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Peaceful Avars?
Fracture Patterns in the Lower Austrian Burial Ground Leobersdorf

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Abstract

When examining human remains, the study of fractures is crucial and may provide valuable information on challenges the deceased had to face. In this work 129 individuals from the Avar burial ground Leobersdorf, mainly dated between the 7th and 8th century CE, were examined for fractures of the cranium, ribs, and cervical vertebrae. Nineteen individuals (14.7%) showed evidence of at least one injury. Hypothesis one, stating that males show more fractures than females could not be confirmed, although more males than females showed fractures. Hypothesis two, stating that older individuals show more fractures than younger individuals, could be confirmed. Individuals older than 35 years showed significantly more fractures than individuals younger than 35 years. Hypothesis three, stating that males and females show different fracture patterns, could not be confirmed. No significant sex differences were found regarding fracture type, more frequently affected side of the body, occurrence of single and multiple fractures and severity. The observed fractures point to accidents, interpersonal conflicts, or work-related injuries as causes, rather than to warfare, indicating quite a peaceful life of the examined individuals. Considering that the Avars are frequently portrayed as hostile and violent people, these results seem surprising. This study contributes to a more differentiated perception of the Avars and allows a more realistic picture of the investigated group. Especially individuals assigned to the Late Avar period were probably mainly engaged in agricultural work, and not so much in nomadism and looting anymore, which seems to be reflected by the herein observed injuries.

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1. Introduction

Anthropologists working in the field of bioarchaeology use their expertise to recover, reconstruct, and interpret human remains. Frequently, their task is to document and examine human bones recovered in the course of archaeological excavations, to study their morphology and the marks lifestyle and postmortem changes left on them. By closely examining the skeletons, numerous clues about the life and death of individuals can be gathered, since the remains (which also include the teeth) mirror the interaction between genetic and environmental factors (Larsen, 1997; White & Folkens, 2005). This is based on the fact that the skeleton responds to its environment even before birth and throughout life up to the time of death, and its condition depends on factors such as health status, diet, and physical activity. Since bones and especially teeth are very resistant, they are quite often the longest preserved evidence of an individual's life (White & Folkens, 2005). By carefully looking at single bones on the one hand and perceiving the individual as a large whole on the other, anthropologists are able to draw a picture of the life circumstances of former living people (Buikstra et al., 2022; Larsen, 1997).

Based on the remains, it is possible to reconstruct age at death, sex, body height, and to identify past diseases and injuries (White & Folkens, 2005). For example, it is possible to determine whether a person who has already died suffered from malnutrition as a child or whether particular muscle groups were used extensively. Sometimes work-related lesions can be identified since certain movements that are frequently performed or certain postures that are often adopted may leave traces on the bones. Occasionally, it is even possible to gather evidence for relationships between individuals (Larsen, 1997; Roberts & Manchester, 2010), for example through their position in multiple burials, although nowadays mainly aDNA (ancient DNA) studies are used for this purpose in strictly biological ways.

In the best case, however, the examined skeletons can reveal even more. Fractures resulting from accidents or interpersonal conflicts may point to challenges the deceased had to face, and sometimes the degree of healing can also narrow down the time period in which the injury occurred. In addition, evidence about social interactions within earlier populations can be obtained from the way a bone has healed. For example, it can be assumed that in cases of very severe injuries that would hardly have been survived without help, the injured person was nursed by others (Larsen, 1997; Roberts & Manchester, 2010; Tilley, 2015). Fractures thus hold the great potential not only to provide information about particular individuals, but also to infer on former population structures, cultural habits, morbidity, and levels of interpersonal violence. Consequently, the study of fracture patterns may allow crucial insights into the evolutionary history of mankind and is therefore of utmost importance (Buikstra et al., 2022; Larsen, 1997; White & Folkens, 2005).

1.1. Aim of this work and hypotheses

This work aims at gathering information about fractures within the Avar group buried in the early medieval cemetery of Leobersdorf, Lower Austria (47° 55’ 43” N, 16° 13’ 0” E, see Figure 1) and about their proximate causes. The objective is to find out how the fractures are distributed anatomically, with what frequency they occur, and whether there are sex or age differences. Moreover, evidence of healing processes, as well as possible ultimate causes of the fractures, are discussed. This thesis focusses on fractures of the cranium, the ribs, and the first four cervical vertebrae. However, the individuals showing fractures in these anatomical regions are analysed in a more holistic way, also considering possible fractures of the long bones, examined in parallel to this work (N. Reiter, personal communication, 2022).

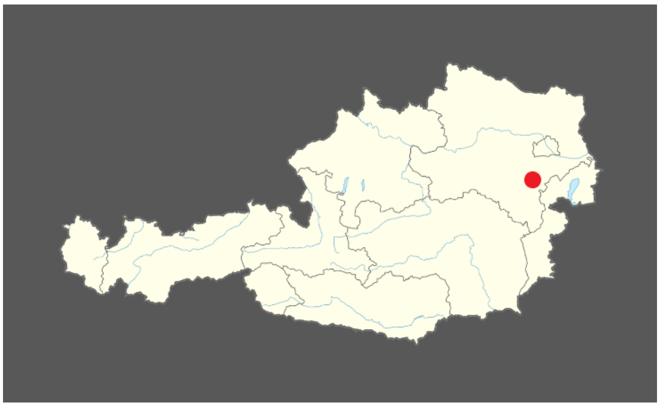

Figure 1. Location of Leobersdorf on the Austrian map (adapted from NordNordWest, 2014).

The results of this work contribute to the HistoGenes Project, which is financed by the European Union in the course of the ERC Synergy Grant Programme, and which examines the population history of the Carpathian Basin between 400 and 900 CE, using aDNA, archaeology, history and anthropology (The HistoGenes Project, 2020). The findings of the anthropological analyses provide information about the individuals on the one hand, and the lifestyle of the group on the other hand. Furthermore, this work is intended to allow comparisons with other populations in terms of fracture prevalence. For this purpose, three hypotheses will be tested.

Hypothesis 1: In general, it can be observed that men are more physically aggressive and risk-taking than women (Eagly & Steffen, 1986; Pawlowski et al., 2008). This leads to a higher chance of fractures caused by accidents, interpersonal violence, or warfare. Thus, it is inferred that skeletons identified as male generally show a higher frequency of fractures than those identified as female.

Hypothesis 2: When studying injuries, it is important to keep in mind that eventual fractures accumulate with increasing age of an individual (Roberts & Manchester, 2010). Also, it should be considered that age-related osteoporosis increases the probability of fractures, especially in women (Roberts & Manchester, 2010; Sahlin, 1990). From this point of view, it is predicted that older individuals generally show more fractures in comparison to younger individuals.

Hypothesis 3: Since Avar cemeteries show sex-specific differences in grave goods, it is assumed that men and women differed regarding their lifestyles and tasks within society (Bott, 1988). Given that this also resulted in different physical burdens and risks, the hypothesis is derived, that sex-specific differences can be found when examining the fracture patterns.

1.2. Biology of bones

Bone as tissue on the one hand and bones as organs on the other play various very important roles in the body. They protect, support, and anchor soft tissues and enable the body's movements. Bones also have critical physiological functions, for example the production of blood cells and the storage of fat and vital elements (Hadjidakis & Androulakis, 2006; White & Folkens, 2005). Bone is among the strongest biological materials that exist, especially when it comes to carrying weight. Despite its great strength, bone is a very light and also quite dynamic material that allows for modification throughout life in the form of remodelling (White & Folkens, 2005).

1.2.1. Bone composition and bone formation

Bone tissue is composed of two types of materials. One is collagen, a large protein molecule that makes up approximately 90% of the organic substance of bone. In the body, it is the most abundant protein, and its molecules are woven into flexible fibres. The other part is made up of hydroxyapatite, a form of calcium phosphate. Its dense inorganic crystals penetrate the collagen matrix and only the interaction of these two materials gives bone its remarkable qualities, such as stability, pliability, and lightness at the same time (White & Folkens, 2005). There are basically three cell types involved in the formation and degradation of bone. Osteoblasts are responsible for bone formation by producing and releasing a collagen-rich organic mass called osteoid. As soon as osteoblasts are surrounded by osteoid matrix, they are called osteocytes. These are designed to preserve the bone tissue. Osteoclasts, in turn, are responsible for the resorption of bone tissue (Hadjidakis & Androulakis, 2006; White & Folkens, 2005).

