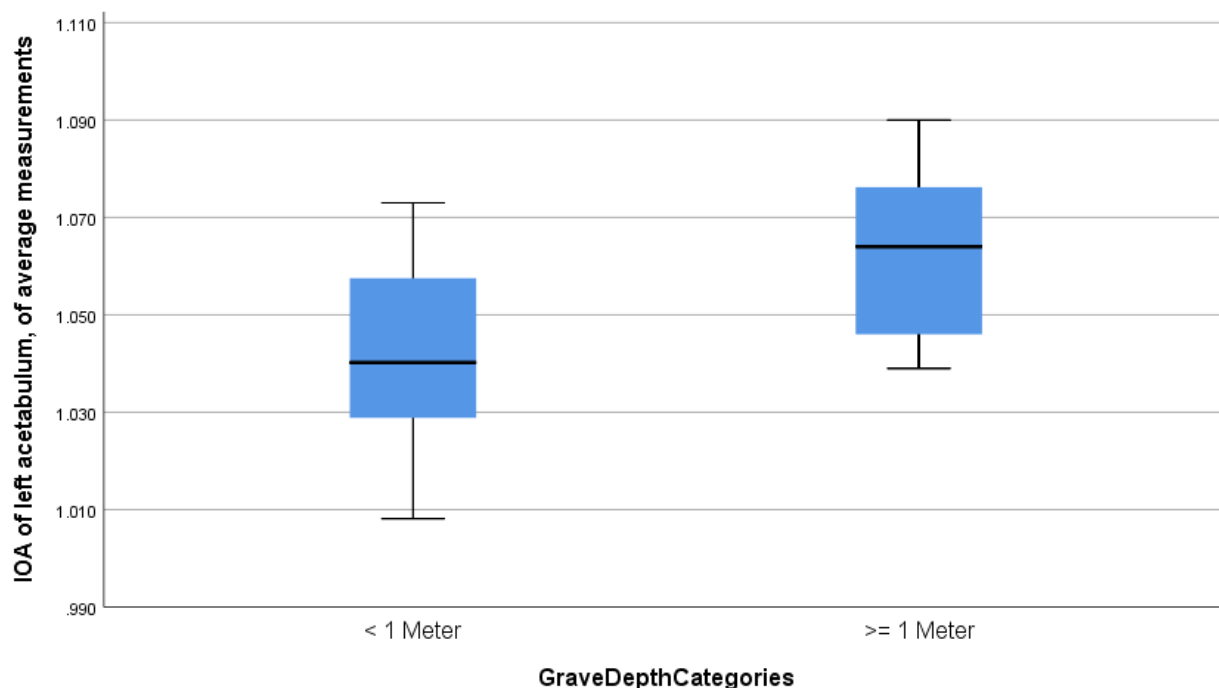


Fig. 53: Mean Index of Ovalization (IOA) of the left acetabulum in “shallow” and “deep” burials; adult male population of the Avar cemetery Wien-Csokorgasse (n = 38)

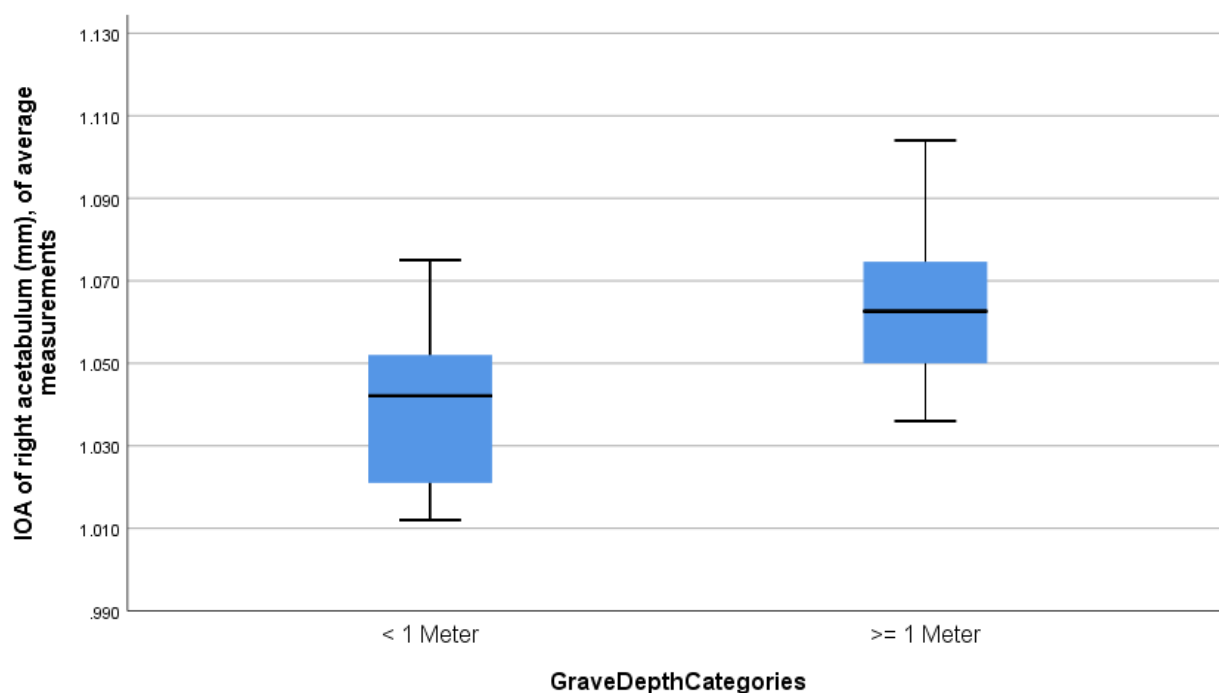


Fig. 54: Mean Index of Ovalization (IOA) of the right acetabulum in “shallow” and “deep” burials; adult male population of the Avar cemetery Wien-Csokorgasse (n = 40)

For the left acetabulum, the IOA was higher in males buried at a depth of 1.00 m or more ($M = 1.063$, $SD = 0.018$, $n = 9$) than in males buried at a depth of less than 1.00 m ($M = 1.041$, $SD = 0.018$, $n = 29$). The results of the T-test were highly significant, $t(36) = -3.145$, $p = 0.003$.

For the right acetabulum, the IOA was higher in males buried at a depth of 1.00 m or more ($M = 1.063$, $SD = 0.018$, $n = 13$) than in males buried at a depth of less than 1.00 m ($M = 1.040$, $SD = 0.019$, $n = 27$). The results were highly significant, $t(38) = -3.617$, $p = 0.001$.

Hence, hypothesis 4b was verified for both sides, with highly significant results.

7 Discussion

7.1 Verification of the “Horse Riding Syndrome” and prevalence of non-metric traits of the anterior femoral head-neck junction

The results of this thesis (see Ch. 6) suggest that several characteristic traits of the so-called “horse riding syndrome” could indeed, as shown by previous researchers (Anđelinović et al. 2015; Baillif-Ducros 2012; Baillif-Ducros & McGlynn 2013; Berthon et al. 2018; Belcastro et al. 2001; Larentis 2017), be potential indicators of habitual horse riding. These particular traits are:

1. The ovalization (= vertical elongation) of the acetabulum
2. “Poirier’s Facet” at the junction of the femoral head and the femoral neck
- 3.1 Pronounced robusticity of gluteal entheses
- 3.2 Pronounced robusticity of entheses of the leg bones

The results suggest possible association between traits 1 and 2 (= Hypothesis 1a), as well as an association between traits 1 and 3.1 (= Hypothesis 1b) and between traits 1 and 3.2 (= Hypothesis 1h):

- Adults with “Poirier’s Facet” in the femoral head-neck junction have a significantly higher mean IOA than adults without this trait (= association between traits 1 and 2; Hypothesis 1a = verified for the left side only).

- Adults with pronounced gluteal entheses on the *Os coxae* have a significantly higher mean IOA than adults without this trait (= association between traits 1 and 3; Hypothesis 1b = verified for both sides).
- In the adult population, there is a low to medium correlation between the mean IOA and the mean entheses robusticity score, in particular for the lower limbs (= association between traits 1 and 3.2; Hypothesis 1h = partly verified).

However, the results presented above suggest that – at least in the sample investigated in this thesis – the other five non-metric traits tested for possible association with the ovalization of same-side acetabulum (using IOA) cannot be regarded as characteristics of the “horse riding syndrome”. Possibly, these five traits are not as “specific” to habitual horse riding activity and should be interpreted rather as “indicators” of general mobility (on foot and on horseback). In this context, it is important to consider the methodological issues associated with the identification of specific activities in a bioarchaeological context (see for example: Jurmain et al. 2012, Foster et al. 2012).

The traits in question are:

- Pronounced *Linea aspera* on *Os femoris*
- Curved *Trochanter major* on *Os femoris*
- Exostosis (“spicules”) in *Fossa trochanterica* on *Os femoris*
- Exostosis (“spicules”) in *Fovea capitis* on *Os femoris*
- Presence of osteoarthritis on the upper outline of the patellar surface on *Os femoris* (as an indication of possible stirrup use)

For these five traits, the small differences regarding the mean IOA and/ or the fact that the independent-sample T-test was not significant could be attributed to the small size of the sample, as a consequence of the insufficient state of preservation of the osteological material in question. More research with large, well-preserved samples from similar bioarchaeological contexts and from reference collections (as an “outgroup”) will be required in order to clarify this research question.

The association between three major characteristics of the horse riding syndrome (the presence of “Poiriers Facet”, the ovalization of the acetabulum and pronounced entheses on the bony pelvis and leg bones) detected within the adult population of Wien-Csokorgasse suggests that the “horse riding syndrome” may indeed be a valid set of characteristics for identifying habitual horse riders in bioarchaeological contexts. This particular “ensemble” of associated traits – “Poiriers Facet” on the proximal femur, ovalization of the acetabulum and pronounced entheses on the bony pelvis and leg bones – is in accordance with the biomechanics of horse riding: The pelvis and legs of the rider play a central role in the communication between rider and horse (Pugh & Bolin 2004). Hence, it is not surprising that osteological traits detected on the bony pelvis, hip joint and proximal femur are major characteristics of the “horse riding syndrome”. Similarly, these three particular traits have been detected most frequently in previous bioarchaeological research on populations of habitual horse riders (Anđelinović et al. 2015; Baillif-Ducros 2012; Baillif-Ducros & McGlynn 2013; Berthon et al. 2018; Belcastro et al. 2001; Larentis 2017). For instance, according to Larsen (1997) the vertical elongation (ovalization) of the acetabulum and facets on the femoral head-neck junction are two major characteristics of habitual horse riding, together with various degenerative changes on the vertebrae, hip and other joints, as well as the robusticity of a number of entheses on the bony pelvis and lower limb.

The results presented above suggest that, at present, “Poirier’s Facet” is the only morphological variation of the anterior head-neck junction of the proximal femur which should be included in the “horse riding syndrome”. According to the current state of research, the aetiology of the other non-metric traits of the anterior head-neck junction of the proximal femur – plaque and cribriform changes (see Radi et al. 2013, Mellado et al. 2014) – is still not quite clear: Although the different types of plaque may also have been caused by mechanical stress of some kind, they can, at present, only be regarded as very unspecific “markers of physical activity” (Lawrence et al. 2018, Radi et al. 2013, Belcastro 2006). The interpretation of cribriform changes of the proximal femur is, at present, even more problematic: It is, as yet, not possible to ascertain whether they should be interpreted as general stress markers or as unspecific markers of physical activity (Radi et al. 2013).