1.2.2. Types of bones

At the histological level, a distinction is made between immature and mature bone (White & Folkens, 2005). Immature (woven) bone is typically formed fast and is found in the skeleton of embryos and growing individuals and in areas of fracture repair. It is the simpler form of bone, in a sense, because it is gross, and the collagen fibres are randomly arranged. Mature (lamellar) bone, on the other hand, forms the portions of the adult skeleton. Here, the collagen fibres are arranged in an orderly pattern, which is the result of repeated layering of identical lamellae. Bones of adult individuals consist of compact and cancellous bone (Adler, 2000; White & Folkens, 2005). The dense part of the bone that is found on the bone surface is referred to as compact, or cortical bone. The spongy bone, which is lighter, is called cancellous, or trabecular bone, and is found, for example, in vertebral bodies or within flat bones. Compact and cancellous bone are identical in composition and only differ in their porosity (White & Folkens, 2005).

1.2.3. Callus formation

When bone is exposed to unusual forces or is weakened, for example by disease, fractures may occur. As soon as this happens, the organism begins to repair the bone. Ruptured blood vessels cause bleeding into the injured area, creating a haematoma which clots once the vessels are sealed (White & Folkens, 2005). After that, osteoblasts deposit osteoid at the fracture sites, displacing the haematoma and bridging the gap. Through successive mineralisation of osteoid a primary bony callus is formed which consists of woven bone. Subsequently, the primary callus is transformed into lamellar bone which again leads to firmly connected bone fragments (Lovell, 1997; White & Folkens, 2005). The bone then is remodelled until it has regained its original shape and in regions where it is exposed to high loads it is even strengthened in the process. If the site of the injury has not been moved much and the bone ends have not been displaced significantly, it is likely that a former fracture can only be identified through radiographs. In cases, in which a fracture has healed well and, moreover, occurred a long time ago, it is also possible that not even the radiograph shows evidence of the fracture (Lovell, 1997; White & Folkens, 2005).

1.3. Interpretation of fractures

1.3.1. Antemortem, perimortem and postmortem fractures

There are some features that indicate whether a fracture occurred some time before death (antemortem), at or near the time of death (perimortem), or after the individual's death (postmortem). The only obvious sign for an antemortem fracture is the onset of healing (Stodder, 2008). A fracture that shows no signs of healing can therefore be classified as perimortem or postmortem. To distinguish between recent and older fractures, the colouring of the fracture surface may be useful. Recently occurred fractures show lighter colouring on the fracture surfaces, pointing to damage during excavation, transport, or storage, and can therefore be clearly classified as postmortem. If the fracture surfaces are the same colour as the surrounding bone, an older fracture can be assumed (Buikstra & Ubelaker, 1994). In addition, fracture patterns can be useful for determining whether a fracture is modern or ancient since bone breaks differently in a living state compared to a dry state. For example, curved or spiral fracture lines are more common in antemortem and perimortem fractures because the hydration level is high, and the collagen fibres are undamaged. Fracture lines that are more angular in shape are more common in postmortem fractures, as the organic components are reduced or entirely lacking, which also causes sharper fracture edges (Stodder, 2008). Despite these clues, the distinction between perimortem and postmortem fractures is not always an easy task, as the degradation of organic components after death occurs step by step, and a clear classification of colouration, shape of fracture lines and edges is not always possible (Villa & Mahieu, 1991).

1.3.2. Taphonomic changes

When examining human remains the role of taphonomic changes has to be considered. Taphonomy illuminates various processes that act on and alter remains from the time of an individual's death until the time of examination (Stodder, 2008). Natural influences, animals and humans may affect the preservation status of human remains. Natural impacts include, for example, temperature ranges, humidity levels and chemical composition of the surrounding medium, as well as vegetation. Animals may influence the condition and the completeness of remains through the use of their sharp teeth or the removal of individual body parts. Human influences include both intentional and unintentional modifications of modern and past people. These include, for example, burial customs, grave robbery, excavation techniques, transport and storage conditions, as well as research methods (Stodder, 2008).

When examining fracture patterns, it is therefore vital to keep in mind that taphonomic changes can, on the one hand, mask existing fractures and, on the other hand, cause osseous changes that may be misinterpreted as evidence for a fracture (Calce & Rogers, 2007).

1.3.3. Radiographs

Radiographs are crucial for the examination of fractures to assess the degree of healing, the extent of deformation or the displacement of fracture ends. Also, radiographs are important in evaluating fractures that have healed well before the death of the individual. In the first weeks after the injury, the callus appears in the radiograph with blurred outlines, with patches showing higher bone density. The older the callus gets, the more the dense areas spread out. Over time, the callus becomes more and more calcified, closely resembling normal healthy bone. A callus that spreads extensively can usually be interpreted as an indication of an inadequate period of recovery, as the movement additionally stimulates the formation of new bone. When examining radiographs of fractures, earlier stages of healing still show a clearly visible fracture line. Advanced stages of healing display fracture lines that are only slightly visible or are already completely obliterated. When evaluating the degree of healing it is, however, important to consider that many different factors affect the time needed for complete healing, such as the location of the fracture, the age, and the nutritional status of the individual among others (Roberts, 1991).

1.3.4. Fracture causes

When investigating fracture causes, the sociocultural context of the population under study should be considered. In general, it can be stated that fractures are often caused by daily activities and more rarely by interpersonal violence and uncommon occurrences, such as warlike situations. Fractures of the cranium, the ribs, and the bones of the hands, however, are considered to be caused more likely by interpersonal violence than other fractures. In the case of cranial fractures, especially injuries of the nasal bone, the zygomatic bone and the mandible are often thought to be the result of violent conflicts (Lovell, 1997).

Nonetheless, in most cases a clear distinction between fractures caused by accidents and fractures caused by violent interpersonal encounters is hardly possible in archaeological contexts since a serial rib fracture, for example, can either occur in the course of a fight, through several strikes against the same area of the rib cage, or due to an accidental fall against a solid object.

Likewise, a cranial fracture can either be caused by a blow against the head with a blunt object, carried out by an opponent in the course of a physical confrontation, or by an object accidentally falling on the head of the injured person. Fractures resulting from armed conflicts, on the other hand, are often easier to classify. For example, in the case of human remains that have been assigned to sites of battlefields, individuals with multiple injuries, perimortem injuries and/or injuries caused by direct sharp force trauma are frequently found (Jordana et al., 2009).

In some cases, it is even possible to match particular fracture patterns to specific weapons, used by opposing groups (Lockau et al., 2013; Rubini & Zaio, 2011; Scaffidi & Tung, 2019). That is why the archaeological context, and the historical information (if present) should always be taken into account when examining human remains. For Leobersdorf, the site under study herein, this information is just being re-evaluated, so that in the future a more reliable picture of the living conditions of the herein examined individuals can be drawn. However, the possibility of warlike conflicts causing fractures that would normally rather be associated with accidents or interpersonal disputes and vice versa cannot be ruled out completely. Thus, the present work refrained from the presentation of clear ultimate causes for the occurring fractures, and only aimed at gathering information on the proximate fracture causes (direct or indirect trauma).

1.4. Types of fractures

Trauma generally describes damage to living tissue caused either incidentally or intentionally by external forces. A distinction can be made between blunt force trauma produced by blunt objects like the ground or a mace, and sharp force trauma which is a penetrating trauma caused by a sharp object like a sword or an axe (Lovell, 2007). A fracture is characterized by a partial or total breach in the bone's continuity. There are different types of fractures, whereby the most common ones are caused by direct or indirect forces. Less common are fractures that are stress-induced or occur as a consequence of pathologies (Lovell, 1997).

1.4.1. Direct trauma

When a force acts on a certain area causing a fracture at the point of impact, it is called direct trauma injury (Lovell, 2007). This type of fracture can be categorised further into penetrating, comminuted, transverse, and crush (see Figure 2).

Penetrating fractures are caused by a large force acting on a very small area resulting in partial or total penetration of the bone surface. This may occur, for instance, when the bone is struck by a sword or injured by a projectile.

In certain cases, penetrating fractures can also occur as **comminuted fractures**. These types of fractures are characterised by the bone being broken into more than two fragments. Such fractures often occur, for example, when blunt force is applied to the head.

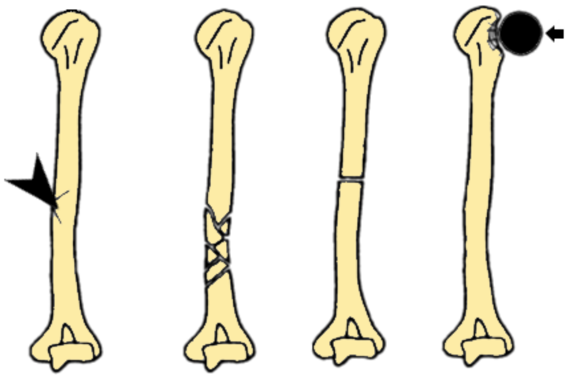

Figure 2. Types of fractures produced by direct trauma: penetrating, comminuted, transverse, and crush (adapted from Lovell, 1997).

Transverse fractures are caused by a comparatively small force acting on a small region perpendicular to the bone's longitudinal axis. A typical example for this type of fracture is a transverse fracture of the tibial shaft caused by a blow to the lower leg (Lovell, 1997).