Similarly, as the results in Ch. 6.1 show, the prevalence of a characteristic “Poirier’s Facet” in the Avar cemetery Wien 11-Csokorgasse is in the range of 20-30% for adult men, just below 10% for adult women and thus, around 15-20% for the total adult population. These values are strikingly similar to those in the adult population from the nearby Avar cemetery of Vösendorf (Pany & Wiltshcke-Schrotta 2017, 5 and 22-23), where the prevalence of “Poirier’s Facet” was 26.8% for adult men (37/138), 7.0% for adult women (11/157) and an average of 16.3% for identified adult individuals of both sexes (48/295). This is interesting, not only because these two Avar cemeteries are both located in the same region, but also because a small number of “equestrian graves”, predominantly from the final phase of the Avar Period (late 8th century) occur in both these Avar cemeteries, while they are absent from many other important Avar cemeteries in the Vienna Basin (Tarcsey 2013). The presence of “equestrian graves” (Trugly 1987, Čilinská 1990) in Avar cemeteries at the end of the Avar period could suggest that horse riding as part of a “mounted warrior lifestyle” may still have played an important role for the Avar population in the Vienna Basin in the 8th century, at least for the “elite” (Tarcsey 2013, Baron 2018). Only interdisciplinary research can resolve the issue of whether the lifestyle and habitual activity patterns of the male Avar elite in the late 8th century AD was in accordance with the way they presented the deceased in funerary culture – as “mounted warriors”. The differences regarding the prevalence of a characteristic “Poirier’s Facet” between men and women is also very similar in the Avar cemeteries of Vösendorf and Wien 11-Csokorgasse. According to Pany et al. (2017, 22-23), the prevalence of this trait in the Avar population buried within the Vösendorf cemetery may originally have been even higher. However, the insufficient state of preservation of the skeletal material from this cemetery makes the identification of this trait difficult in many cases. The same may be true for our sample, where the state of preservation of the osteological material is also far from ideal. Furthermore, the proportion of male adults with a characteristic “Poirier’s Facet” in the Avar cemetery Wien 11-Csokorgasse is roughly equivalent to the proportion of “high status” burials (graves with depth 1.00 m or more and/ or with belt-sets and/ or weapons), within the same cemetery (in the range of 25-35%), see ch. 7.4 with figs. 55-58.

There are no comparative data from Avar cemeteries on the prevalence of plaque on the femoral head-neck junction. However, in two early medieval cemeteries from Kulubnarti (Nubia), Lawrence (2018) found evidence for plaque in approximately half the adult

population, which is similar to the percentages found in the adult Avar population buried at Wien-Csokorgasse, see ch. 6.1, above. In a modern skeletal collection, Radi (2013) detected an extremely high percentage of individuals with plaque and concluded that plaque on the proximal femur may be the “normal condition” in adults.

In the adult population buried in the Avar cemetery of Wien11-Csokorgasse, type 2 cribriform changes on the proximal femur (“Allens Fossa”) were found more frequently on female than on male individuals (see Ch. 6.1, below). Radi (2013) made similar observations on human osteological material from a modern collection. However, there is no significant sex difference regarding the occurrence of type 1 cribriform changes on the proximal femur and the prevalence of this trait in the total adult population is similar to that of plaque (see ch. 6.1, above). Hence, there could be an association between Plaque (especially type B and C) and cribriform changes type 1. Research on living adults may contribute to the interpretation of this trait (see below).

Evidence from other protohistoric populations suggests that “Cribra femora” is relatively common in both in non-adults and (young) adults. In this context, the case study of a juvenile Magyar warrior buried around 900 AD in Gnadendorf (Lower Austria) is particularly relevant. In their osteological study of this individual who died in adolescence, at the age of about 15, Pany et al. (2006, 29-67) observed characteristic traits of the “Horse Riding Syndrome” (for example robust entheses of the lower limb), as well as cribriform porosities on the *Collum femoris*, the distal Tibiae, the *Calcanei* and the Vertebrae. According to Pany et al. (2006, 65 and Abb. 19), the aetiology of the cribriform porosities could be pathophysiological, such as anaemia or malaria. In this context, it may be important to discriminate between Cribra femora occurring by itself and other types of cribriform lesions, which form on plaque as herniation pits. It is possible that the latter are indeed a result of activity, as suggested by current clinical research (see Mellado et al. 2014).

The observation that plaque and cribriform variations frequently occur together in the anterior head-neck junction of the femur is consistent with the “reaction area” concept (see Finnegan & Faust 1974), which includes both elevated and excavated variations on the bone surface detectable in the bioarchaeological record. Multiple detector computed tomography

(MDCT) of the anterior femoral head neck junction in living adults (Mellado et al. 2014) has also demonstrated that the “reaction area” may include both elevated (“plaque”) and excavated (“cribriform lesions”; “cribra”; “Allens’s Fossa”) changes on the bone surface. In addition to this, medical/ radiological research using MDCT has also provided evidence that increased physical activity and/ or advanced age may be factors, which influence the appearance of the “reaction area”. According to Mellado et al. (2014), active athletes are more likely to develop prominent, elevated and/ or excavated changes in the “reaction area” at the anterior femoral head-neck junction. Mellado et al. (2014) have also found that while young adults tend to have only slight changes in the reaction area, these are likely to become more prominent with increasing age, with a rough surface and, in many cases, a combination of elevated and excavated traits.

Hence, in the context of the “reaction area concept”, plaque and cribriform lesions in the anterior head-neck junction of the human femur appear to be associated phenomena with a common aetiology. In contrast, according to the present state of research, “Poiriers facets” appear to be a trait that is not associated with the reaction area concept. Our results, as presented above, are consistent with this view. However, further research is required regarding possible effects of the human ageing process on the appearance of the variations of the femoral anterior head-neck junction. This aspect has not been considered within the scope of this thesis: According to Mellado et al. (2014), a relatively uniform, elevated bone surface change in the “reaction area” of the anterior proximal femur (“Plaque”) seems to be characteristic for young adults with a particularly active lifestyle (athletes). In older adults however, according to Mellado et al. (2014), the appearance of the “reaction area” of the anterior proximal femur is normally more heterogeneous, with a combination of elevated and excavated bone surface changes. In this context, it is possible that the “herniation pits” observed by radiologists in living patients are the equivalent of the cribriform changes observed on dry bone from bioarchaeological contexts. It is crucial to be aware that any classification system for non-metric osteological traits is a reduction of complexity, of “forcing” a continuous trait into (non-continuous) categories.