Crush fractures are characterised by the bone falling in upon itself. They are most common in cancellous bone and occur, for example, when a heavy object strikes the hand or foot. As shown in Figure 3, there are further subcategories into which crush fractures can be divided (Lovell, 1997). *Depression fractures* are frequently found on the cranium and are characterised by unilateral crushing of the involved bone. *Compression fractures*, on the other hand, are caused by bilateral crushing of the bone and are frequently found in vertebral bodies.

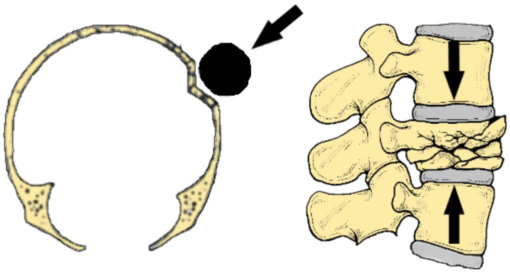

Figure 3. Subcategories of crush fractures: depression and compression (adapted from Lovell, 1997; Old & Calvert, 2004).

1.4.2. Indirect trauma

In an indirect trauma injury, the fracture occurs at a location that is not directly affected by the applied force (Lovell, 2007). Such a fracture can be further classified as greenstick, oblique, spiral, impacted, avulsion or burst fracture (see Figure 4).

Greenstick fractures are most common in children, as their bones are more flexible and therefore harder to break than those of adults. These fractures are caused by an indirect force that bends the bone and causes an incomplete fracture on the side that is exposed to the bending. In children, such fractures often involve the clavicle in the course of childbirth or the still-developing long bones, whereas in adults the ribs are frequently involved (Lovell, 1997).

Oblique fractures are caused by a combination of angulated and rotational forces and are characterised by a fracture line that runs at an angle to the longitudinal axis of the bone (Harkess & Ramsey, 1991, as cited in Lovell, 1997).

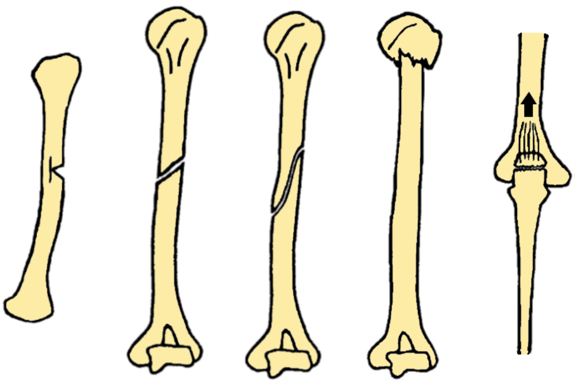

Figure 4. Types of fractures produced by indirect trauma: greenstick, oblique, spiral, impacted, and avulsion (adapted from Lovell, 1997).

Spiral fractures are caused by a downward and rotating force and are characterised by a break that winds around the longitudinal axis of the bone.

An **impacted fracture** occurs when the two ends of the broken bone are pushed into each other. Such fractures are often found on the proximal humerus after a fall on the outstretched arm or on the metacarpals after a punch with a closed fist (Lovell, 1997).

Avulsion fractures occur when joint capsules or tendons are pulled away forcefully from their attachments and tear off a part of the bone in the process. An example for this fracture is the so-called "clay-shoveller's fracture" where the spinous process of the seventh cervical vertebra or the first thoracic vertebra is ripped off (Knüsel et al., 1996; Lovell, 1997; also see chapter 1.4.7.).

When a large force acts on the spine, compressing the vertebral bodies in such a way that the intervertebral disc ruptures and the tissue of the disc penetrates the vertebral body, it is referred to as a **burst fracture** (see Figure 5). In human remains mild manifestations of such fractures, the so called "Schmorl's nodes" that appear as roundish impressions, are frequently found (Lovell, 1997).

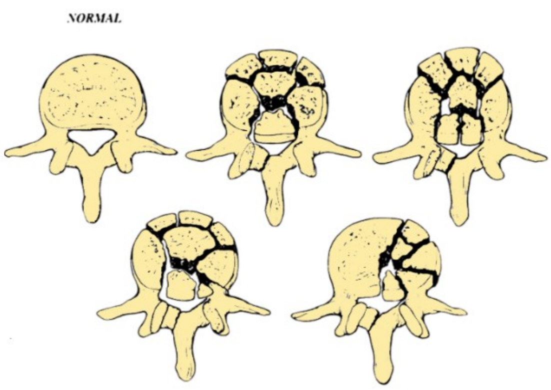

Figure 5. Different manifestations of burst fractures (adapted from Atlas, Regenbogen, Rogers & Kim, 1986).

Comminuted and **crush fractures** can be caused not only by direct trauma but also by indirect trauma. A comminuted fracture caused by indirect forces frequently has a "T" or "Y" shape, which is caused by the bone being split into different directions (Perkins, 1958, as cited in Lovell, 1997). Crush fractures caused by indirect forces affect, for example, the calcaneus after a jump from a great height (Lovell, 1997).

1.4.3. Stress fractures

So-called stress fractures may be confused with transverse fractures caused by direct trauma, since the fracture line also runs perpendicular to the bone's longitudinal axis. Stress fractures, however, are caused by a force acting recurrently on the bone, resulting in a hairline fracture. Such a fine tear in the bone tissue cannot be visualised by radiographs and frequently only becomes obvious when the bone reacts to the injury by forming a callus (Lovell, 1997). Typical stress fractures are commonly found in the metatarsals of soldiers and are thus termed "marching fractures". Stress fractures affecting the tibia are often found in athletes (Orava, 1980).

1.4.4. Pathological fractures

Fractures can also be triggered by pre-existing diseases. Such pathological fractures occur when the bone is already weakened, for example due to a lack of nutrients or a disturbed metabolism. In cases like these, it is more likely that even small forces that would normally not cause an injury result in a fracture (Lovell, 1997). People suffering from tuberculosis of the spine (Pott's disease), for example, frequently experience a breakdown of the vertebral bodies (Dass et al., 2002). Likewise, older women who already suffer from osteoporosis show a higher prevalence of fractures (Cawthon, 2011).

1.4.5. Cranial fractures

Pathological fractures and stress fractures are rarely seen in the cranium. The majority of cranial fractures results from direct trauma and affects the neurocranium. Cranial fractures resulting from direct force can be classified as linear, depressed (crush), or penetrating (see Figure 6).

These, however, are not mutually exclusive. Both linear fractures and depressed fractures are usually caused by blunt force trauma, whereas penetrating fractures are usually caused by objects that are shaped more sharply (Lovell, 1997).

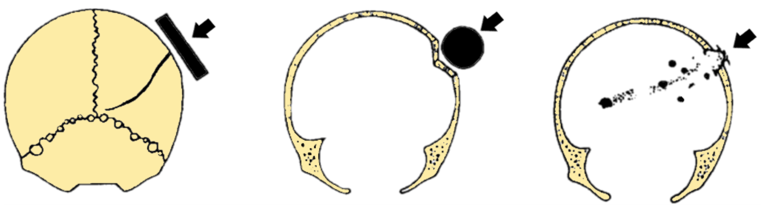

Figure 6. Fractures of the neurocranium caused by direct trauma: linear, depressed (crush), and penetrating (adapted from Lovell, 1997).

In general, the patterns of linear fractures vary with the intensity of the applied force. A single linear fracture is caused by less force than a fracture with star-shaped fracture lines (Gurdjian et al., 1950, as cited in Lovell, 1997). Star-shaped fractures form directly at the point of impact, whereas single linear fractures spread from the point of impact. In the case of multiple fractures of the cranium the chronological order of the fractures can sometimes be reconstructed, given that newly added fracture lines cannot spread across already existing ones.

In depressed (crush) fractures the point of impact can be recognised by an imprint in the bone, from which ring-shaped fracture lines expand. The involved area may also be comminuted, which results in a mosaic-like pattern.

Penetrating fractures are commonly caused by projectiles or sharp objects. Depending on the shape of the striking object and the severity of the acting force, also penetrating crush fractures may occur (Lovell, 1997).

Injuries of the cranium caused by indirect forces are rarely seen. Such fractures can result, for example, from a fall, where the force is transmitted through the spine, or from force against the chin, where the force is transmitted through the mandible to the region around the temporomandibular joints (Harvey & Jones, 1980). The individual bones of the viscerocranium are closely connected to each other, which means that a fracture often spreads over more than one bone. Although facial fractures may be very complicated, they often heal well without any medical intervention (Lovell, 1997).

1.4.6. Rib fractures

Ribs may be affected by stress fractures, produced, for example, by frequent coughing or repeated vomiting. Fractures caused by direct trauma, however, are more common in ribs. A transverse rib fracture is typically a result of a direct chest trauma, like a punch or a fall onto a solid object.

An oblique fracture is typically a result of an indirect chest trauma, like a crushing or bending of the affected area (Lampe, 2007; Lovell, 2007; Galloway, 1999). Ribs four to nine are most frequently affected. If ribs one to three are affected, it can be assumed that a particularly large force was involved, as those ribs lie underneath the shoulder girdle. A fracture of the lower ribs may indicate internal injuries due to the high flexibility of these ribs (Lampe, 2007; Lovell, 2007; Galloway, 1999). In the case of indirect chest trauma, the location of the rib fracture can be used to infer the direction of the acting force. If the fracture is located in the region around the rib's angle, the load was frontally exerted. If, however, the fracture is located near the spine, the load was applied from behind. If fractures are found close to the spine and also close to the sternum, the load was acting from the side.

However, it should be kept in mind that under certain circumstances a single punch may also cause several fractures at different locations. Independent of the type of force applied, the posterior angle of the rib is generally the most vulnerable point for a fracture (Lampe, 2007; Love & Symes, 2004; Lovell, 2007).

In the case of rib fractures, the possible involvement of soft tissue should always be considered. Ribs are quite flexible by nature, which means that they may bend inwards during the fracturing event. This may enable severe soft tissue damage, even though the fracture itself might not appear that severe after the force is removed. Also, problems may arise if a rib is fractured in a way that results in a freely movable bone segment. Rib fractures can, under certain circumstances, lead to injuries of blood vessels, the pleura, and the lungs. Such injuries used to be impossible to treat in the past and were therefore a likely cause of death. Rib fractures that have already healed tend to indicate injuries that were not life-threatening, since fractures that caused the death of an individual can only be classified as perimortem in archaeological remains (Brickley, 2006; Love & Symes, 2004; Lovell, 2007).

1.4.7. Vertebral fractures

The spine is most frequently affected by stress fractures, pathological fractures and fractures caused by indirect trauma (Lovell, 1997). The so-called "clay-shoveller's fracture" is a stress fracture that is recognised by the avulsion of the spinous process of the seventh cervical vertebra or the first thoracic vertebra and owes its name to the association with shovelling heavy material (Knüsel et al., 1996; Lovell, 1997). In vertebrae weakened by osteoporosis, pathological fractures frequently cause a biconcave shape as the vertebral bodies collapse under the pressure of the intervertebral discs. Fractures caused by indirect trauma may occur in falls or jumps where the force is transmitted through the spine. In these cases, the above-mentioned burst fractures may be observed (Lovell, 1997).

Vertebral fractures caused by direct trauma are relatively rare in the spine (Lovell, 1997). Strangulation and decapitation, for example, may leave marks on the upper cervical vertebrae. In the case of strangulation, where death is caused by asphyxiation due to compression of the blood vessels and airways, there may only be hardly visible marks, such as transverse hairline fractures of the C2 (Chapman & Gearey, 2019; Maples, 1986; Waldron, 1996).

In contrast to this, signs of decapitation are relatively easy to identify. In some cases, the discovery of the cranium in an unusual location, for example near the legs, already points to a possible beheading. However, a violent severance of the head can only be determined conclusively by examining the cervical vertebrae. If traces of slashes or cuts can be found, these may be considered as indicators for decapitation. Here, one or more vertebrae may be affected, whereby the marks are usually found on the upper cervical vertebrae. Under certain circumstances, also the mandible and the mastoid processes can be affected (Maples, 1986; Waldron, 1996). The observable marks may vary depending on the type of weapon used for the decapitation. For example, the transverse processes may show crush fractures when an axe has been used instead of a sword (Waldron, 1996).

In the case of death by hanging, the observable injuries also depend on the used technique. When a person is hanged with a running noose without falling from a height, transverse hairline fractures of the upper cervical vertebrae, similar to the injuries found in cases of strangulation, may be found. When a person is hanged by using a noose with a knot and by falling from a greater height, death is caused by injury of the spinal cord, whereby displacements and/or fractures of the upper cervical vertebrae may occur (Spence et al., 1999; Waldron, 1996). The so-called "hangman's fracture" is one of the fractures that may occur in hanging situations and is characterised by a fracture dislocation of the second cervical vertebra (Waldron, 1996). Although injuries of the cervical vertebrae which result from hanging may vary considerably, displacement of the cervical vertebrae is most commonly seen between C1 and C2 or C2 and C3 (Spence et al., 1999).

1.5. The Avars

Considering the fact that they were a very powerful force in Europe in late antiquity and the early Middle Ages, the Avars are relatively unknown today. They ruled large areas of Central and Eastern Europe from 558 to 796 CE including present-day Burgenland, Lower Austria, and Vienna (Großschmidt, 1990; Pohl, 2018).

The exact origin of the Avars is still disputed today but at least some of them emerged from the Asian steppe (Pohl, 2018; Pohl et al., 2021). From 560 CE the Avars ruled over the Black Sea steppes and received tribute payments from Byzantium. They signed a peace treaty with the Lombards and took over the rule in the Carpathian Basin after the Lombards moved to Italy in 568 CE. They spread along the Danube and soon dominated the area of present-day Hungary. By 600 CE, Avar settlements had spread as far as the Vienna Woods (Daim, 1977; Großschmidt, 1990). Their raids extended over most of the Balkan peninsula and also touched Friuli and Thuringia. In 626 CE, a siege of Constantinople failed, which led to a substantial weakening of the Avars (Pohl, 2018).

After that, no more significant Avar attacks were carried out. After more than 200 years during which the Avars were the most powerful people in the Carpathian Basin, their empire was finally destroyed by Charlemagne at the end of the 8th century. The term "Avars" disappeared at the beginning of the 9th century and the Avars themselves merged with the Slavs, perhaps contributing to the gene pool of today's Austrians (Daim, 1977; Großschmidt, 1990; Pohl, 2018).

1.5.1. Life and death of the Avars

Little is known about the language of the Avars and very few written records - some short runic texts, titles (Khagan, Katun, Tudun), and names (Solak, Samur, Kok) - are preserved. These point to the Turkish language and a political organisation and administration similar to that of the Turks (Großschmidt, 1990; Pohl, 2018). “Baian” is the only known name of an Avar leader, all other leaders are simply referred to as “Khagan” in the records (Pohl, 2002). Thus, the picture we have of the Avars today was mostly drawn by their opponents. When arriving in Constantinople for the first time, Greek sources described the unusual appearance of the Avars, and in particular the long, braided plaits. The foreign-looking horsemen seemed primitive and brutal to the more cultivated Byzantines (Pohl, 2018). Many contemporary sources written by their enemies characterize the early Avars as violent, unpredictable, and greedy equestrian people with raids, abduction, and extortion being part of their daily business.

Works of Frankish and Byzantine authors describe Avar warriors as heavy-armed riders equipped with swords, coats of mail, and heavy lances (Großschmidt, 1990). The Avar military campaigns spread fear and terror, but what their enemies perceived as reckless aggressiveness was a subtle interplay of negotiation skills, raids, and intimidation (Pohl, 2018). Their scythian reflex bows, combined with triple-bladed arrowheads on long shafts, enabled a firing rate of 20 arrows per minute with a range of up to 500 metres. Also, the Avars brought innovations, like the first use of iron stirrups in Europe and with it a new riding technique which was quickly imitated by Byzantine riders (Großschmidt, 1990; Pohl, 2002).

Table 1. The six Avar periods with associated time ranges (after Daim, 1987).

Historical period	Time range
Early Avar period	- 650 CE
Middle Avar period	650 - 710 CE
Late Avar period I	710 - 800 CE
Late Avar period II	710 - 800 CE
Late Avar period IIIa	710 - 800 CE
Late Avar period IIIb	after 800 CE

Table 1 gives an overview of the six Avar periods and the associated time ranges (Daim, 1987). The Early Avar period differs from the Late Avar periods in terms of social structure, culture, and economy. As a steppe people the Avars lived as nomads at first and raised livestock, but from the first third of the 7th century on they gradually changed to a settled way of life and livestock farming was combined with agriculture (Pohl, 2002).

In the Late Avar periods the settlement area expanded and a much denser settlement of southern Slovakia, the Vienna Basin and the Little Hungarian Plain evolved, compared to the Early Avar period (Daim, 1996; Pohl, 2002). The final homeland of the Avars in the Carpathian Basin was characterised by vast sand and salt heaths and steppe-like areas. The generally dry and warm climate made it possible to live in tents and simple huts and houses (Kollautz & Miyakawa, 1970).

More and more larger burial fields with long periods of occupancy were created. The cemeteries of the Middle and Late Avar periods are laid out in a more structured manner and were partly occupied over several generations, in contrast to the often isolated burials of the Early Avar period. As the remains of some graves suggest, Avar warriors were partly entombed in company of their horses and especially in the Early Avar period, the bodies of high-ranking warriors were buried in traditional costumes and equipped with their arms.