From a methodological point of view, the historical and archaeological context of the human osteological material examined in this thesis is a particular asset for studying the so-called

“horse riding syndrome”. Previous researchers (for example: Berthon et al. 2018) have stressed the relevance of the archaeological context for research on the “horse riding syndrome”. Presumably, a considerable proportion of Avar men, at least of those who lived and fought in the seventh century AD, were accomplished mounted archers, who had spent a lot of time on horseback since early childhood (see ch. 2, above). Hence, variations in habitual activity patterns detected within the adult Avar population of Wien 11-Csokorgasse are quite likely to be the result of differences regarding habitual horse riding activity. In this context, the existence of chronological trends and differences between gender and socioeconomic groups regarding the prevalence of characteristics of the “horse riding syndrome” is relevant, especially because these trends are also consistent with the historical context (Anke et al. 2008, Pohl 1988, Daim 1987, Daim 2003).

One of the major limitations of this study was the state of preservation of the leg bones and bony pelvis, which was in many cases, not ideal for our research question. Therefore, the actual sample sizes for testing the different hypotheses were not identical and were always considerably smaller than the total sample size ($n = 149$). Hence, further research is desirable, not only with additional criteria and on other adult populations from Avar cemeteries, but also on the juvenile segment of Avar populations. The reason for focusing exclusively on the age groups “adult and above” (from around 20 years to 60 years plus) in this study of the “horse riding syndrome” was the consideration that non-metric traits of the proximal femur, in particular “Poirier’s Facet” could be observed best only if epiphysis of the femoral head is already closed. However, it would be important to examine the juvenile population of the same cemetery, because of the increased prevalence of activity-related, osteological adaptation processes in juvenile individuals (Pearson & Lieberman 2004). Another limitation of the research carried out here was the lack of an “outgroup”, such as a population of non-horse-riders from a modern reference collection. It would be important to include this in any further research on the topic.

7.2 Differences between the sexes

The results presented in Ch. 6.2.3 (verification of hypothesis 2) have demonstrated that prevalence of two characteristic traits of the “Horse Riding Syndrome” – “Poirier’s Facet” and the “Ovalization of the Acetabulum” – is significantly higher in the adult male population than in the adult female population buried in the Avar cemetery Wien-Csokorgasse. On the basis of the issues discussed above (see Ch. 7.1), this could suggest significant differences in the lifestyle and activity patterns of the sexes, especially concerning habitual horseriding. Similarly, according to Dukić (2017, 35), the results of a study of entheses and stress markers from the Avar necropole of Čik (Serbia) suggests that the men buried within this cemetery show more frequent use of the muscles specific for horse riding than the women from the same population.

However, according to the results presented above (see ch. 6.1), there are only minimal differences regarding the prevalence of plaque (of all types together) in Avar males and females, although there are slight differences regarding the frequency of the three types of plaque. Plaque type C was the most common type of plaque in the total adult population and in adult females, while in adult males, the prevalence of plaque type B and C was very similar, with a frequency of around 20%. Plaque A, however, was relatively rare in the total adult population, as well as in adult males and females separately, with frequencies below 10% in each case. Similarly, there is no significant sex difference regarding the occurrence of type 1 cribriform changes on the proximal femur. In addition, the frequency of this trait is similar in the total adult population to that of plaque. Hence, there could be an association between Plaque (especially type B and C) and cribriform changes type 1, but further research is required on this topic. According to some authors, “cribra femoris” may have systemic or physiological causes, rather than being a non-metric trait. Similarly, research on modern patients has shown that herniation pits may appear on plaque (Mellado et al. 2014). Again, this illustrates the methodological issues of classification of non-metric traits in bioarchaeological contexts.

However, in the adult population buried in the Avar cemetery of Wien-Csokorgasse, Type 2 cribriform changes on the proximal femur (= “Allens Fossa” according to Finnegan & Faust

1974) were much more common in female than in male individuals. Radi (2013) made similar observations on human osteological material from a modern collection. Although biomechanical stress on the hip joint during flexion and extension may be a major factor in causing morphological variations of the femoral head-neck junction, other factors such as hormonal and metabolic levels may also influence the prevalence and appearance of these variations. Hence, biomechanical stress on the hip joint could cause differential adaptive effects, for example in males and females, as well as in different age groups (Belcastro et al. 2006, 324-325). Possibly, this could explain the difference regarding the prevalence of “cribriform changes type 2” between the sexes (see ch. 6.1).

The role of women in Avar society is a topic that merits further research, especially using a combination of criteria, with respect to lifestyle, activity patterns and health, as well as material culture and burial customs. At present, material culture, predominantly grave goods, suggests that the daily life of women in Avar communities in the Carpathian Basin tended to focus on the domestic sphere, with textile-production activities such as spinning and sewing documented by the grave goods. On the other hand, there are a small number of “female equestrian graves” from the Avar Period: Although no weapons occur in these burials, grave goods associated with domestic activities such as spinning and sewing are usually missing from female equestrian graves (Čilinská 1990).

In this context, it is relevant that the results presented in ch. 6.2.3 could suggest that, at least in the early periods of Avar history, women – or at least a particular segment of the female Avar population – also participated in some of the men’s activities requiring horseback riding, such as herding, hunting or even fighting. While there is no clear chronological trend regarding the “ovalization” of acetabulum for men and for the total adult population, Avar women buried in the early phases of this cemetery had a significantly higher Index of Ovalization (IOA) than those buried in later phases. Hence, it is possible that the general lifestyle of the “immigrant generation” of Avar women buried within this cemetery was very different from the lifestyle of later generations of Avar women. Presumably, they had spent more time on horseback, if only as part of a more mobile, nomadic lifestyle, as well as the process of travelling. Perhaps, within the early phases of Avar history, women – or at least a particular segment of the Avar population – also participated in some of the men’s activities requiring

horseback riding, such as herding, hunting or even fighting. However, so far, these conclusions are based only on two criteria of the “horse riding syndrome” and research that is more detailed is required in order to verify these assumptions.

7.3 Chronological differences

The results in Ch. 6.2.4 show that, for both the total adult population and for the adult male population of the Avar cemetery Wien11-Csokorgasse, the chronological differences regarding the mean Index of Ovalization of Acetabulum (IOA) are minimal. If the assumption, that the mean Index of Ovalization of Acetabulum (IOA) is a major characteristic of the “horse riding syndrome” (and therefore suitable for detecting changes in lifestyle within the population in question, see ch. 7.1) is correct, it may be feasible to conclude that the overall changes in lifestyle in the male adult population and in the total adult population, were not dramatic.

However, as discussed above (ch. 7.2), adult females buried in the early phase of the Avar cemetery Wien11-Csokorgasse had a much higher mean Index of Ovalization of Acetabulum (IOA) than adult females buried in the middle and late phase of the same cemetery. This is true especially for the left acetabulum but also, to some extent, for the right side. The early generations of women buried in Avar cemeteries in Austria would be those most affected by the migration process from Eastern Europe or even Central Asia. Perhaps, within the early periods of Avar history, women – or at least a particular segment of the female Avar population – also participated in some of the men’s activities requiring horseback riding, such as herding, hunting or even fighting. In this context, it is relevant that the female adult individuals buried in the early phase of this cemetery have, in general, more “robust” entheses than females buried in the middle and late phase of the same cemetery. However, further research would be required in order to address this issue, for example in-detail case studies of the individuals in question. For example, it would be important to determine whether there is evidence that the “robust” females from the early phase were not only habitual horse riders, but also practiced archery. Such research could make an important contribution to the historical interpretation of this particular Avar cemetery and to Avar archaeology in general.

In this context, it is important to note that, from an archaeological point of view, the burials of the Avar women from the earliest phase do not provide any evidence of these lifestyle differences.

However, according to both archaeological and historical research, a number of fundamental changes took place within the Avar Empire in Central Europe after the middle of the seventh century AD, including the trend to establishing more permanent settlements and the transition to an economy based more on agriculture and less on herding and plundering (“war economy”). In a previous, detailed paleopathological study of the Avar population from Wien-Csokorgasse, Großschmidt (1990, 341) had observed that spondylolysis of lumbar vertebrae (in particular L5) occurred less frequently in the Late Avar Period (8th century AD) than in the Middle Avar Period (second half or final third of the 7th century AD). Hence, Großschmidt (1990, 341) concluded that this could be due to changes of lifestyle within the Avar population buried at Wien 11-Csokorgasse, such as a decrease in habitual horse riding. This hypothesis, so Großschmidt (1990, 341), is also supported by a decrease in the prevalence of other degenerative conditions, in particular of the spine, the knee and the hip. Similarly, Großschmidt (1990, 341) had also observed that the prevalence of general stress markers in the Avar population buried in the cemetery of Wien-Csokorgasse decreased from the (late) 7th to the 8th century, presumably as a consequence of improved living conditions.

7.4 Socioeconomic differences

Assuming that the ovalization of the acetabulum is indeed, as discussed above (see ch. 7.1), an important characteristic of the “horse riding syndrome”, then it is possible that the highly significant differences regarding the occurrence of this trait between “high-status” and “low-status” adult males (see results in ch. 6.2.5), reflect considerable differences in lifestyle and/or habitual activity patterns. In particular, these observations may suggest differences regarding the prevalence of habitual horse riding between “high-status” and “low-status” adult males. Therefore, with the help of a major criterion of the “horse riding syndrome” – the ovalization (vertical elongation) of the acetabulum – we may have identified a group of high-status Avar warriors, whose lifestyle appears to have differed from that of the lower-status

male population buried within the Avar cemetery in question. However, more research – using additional criteria and comparative material from other sites – is required in order to support this assumption. The results are also relevant for the issue of an increased prevalence of “equestrian burials” (Trugly 1987, Tarcsay 2013) along the northwestern border of the Avar Empire in Late Avar Period II-III (second half of the eighth century AD), in particular in present-day Slovakia and Eastern Austria. In view of the results presented in ch. 6.2.5, this phenomenon could be more than just a distant reflection of the “steppe nomadic” past of Avar society. Instead, it could suggest that a particular, high status “social group” preserved “mounted warrior traditions” – a lifestyle dominated by training for mounted combat as well as hunting – even at a time when the vast majority of lower-status inhabitants of the Avar Empire led a very different lifestyle, focusing on agriculture. In order to reach the level of proficiency attested to them by historical sources such as the Byzantine *“Strategikon”* from around 600 AD, Avar mounted warriors must have begun their training at an early age and worked a considerable amount of time every day on perfecting their skills. Mounted archery, in particular, requires an extraordinary amount of training, because the technique of taking aim is “instinctive”, which can only be effective if the archer acquires sufficient routine in shooting from horseback. For Avar mounted warriors, hunting from horseback was presumably one way of staying in training during long periods of peace. Hence, it is likely that hunting was an important part of the lifestyle of the Avar elite, also because it allowed the mounted warriors to train their fighting skills during times of peace.

It is remarkable that the proportion of male adults with a characteristic “Poiriers Facet” in the Avar cemetery Wien 11-Csokorgasse (see ch. 6.1), is in a similar range (20-35%) as the proportion of “high status” male burials, according to different archaeological criteria such as grave depth, or the presence of belt-sets and weapons (see Figs. 55-58, below). This could provide further support for the working hypothesis of lifestyle differences between socioeconomic groups of the Avar male population.