In the Late Avar period, however, weapons as grave goods become less common, whereby agricultural instruments are more frequently found (Daim, 1996; Pohl, 2002; 2018). Archaeological findings point to clothing components of Chinese and shamanistic tradition, and some objects are also associated with the Sassanid culture of Iran, suggesting influences of different ethnic groups. Skilfully ornamented belt-fittings made of copper-alloy, in many cases gilded, are common burial goods found in Avar graves of the 8th century. Silver and golden earrings which were worn by both men and women are often found. In graves of high-ranking women, also beaded necklaces were discovered (Großschmidt, 1990; Szenthe, 2021; Winter, 1997).

In general, it can be said that the Avars had two mainstays. On the one hand they provided themselves (sometimes also through subjugated populations) with the most essential goods, such as food and ceramics, on the other hand they accumulated wealth through raids and tribute payments (Pohl, 2018). In some graves that were assigned to the Avars, objects of foreign origin, associated for example with the Bavarian-Alemannic region, Italy, and the Byzantine Empire, could be found (Großschmidt, 1990; Foghammar, 1985; Lippert, 1969). Although little is known about the trading relations of the Avars, they probably played a rather subordinate role in the procurement of goods (Pohl, 2018). Especially prestige objects and raw materials for their own production sites were often obtained in the course of military campaigns. This approach allowed the Avars to ensure their survival, maintain a certain status and build up their empire (Pohl, 2018).

Written sources of the time hardly mention the “calmer” Avars of the later periods (after 710 CE), where the majority of the population was probably engaged in agricultural work, in contrast to the more “aggressive” ones of the Early Avar period, where nomadism and military campaigns still played a more important role (Pohl, 2002).

Evidence of about 600 Avar settlements, many of them in south-eastern Hungary, has been found. Of these, however, only about a handful have been studied in more detail and published, and none of these settlements has yet been fully excavated (Herold, 2018; Szentpéteri, 2002). This makes anthropological studies of skeletal remains recovered from Avar burial grounds all the more important for gathering information about former populations and their way of living.

2. Material and Methods

2.1. Material

The human remains examined herein belong to the osteological collection of the Department of Anthropology at the Natural History Museum Vienna (NHMW). The remains, which were dated to the 7th and 8th century CE, originate from the burial ground Leobersdorf in Lower Austria, and were assigned to the Avars (Daim, 1987). This assignment, as well as the dating, was mainly based on written sources of the time, burial rites, and archaeological finds, such as components of traditional costumes and grave goods (Daim, 1987).

Of the 129 individuals which were examined herein for the presence of fractures, 125 were associated with the Middle (approx. 650 to 710 CE) and Late Avar period (approx. 710 to 800 CE and after 800 CE). Thus, it is likely that most of the examined individuals lived as sedentary farmers, in contrast to the four individuals assigned to the Early Avar period (approx. 568 to 650 CE) also found in this cemetery (Daim, 1977). The osteological material is relatively well preserved and has already been partly anthropologically investigated (including determination of sex and age at death, see Grefen-Peters, 1987), which was useful for the more in-depth analyses carried out herein.

2.1.1. Circumstances of discovery and excavation of the archaeological site Leobersdorf

In 1953, an unmarked grave was discovered during construction works of a brickyard in the Lower Austrian market town Leobersdorf, which is located 40 km south of Vienna (see Figure 1). The grave was excavated by Franz Hampl, the then head of the Department of Prehistory and Early History of the Lower Austrian Provincial Museum. According to the brickyard owner, no other graves were discovered within a radius of 5 metres, since any such graves also would have been noticed during the construction works, and so the investigations were terminated (Daim,1987).

In 1976, at some distance from the first grave, several other graves were discovered during renewed construction works on the brickyard area. Under the supervision of Dr. Falko Daim archaeological excavations then were carried out from 1977 to 1983, and a burial ground of the Avar period with 153 graves was exposed (Daim, 1987). Most of the graves were assigned to the Middle and Late Avar period (second half of the 7th and 8th century CE), although a few graves (11, 38, 152 and 153; see Table 1 in the Appendix) were attributed to the Early Avar period (Daim, 1987). From the 153 graves, the remains of a total of 171 individuals were recovered.

Of these 171 individuals, 63 were classified as adult males, 68 as adult females and 40 as subadults (Grefen-Peters, 1987). The anthropological investigations revealed 16 double, three triple and one multiple burial (Grefen-Peters, 1987). Furthermore, five secondary burials could be observed. In many graves, remains of wood coffins or tomb installations could be found. Also, 121 graves revealed long bones from domestic and wild animals which indicate that animals or animal parts were added as burial gifts (Daim, 1987). Furthermore, the archaeological investigations revealed 17 additional burials. Of these, however, no skeletal remains have been preserved, presumably due to the poor state of preservation, grave disturbances and/or robbery of the graves. They were attributed to nine adults and eight children due to certain features of coffin traces and grave goods (Daim, 1987). Thus, the Avar burial ground Leobersdorf must have originally contained a total of 188 individuals.

With few exceptions the excavated individuals were buried in stretched back position facing East. The human remains, which were recovered during the excavations, were cleaned and curated at the Institute of Human Biology of the Technical University of Braunschweig. After completion of the anthropological investigations by S. Grefen-Peters (1987), during which the state of preservation, age at death, sex, as well as some morphometric and pathological characteristics were recorded, the collection was transferred to the Department of Anthropology of the Natural History Museum Vienna, where it is still stored today.

2.2. Methods

The osteological analyses described and discussed herein were carried out at the Natural History Museum Vienna. Only individuals from the age of about 13 years onwards were examined, since fractures in children show different characteristics than fractures in adults due to immature bone and fast repair mechanisms, which frequently makes it impossible to determine injuries in children's bones in the first place (Lewis, 2007). This led to a sample of 131 adult individuals. The remains of one adult individual (grave number 71) were missing during the time of data collection and could therefore not be considered for the examinations. Furthermore, individuals that suffered from underlying diseases that promote fractures were excluded from the calculations of fracture prevalence since eventual fractures of these individuals cannot be considered exclusively traumatic. As the individual excavated from grave number 104 likely suffered from tuberculous spondylitis of the spine (Pott's disease; see Grefen-Peters, 1987), this individual was excluded from the calculations of fracture prevalence. Thus, for a sample of 130 adult individuals the state of preservation and for a sample of 129 adult individuals the prevalence of fractures could be examined.

The present thesis focused on the cranium, the ribs and the first four cervical vertebrae, since fractures in these areas are frequently associated with intentional interpersonal violence (Larsen, 1997; Lovell, 1997; Maples, 1986; Spence et al., 1999; Waldron, 1996). First, all bones of a given individual were placed in anatomical position. Since part of them were fragmented due to taphonomic processes, they were inspected carefully to neatly separate the relevant cranial, rib, and vertebral fragments. As far as possible, the existing cervical vertebrae were put in the correct order, a determination of the side and also the relative position of the ribs within the ribcage was carried out, the present cranial fragments were described, and the former connections to each other were analysed. Afterwards, the state of preservation was documented, both photographically and by means of a database. Also, observations on unusual features such as inflammatory reactions were noted.

The remains were then carefully, systematically, and macroscopically checked for existing fractures occurred during life, with healing marks or callus formations, and those possibly occurred perimortem, or even postmortem. When a fracture was detected, it was examined under a magnification lens and its exact location on the bone was documented. It was first roughly classified according to the mechanism that could have led to the fracture, i.e., direct or indirect trauma, and then divided into further subcategories (Lovell, 1997). Ribs with obvious callus formations and/or on the radiographs clearly visible fracture lines were considered as results of a total break of the rib (complete fracture) and counted as "severe fracture". Ribs with only slight thickenings or irregularities and no evidence of fractures visible on the radiographs were considered to be results of a partial break of the rib (incomplete fracture) and were classified as "minor fracture".

In addition, the degree of healing and the manner of callus formation was documented according to Lovell (1997). Here, it was documented whether the fracture had healed a long time before death, or whether it was still in the process of healing when the individual died. It was also documented whether the fracture had healed well or poorly, for example due to displacement of the fracture ends.

2.2.1. Radiographs and CT scans

Radiographs and/or CT scans of the existing fractures were produced in collaboration with the University of Veterinary Medicine Vienna. Here, the Siemens Axiom Iconos R 200 X-ray system was used for the radiographs and a Siemens Somatom Emotion 16 system was used for the CT scans. Some of the radiographs were also taken with the Gierth HF 200 A power X-ray system belonging to the Natural History Museum Vienna.

Under consideration of the radiological imaging, which provided a more detailed visualization of the biomechanical fracture patterns, the degree of callus formation, the extent of bone deformation and the displacement of fracture ends was investigated. Clearly visible fracture lines were assessed as indicators for earlier stages of healing than fracture lines that were only slightly visible or already completely obliterated. These were assessed as indicators for more advanced healing stages.

2.2.2. Data collection

For each individual, associated time period, grave number, sex, age at death, body height (if possible) and state of preservation of the cranium, ribs and first four cervical vertebrae were recorded in a specially created digital database (not presented herein due to space constrictions). Here, the associated time period and the grave number were adopted from Daim (1987). Sex, age at death and body height were adopted from Grefen-Peters (1987). According to Daim, each individual was assigned to one of six time periods ("Early Avar period", "Middle Avar period", "Late Avar period I", "Late Avar period II", "Late Avar period IIIa" or "Late Avar period IIIb"). Based on Grefen-Peters' age determination, the remains were divided into four age at death categories. The categories were subadult (<20 years), young adult (20-34 years), middle adult (35-49 years), and old adult (50+ years) (Buikstra & Ubelaker, 1994).

For the age at death determination Grefen-Peters considered the obliteration of the cranial sutures, the spongiosa structure of the proximal humeral and femoral epiphyses and the relief of the pubis symphysis according to Nemeskéri, Harsányi & Acsádi (1960). Also, the instructions for age estimation by Breul (1974), Kobayashi (1967), Acsádi & Nemeskéri (1970), Stevenson (1924), McKern (1970) and Kerley (1970) had been considered. Where possible, the sternal articular surfaces of the clavicles according to Szilvássy (1977; 1978) were considered as well (Grefen-Peters, 1987). In infantile and juvenile individuals, mainly tooth eruption and degree of mineralisation of the teeth were examined (see Bradley, 1961; Van der Linden, 1983; Nemeskéri, Harsányi & Acsádi, 1960 and Schranz, 1959), along with the stages of skeletal maturity (Nemeskéri, Harsányi & Acsádi, 1960). Only if there was no other option due to poor preservation, the degree of abrasion of the teeth after Miles (1963) was used to estimate the age at death (Grefen-Peters, 1987).

In addition to the usual morphological characteristics of the cranium (nuchal crest, mastoid process, supraorbital margin, prominence of the glabella, mental eminence) and the general shape and size of the skeleton, in particular the coxal bone (ventral arc, subpubic concavity, ischiopubic ramus ridge, greater sciatic notch, preauricular sulcus) was used for sex determination (Buikstra & Ubelaker, 1994; Grefen-Peters, 1987; Novotný, 1968; 1971).

The formulae by Breitinger (1937) and Bach (1965), which were developed based on measurements of living German male and female athletes, were used to calculate the body heights from the maximum lengths of the long bones (Grefen-Peters, 1987). However, in her work, Grefen-Peters points out that the calculated body heights can only be regarded as rough estimations, as the preservation status of the remains often allowed only two or three long-bone measurements to be used for calculation for each individual.

For the present thesis and to assess the state of preservation, various variables were created for the cranium, the ribs, and the first four cervical vertebrae. The individual cranial bones were assessed separately. Here, only those cranial bones that play a major role in the formation of the neuro- and viscerocranium were considered, which led to a total of 22 cranial variables. To assess the state of preservation of the ribs, four different variables per side were created. To assess the state of preservation of the first four cervical vertebrae, one variable each was created. Overall, a total of 39 variables was recorded systematically for each one of the 129 herein examined individuals.

For most variables, the degree of preservation was reported as 0 for “not present”, 1 for “present, 0-25%”, 2 for “present, 25-50%”, 3 for “present, 50-75%” or 4 for “present, 75-100%” (adapted according to Buikstra & Ubelaker, 1994). Table 2 provides an overview of the examined bones, the associated variables, and how they were recorded.

Table 2. Bones and body areas examined, divided according to the variables created for data collection and documentation mode of each variable.

Examined bone or area	Variables	Mode of documentation
Cranium		
Frontal bone	Frontal bone	0 = not present 1 = present, 0-25% 2 = present, 25-50% 3 = present, 50-75% 4 = present, 75-100%
Parietal bone	Parietal bone, left side	
	Parietal bone, right side	
Occipital bone	Occipital bone	
	Occipital condyle, left side	
	Occipital condyle, right side	
Temporal bone	Temporal bone, left side	
	Temporal bone, right side	
	Mastoid process, left side	
	Mastoid process, right side	
Nasal bone	Nasal bone, left side	
	Nasal bone, right side	
Zygomatic bone	Zygomatic bone, left side	
	Zygomatic bone, right side	
Maxilla	Maxilla, left side	
	Maxilla, right side	
Mandible	Ramus, left side	
	Ramus, right side	
	Corpus	
	Caput, left side	
	Caput, right side	
Cranium	Preservation status of whole cranium	
Ribs		
1st Rib	1st Rib, left side	0, 1, 2, 3 or 4
	1st Rib, right side	
Ribs 2 to 10	Ribs 2 to 10, left side	Number of rip heads counted
	Ribs 2 to 10, right side	
Ribs 11 and 12	Ribs 11 and 12, left side	
	Ribs 11 and 12, right side	
Ribs 1 to 12	Ribs 1 to 12, left side	0, 1, 2, 3 or 4
	Ribs 1 to 12, right side	
Cervical vertebrae		
Cervical vertebra 1	Cervical vertebra 1	0, 1, 2, 3 or 4
Cervical vertebra 2	Cervical vertebra 2	
Cervical vertebra 3	Cervical vertebra 3	
Cervical vertebra 4	Cervical vertebra 4	

2.2.3. Statistical analyses

The distributions and frequencies of the occurring fractures within the cemetery population Leobersdorf were examined using the statistics programme IBM SPSS Statistics.

To ensure better statistical comparability, some of the originally six Avar periods were combined into 3 categories. Since only four individuals could be assigned to the Early Avar period, the Early and Middle Avar period were combined. Likewise, the Late Avar periods I-IIIa were combined, since according to Daim (1987) they cover the same historical period (710 - 800 CE).

For the statistical analyses, this resulted in three categories: "Early + Middle Avar period", "Late Avar period I-IIIa" and "Late Avar period IIIb" (adapted from Daim, 1987). Similarly, the four age categories were combined into two groups: Individuals younger than 35 years and individuals aged 35 years or older. Furthermore, incomplete fractures were categorised as "minor fractures" and complete fractures as "severe fractures". Individuals with both complete and incomplete fractures were assigned to the "severe fracture" group. When categorising the individuals with fractures according to the affected side, individuals with fractures on both sides were categorised according to the more severely affected side. Here, three individuals were excluded because either both sides were equally affected or a definitive assignment of the fracture to one side was not possible. One individual (grave number 109, male) showed rib and cranial fractures. This individual was assigned to the “cranial fracture” group only for the statistical analyses of fracture types.

The three hypotheses were either tested with the Chi-Squared Test or the Fisher's Exact Test depending on the number of available cases, whereby the significance level was set at 0.05. The reported p-values represent the exact two-sided significance.

3. Results

3.1. Sample

The examined sample comprised a total of 131 individuals. Grefen-Peters (1987) carried out a sex determination for all of them, whereby 63 individuals (48.1%) were classified as male and 68 individuals (51.9%) as female. Furthermore, she estimated the age at death of 129 of those individuals and calculated the body height of 66 individuals. Daim (1987) assigned 130 individuals to one of the Avar periods. In the present thesis, the state of preservation could be determined for 130 individuals and the presence of fractures was examined for 129 individuals.

3.1.1. Age at death and sex

Of the 129 individuals for which age at death could be determined, 63 had been classified as male (48.8%) and 66 as female (51.2%), by Grefen-Peters (1987). For two females, no age determination could be made. Figure 7 and Table 3 show the distribution of age at death categories within the examined sample, divided by sex.

The age at death category which comprised the highest proportion of individuals was old adult / 50+ years (28.7%), followed by middle adult / 35-49 years (26.4%).

Most females were younger than 35 years, whereas most males were 35 years or older. These differences were statistically highly significant (X^2 (1, N = 129) = 10.903, p = 0.001).