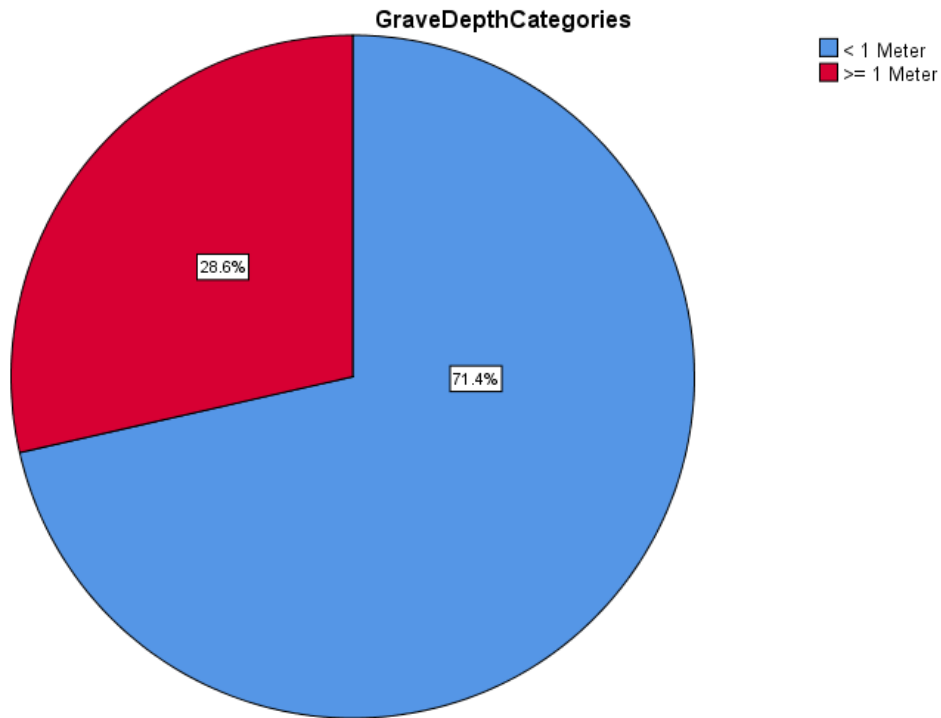


Fig. 55: Proportion of “shallow” (depth of grave less than 1.00 m) and “deep” burials (depth of grave = 1.00 m or more) in the male adult population of the Avar cemetery Wien-Csokorgasse (n = 77)

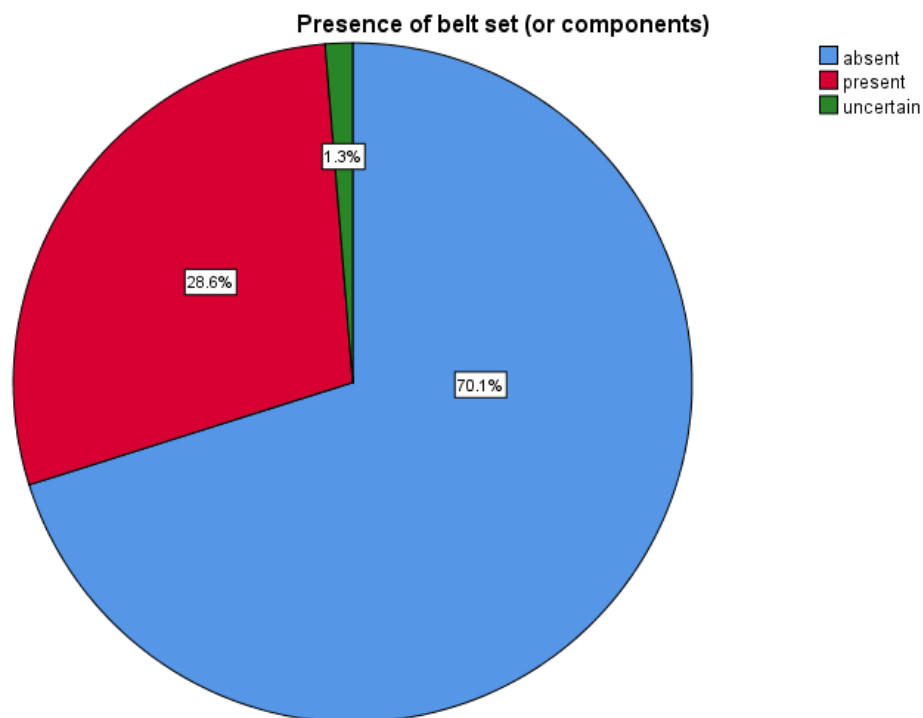


Fig. 56: Proportion of burials with presence/ absence of multi-part belt-sets in the male adult population of the Avar cemetery Wien-Csokorgasse (n = 77)

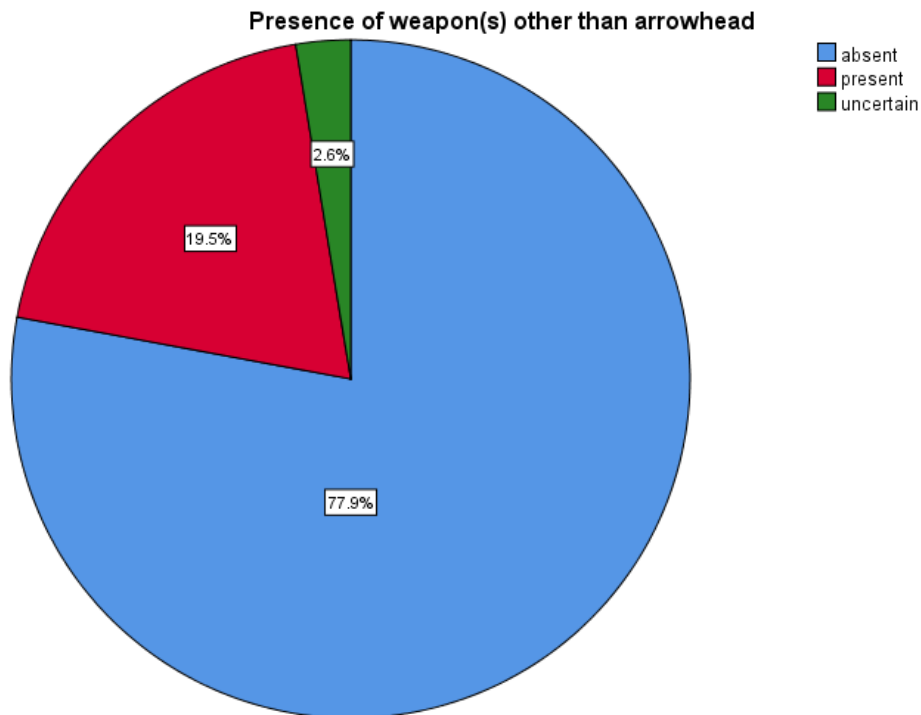


Fig. 57: Proportion of burials with presence/ absence of weapons (bow, sabre, sword, axe) in the male adult population of the Avar cemetery Wien-Csokorgasse (n = 77)