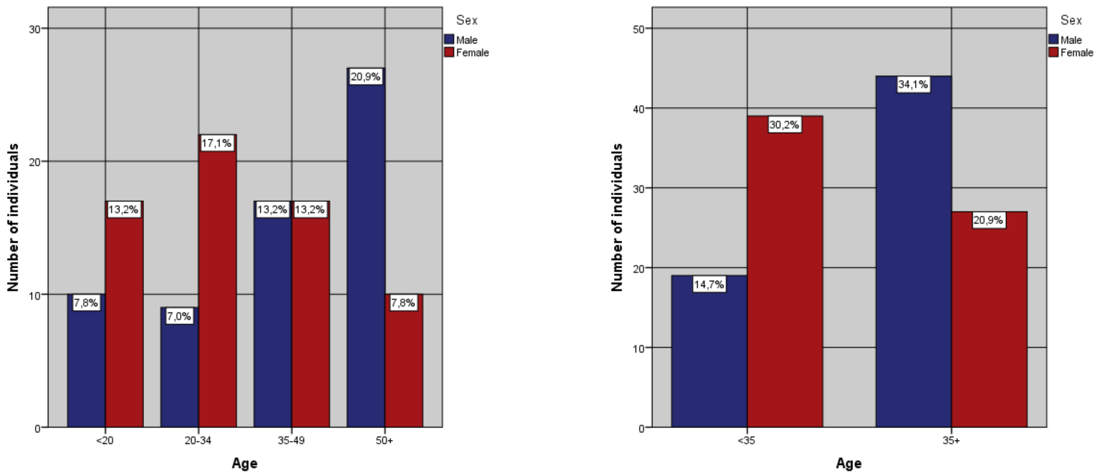

Figure 7. Distribution of the 129 studied individuals within the age at death categories (in years), divided by sex.

Table 3. Distribution of the studied individuals within the age at death categories in absolute (n) and relative (% of the total) numbers, divided by sex.

Age category	Male	Female	Total
Subadult (< 20 years)	10 (7.8%)	17 (13.2%)	27 (20.9%)
Young adult (20-34 years)	9 (7.0%)	22 (17.1%)	31 (24.0%)
Middle adult (35-49 years)	17 (13.2%)	17 (13.2%)	34 (26.4%)
Old adult (50+ years)	27 (20.9%)	10 (7.8%)	37 (28.7%)
<35 years	19 (14.7%)	39 (30.2%)	58 (45.0%)
35+ years	44 (34.1%)	27 (20.9%)	71 (55.0%)
Total	63 (48.8%)	66 (51.2%)	129 (100.0%)

3.1.2. Historical period and sex

Daim (1987) assigned 130 individuals to one of the six Avar periods (Early Avar period, Middle Avar period, Late Avar period I, Late Avar period II, Late Avar period IIIa, Late Avar period IIIb). For one female, no assignment could be made. Figure 8 and Table 4 show the distribution of the Avar periods within the examined sample, divided by sex.

For the statistical analyses, the six Avar periods were combined into three categories (Early + Middle Avar period, Late Avar period I-IIIa, Late Avar period IIIb; adapted from Daim, 1987).

The majority of the individuals was assigned to the Late Avar period I-IIIa (68.5%), followed by the Early + Middle Avar period (18.5%). There were no statistically significant differences in the distribution of males and females within the three historical periods (X^2 (2, N = 130) = 0.585, p = 0.800).

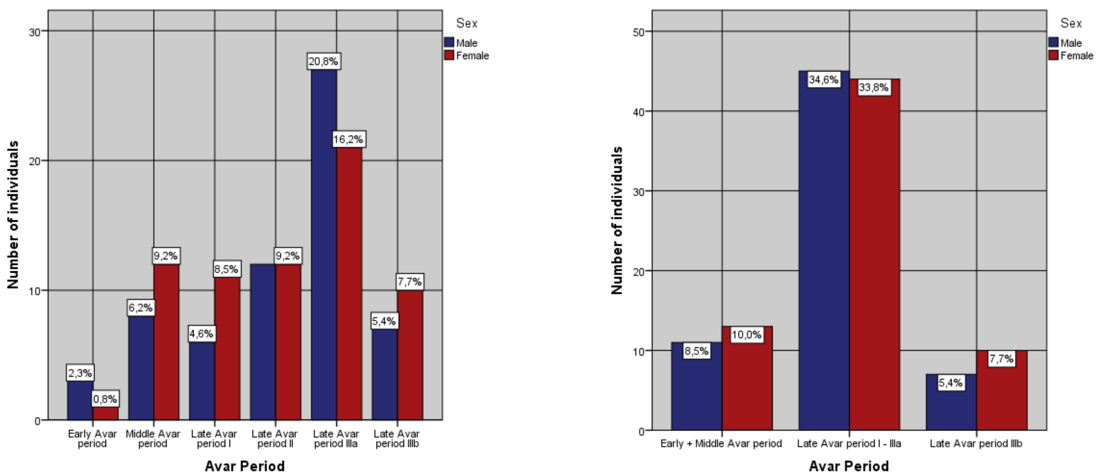

Figure 8. Distribution of the studied individuals within the historical periods, divided by sex.

Table 4. Distribution of the studied individuals within the historical periods in absolute (n) and relative (% of the total) numbers, divided by sex.

Historical period	Male	Female	Total
Early Avar period (- 650 CE)	3 (2.3%)	1 (0.8%)	4 (3.1%)
Middle Avar period (650 - 710 CE)	8 (6.2%)	12 (9.2%)	20 (15.4%)
Late Avar period I (710 - 800 CE)	6 (4.6%)	11 (8.5%)	17 (13.1%)
Late Avar period II (710 - 800 CE)	12 (9.2%)	12 (9.2%)	24 (18.5%)
Late Avar period IIIa (710 - 800 CE)	27 (20.8%)	21 (16.2%)	48 (36.9%)
Late Avar period IIIb (after 800 CE)	7 (5.4%)	10 (7.7%)	17 (13.1%)
Early + Middle Avar period (- 710 CE)	11 (8.5%)	13 (10.0%)	24 (18.5%)
Late Avar period I-IIIa (710 - 800 CE)	45 (34.6%)	44 (33.8%)	89 (68.5%)
Late Avar period IIIb (after 800 CE)	7 (5.4%)	10 (7.7%)	17 (13.1%)
Total	63 (48.5%)	67 (51.5%)	130 (100.0%)

3.1.3. Body height and sex

Grefen-Peters (1987) determined the body height of 66 individuals (50.4%). For 65 individuals (49.6%), the determination of the body height was not possible, due to the state of preservation of the long bones. Table 5 shows the distribution of the body height within the examined sample, divided by sex. Overall, the mean body height was 164.9 cm, with a minimum of 152 cm and a maximum of 177 cm (*SD* = 6.4 cm). The mean body height for males was 169.8 cm (*SD* = 4.0 cm), for females it was 159.4 cm (*SD* = 2.3 cm).

Table 5. Distribution of body height of the examined individuals, divided by sex.

Sex	Number of individuals (*n*)	Mean (cm)	Standard deviation (cm)	Minimum (cm)	Maximum (cm)
Male	35	169.77	3.98	158	177
Female	31	159.39	2.26	152	167
Total	66	164.89	6.36	152	177

3.1.4. State of preservation

For 130 individuals the preservation status of the separate cranial bones and bone structures including the parts of the mandible, the whole cranium, the ribs, and the first four cervical vertebrae was recorded. One individual (grave number 71) was missing and therefore not taken into account when recording the state of preservation. Also, the cranium of the individual excavated from grave number 21B was missing and could therefore not be examined.

Tables 6 to 8 and Figures 9 to 11 show the distribution of the categories, defined for recording of the preservation status, divided by the different anatomical regions. For simplification, and to show the most important sites usually involved in fractures, Figure 9 only shows the distribution for the frontal, the right and left parietal, the occipital, and the whole cranium.

Table 6. Distribution of preservation status categories for the separate bones/bone structures of the cranium and for the whole cranium in absolute (n) and relative (% per bone/bone structure) numbers.

Cranial bone/ bone structure	Not present	Present, 0 - 25%	Present, 25 - 50%	Present, 50 - 75%	Present, 75 - 100%
Frontal	46 (35.4%)	7 (5.4%)	4 (3.1%)	17 (13.1%)	56 (43.1%)
Right parietal	37 (28.5%)	20 (15.4%)	12 (9.2%)	15 (11.5%)	46 (35.4%)
Left Parietal	34 (26.2%)	20 (15.4%)	10 (7.7%)	13 (10.0%)	53 (40.8%)
Occipital	45 (34.6%)	22 (16.9%)	12 (9.2%)	33 (25.4%)	18 (13.8%)
Right occipital condyle	88 (67.7%)	3 (2.3%)	4 (3.1%)	12 (9.2%)	23 (17.7%)
Left occipital condyle	88 (67.7%)	5 (3.8%)	5 (3.8%)	13 (10.0%)	19 (14.6%)
Right temporal	44 (33.8%)	9 (6.9%)	22 (16.9%)	17 (13.1%)	38 (29.2%)
Left temporal	41 (31.5%)	12 (9.2%)	13 (10.0%)	23 (17.7%)	41 (31.5%)
Right mastoid process	58 (44.6%)	5 (3.8%)	3 (2.3%)	10 (7.7%)	54 (41.5%)
Left mastoid process	61 (46.9%)	0 (0.0%)	5 (3.8%)	6 (4.6%)	58 (44.6%)
Right nasal bone	102 (78.5%)	1 (0.8%)	2 (1.5%)	10 (7.7%)	15 (11.5%)
Left nasal bone	100 (76.9%)	1 (0.8%)	3 (2.3%)	9 (6.9%)	17 (13.1%)
Right zygomatic	60 (46.2%)	1 (0.8%)	5 (3.8%)	14 (10.8%)	50 (38.5%)
Left zygomatic	64 (49.2%)	1 (0.8%)	4 (3.1%)	10 (7.7%)	51 (39.2%)
Right maxilla	48 (36.9%)	23 (17.7%)	24 (18.5%)	12 (9.2%)	23 (17.7%)
Left maxilla	56 (43.1%)	24 (18.5%)	13 (10.0%)	12 (9.2%)	25 (19.2%)
Mandible - right ramus	37 (28.5%)	11 (8.5%)	3 (2.3%)	15 (11.5%)	64 (49.2%)
Mandible - left ramus	42 (32.3%)	7 (5.4%)	5 (3.8%)	15 (11.5%)	61 (46.9%)
Mandible - corpus	29 (22.3%)	0 (0.0%)	11 (8.5%)	24 (18.5%)	66 (50.8%)
Mandible - right caput	60 (46.2%)	3 (2.3%)	6 (4.6%)	19 (14.6%)	42 (32.3%)
Mandible - left caput	68 (52.3%)	6 (4.6%)	5 (3.8%)	13 (10.0%)	38 (29.2%)
Whole cranium	19 (14.6%)	35 (26.9%)	27 (20.8%)	28 (21.5%)	21 (16.2%)