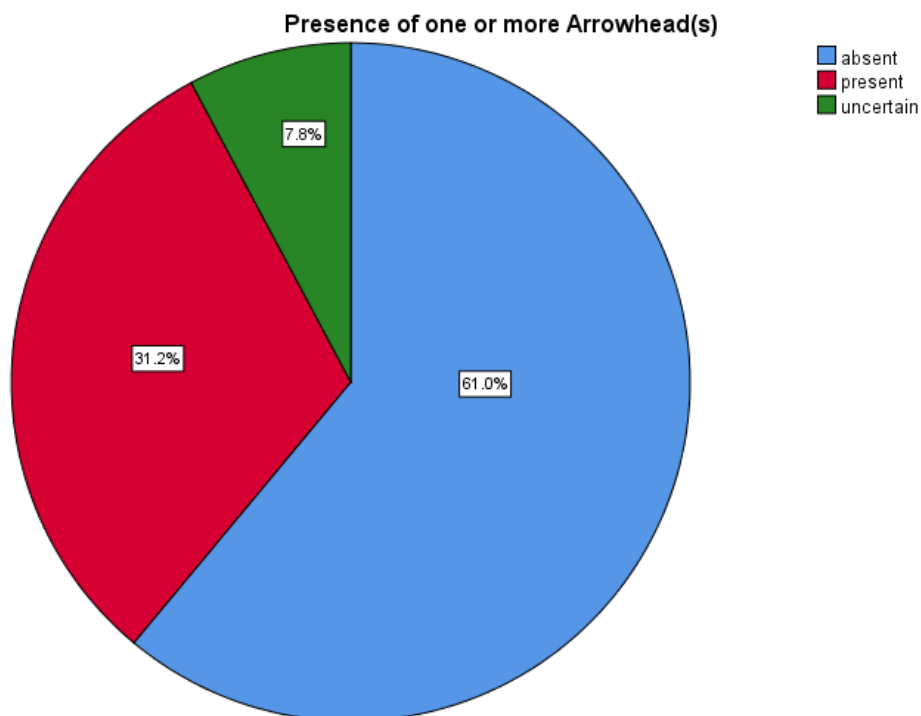


Fig. 58: Proportion of burials with presence/ absence of arrowheads in the male adult population of the Avar cemetery Wien-Csokorgasse (n = 77)

In conclusion, it is possible that, with the help of the “horse riding syndrome”, we have succeeded in identifying a group of “elite Avar warriors”, whose lifestyle appears to have differed from that of the lower-status male population buried within the Avar cemetery in question. In this context, the results of recently published archaeogenetic research on Avar populations from Hungary are relevant: *“The detected East-Central Asian maternal and paternal genetic composition of the elite was preserved through several generations after the Avar conquest of the Carpathian Basin. This result suggests a consciously maintained closed society, probably through internal marriages or intensive contacts with their regions of origin. The results also hold valuable information regarding the social organisation of the Avar period elite. The mitochondrial DNA data suggest that not only a military retinue consisting of males migrated, but an endogamous group of families”* (Csáky et al. 2020). The concept of the Avar elite as a “closed society” is compatible with the idea of a “conservative”, mounted-warrior lifestyle preserved by high-status men up to the end of the Avar period (late 8th century AD), as documented by “equestrian burials” such as those at Wien11-Csokorgasse and Vösendorf and by evidence for habitual horse riding. In addition to this, the concept of migration in family groups fits well with the observations presented in this thesis regarding Avar women buried in the 7th century AD, with characteristic traits of the “horse riding syndrome”.

8 Conclusions

According to historical sources, the Avars were accomplished mounted warriors. Although there is no detailed information regarding the preparation of Avar children for their future participation in mounted combat, historical analogies suggest that training, in particular in horseback archery, began at an early age. The training of young Avar warriors for mounted combat will have been quite intense, in order enable them to reach a suitable level of proficiency in late adolescence, which was the “normal” age for participation in battle in protohistoric warrior societies. Hence, Avar populations are ideally suited for methodological research on the “horse riding syndrome”, due to the historic context, because one can expect that they include a relatively high number of individuals who had spent a considerable amount of time on horseback, throughout their lifetime. The association between three major characteristics of the “horse riding syndrome”, detected within the adult population from the

Avar cemetery Wien 11-Csokorgasse, suggests that the “horse riding syndrome” may indeed be a valid set of traits for detecting habitual horse riders in archaeological contexts. This small “ensemble” of characteristic traits (1. “Poiriers Facet” on the proximal femur, 2. Ovalization (vertical elongation) of the acetabulum and 3. Pronounced entheses on the bony pelvis and bones of the lower limb), detected within the adult population (n = 149) of the Avar cemetery Wien 11-Csokorgasse, is in accordance with the biomechanics of horse riding.

Similarly, there is evidence for chronological trends regarding the prevalence of characteristics of the “horse riding syndrome” within the adult Avar population (Hypothesis 3 = partly verified), as well as for differences between men and women (Hypothesis 2 = verified) and between socioeconomic groups (Hypothesis 4 = partly verified). The results suggest that there are differences regarding the habitual activity patterns of Avar men and women, as well as among “high status” and “low status” Avar men. Given the historical context of Avar populations in Eastern Austria, it is reasonable to assume that the differences in habitual activity patterns detected between different segments of the Avar population, as well as the chronological differences, could in fact be associated with differences regarding the prevalence of habitual horse riding. From a historical point of view, the chronological differences regarding the prevalence of characteristics of the “horse riding syndrome” within the adult population buried in the Avar cemetery Wien 11-Csokorgasse are consistent with the current state of research on lifestyle and habitual activity patterns in the Avar period. Both archaeological data and historical sources have suggested that a number of fundamental changes took place within the Avar populations in Central Europe after the middle of the seventh century AD, including the trend to establishing more permanent settlements and the transition to an economy based more on agriculture and less on herding and plundering (“war economy”). The results of this thesis support this hypothesis. However, it is the first systematic study of the horse riding syndrome in an Avar population which uses more than one characteristic, so further research is needed, not only on other adult populations from Avar cemeteries, but also on the non-adult segment of Avar populations. There is evidence suggesting that the characteristics of the “horse riding syndrome” are fully evident already in young adults. Hence, the formation of the characteristic traits of the “horse riding syndrome” may already have occurred during adolescence in Avar populations.

Osteological research on the “horse riding syndrome” in Avar populations could serve as a “control” for the results of archaeological research, thus adding an additional dimension to historical interpretations. In particular, this could be extremely relevant for the issue of “identities” of different segments of the population in the Avar period, in particular the “Avar warrior elite”. The results so far suggest that, with the help of the “horse riding syndrome”, we may have succeeded in identifying a group of elite Avar warriors, whose lifestyle appears to have differed from that of the lower-status male population buried within the Avar cemetery in question. For example, this is relevant in the discussion regarding the increased prevalence of “equestrian burials” along the northwestern border of the Avar Empire in Late Avar Period II-III (second half of the eighth century AD). In view of our results, this phenomenon could be more than just a distant reflection of the “steppe nomadic past” within Late Avar Society. Instead, it could suggest that a particular, high status “social group” preserved “mounted warrior traditions” – a lifestyle dominated by training for mounted combat as well as hunting – even at a time when the vast majority of lower-status inhabitants of the Avar Empire led a very different lifestyle, focusing on agriculture. Similarly, the results regarding “immigration generation Avar women” with an increased prevalence of the “horse riding syndrome” could add a new perspective on the role of women in Avar society.

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Abstract

The “horse riding syndrome” comprises a number of changes on the human skeleton which, if found in association, could indicate that the individual in question practiced horse riding as a habitual activity during his or her lifetime. In the bioarchaeological literature, “Poirier’s Facet” (*Reiterfacette*) has been referred to as one characteristic trait of the “horse riding syndrome”. Therefore, in archaeological contexts, individuals where “Poirier’s Facet” (*Reiterfacette*) is present on one or both femurs could be expected to exhibit a higher prevalence of other characteristics of the “horse riding syndrome”. Firstly, the aim of this thesis is to contribute to methodological research on the “horse riding syndrome”, by testing possible associations between different characteristics within the adult population of an Avar cemetery of the 7th-8th century AD from Eastern Austria (Wien11-Csokorgasse). Avar populations are ideally suited for methodological research on the “horse riding syndrome”, because – according to historical sources – the Avars were accomplished mounted warriors. Indeed, the results demonstrate a clear association between the presence of “Poirier’s Facet” on the proximal femur of an individual and the prevalence of other characteristics of the “horse riding syndrome” on the bony pelvis and leg bones of the same individual. Secondly, the aim of this thesis is to identify possible differences in the prevalence of characteristics of the “horse riding syndrome” between different groups within the adult population of Wien11-Csokorgasse. This research is expected to contribute to existing knowledge regarding the “way of life” and habitual activity patterns of Avar populations in Eastern Austria. The results suggest differences in habitual activity patterns within the Avar population in question, especially between the sexes and socioeconomic groups, as well as chronological differences.

Zusammenfassung

Das „Reitersyndrom“ (*horse riding syndrome*) umfasst eine Reihe von Merkmalen, die an menschlichem Skelettmaterial aus archäologischem Fundzusammenhang häufig gemeinsam identifiziert worden sind und für die ein Zusammenhang mit einer Lebensweise, bei der viel Zeit auf dem Pferderücken verbracht wurde, diskutiert worden ist. Die sogenannte „Reiterfacette“ (*Poirier's Facet*) wird in der bioarchäologischen Literatur besonders häufig als kennzeichnendes Merkmal des „Reitersyndroms“ genannt. Insofern ist davon auszugehen, dass Individuen, die durch eine „Reiterfacette“ im Bereich des proximalen Femurs (ein- oder beidseitig) gekennzeichnet sind, häufig auch weitere Merkmale des „Reitersyndroms“ aufweisen. Das erste Ziel der vorliegenden Masterarbeit war es daher, aus methodischer Sicht einen Beitrag zur Erforschung des „Reitersyndroms“ zu leisten, indem Zusammenhänge zwischen verschiedenen Merkmalen dieses Syndroms im adulten Anteil einer awarenzeitlichen Population des 7-8. Jahrhunderts n. Chr. (Gräberfeld Wien11-Csokorgasse) untersucht wurden. Die historischen Quellen berichten, dass die Awaren hervorragende Reiterkrieger gewesen seien, daher ist anzunehmen, dass sich awarische Populationen zur osteologischen Untersuchung des „Reitersyndroms“ besonders gut eignen. Das zweite Ziel der vorliegenden Arbeit bestand darin, eventuelle Unterschiede bezüglich der Häufigkeit der Merkmale des „Reitersyndroms“ innerhalb bestimmter Gruppen der adulten Population des awarischen Gräberfeldes Wien11-Csokorgasse zu identifizieren. Diese Arbeit soll einen Beitrag zur Erforschung der Lebensweise und Aktivitätsmuster der awarenzeitlichen Bevölkerung des Wiener Beckens leisten. Die Ergebnisse weisen auf das Vorliegen von Unterschieden bezüglich Lebensweise und Aktivitätsmuster innerhalb der untersuchten awarenzeitlichen Population hin, insbesondere zwischen Männern und Frauen und zwischen Gruppen mit unterschiedlichem sozialen Status. Chronologische Unterschiede konnten ebenfalls beobachtet werden.