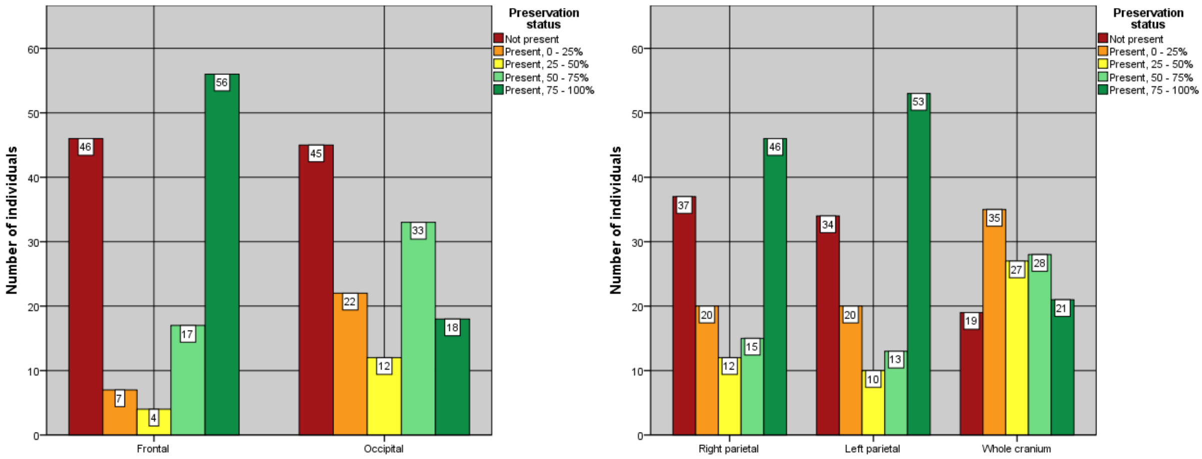

Figure 9. Distribution of preservation status categories for the frontal and occipital (left), as well as for the right and left parietal and the whole cranium (right).

Table 7. Distribution of preservation status categories for the first ribs of each side and all ribs of each side in absolute (n) and relative (% per rib/side) numbers.

Rib/Side	Not present	Present, 0 - 25%	Present, 25 - 50%	Present, 50 - 75%	Present, 75 - 100%
First right rib	64 (49.2%)	4 (3.1%)	11 (8.5%)	17 (13.1%)	34 (26.2%)
Ribs right side	47 (36.2%)	51 (39.2%)	26 (20.0%)	4 (3.1%)	2 (2.5%)
First left rib	62 (47.7%)	7 (5.4%)	14 (10.8%)	16 (12.3%)	31 (23.8%)
Ribs left side	46 (35.4%)	58 (44.6%)	22 (16.9%)	1 (0.8%)	3 (2.3%)

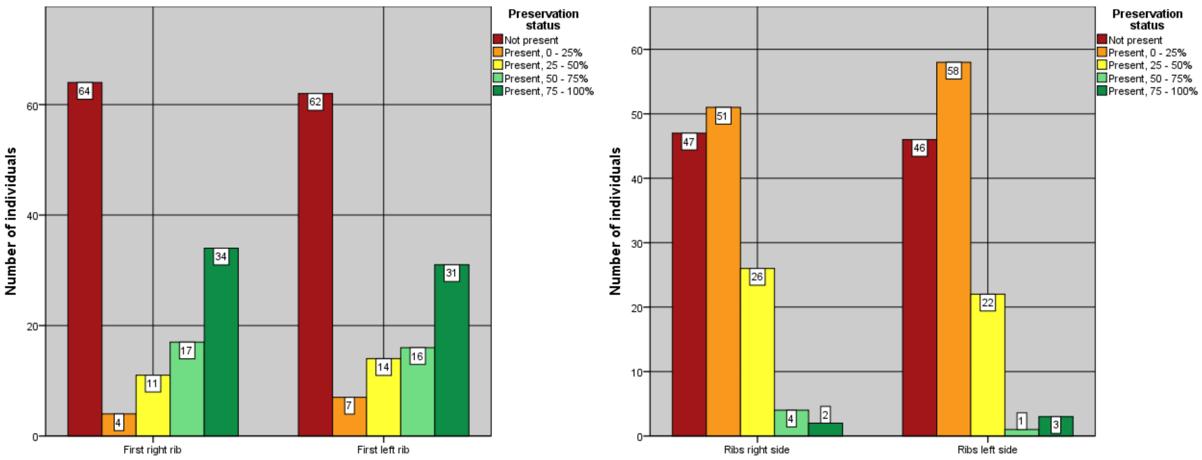

Figure 10. Distribution of preservation status categories for the right and left first rib (left) and for all the ribs of each side (right).

Table 8. Distribution of preservation status categories for the first four cervical vertebrae in absolute (n) and relative (% per cervical vertebra) numbers.

Cervical vertebrae	Not present	Present, 0 - 25%	Present, 25 - 50%	Present, 50 - 75%	Present, 75 - 100%
C1	55 (42.3%)	11 (8.5%)	14 (10.8%)	6 (4.6%)	44 (33.8%)
C2	58 (44.6%)	5 (3.8%)	8 (6.2%)	15 (11.5%)	44 (33.8%)
C3	74 (56.9%)	1 (0.8%)	6 (4.6%)	15 (11.5%)	34 (26.2%)
C4	76 (58.5%)	1 (0.8%)	9 (6.9%)	10 (7.7%)	34 (26.2%)

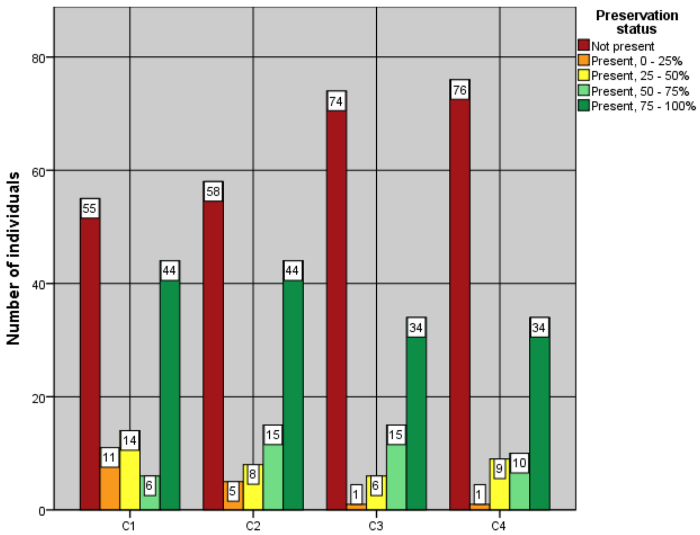

Figure 11. Distribution of preservation status categories for the first four cervical vertebrae.

3.2. Documentation of the individuals showing fractures

Before testing the proposed hypotheses, this chapter aims at documenting all individuals of the cemetery of Leobersdorf showing evidence of fractures. Each individual found to be affected with any kind of fracture of the cranium, the first four cervical vertebrae and/or the ribs is described here in detail. In total, 19 individuals showed evidence of fractures among the 129 individuals examined herein (see Table 9). Their position within the cemetery can be viewed in Figure 12. Most of the individuals showing fractures were located in the central and northern section of the cemetery, which represent the Late Avar periods II and III. The graves located further in the south and east of the cemetery (11, 34, 46 and 152) were associated with the Early and Middle Avar period (Daim, 1987).

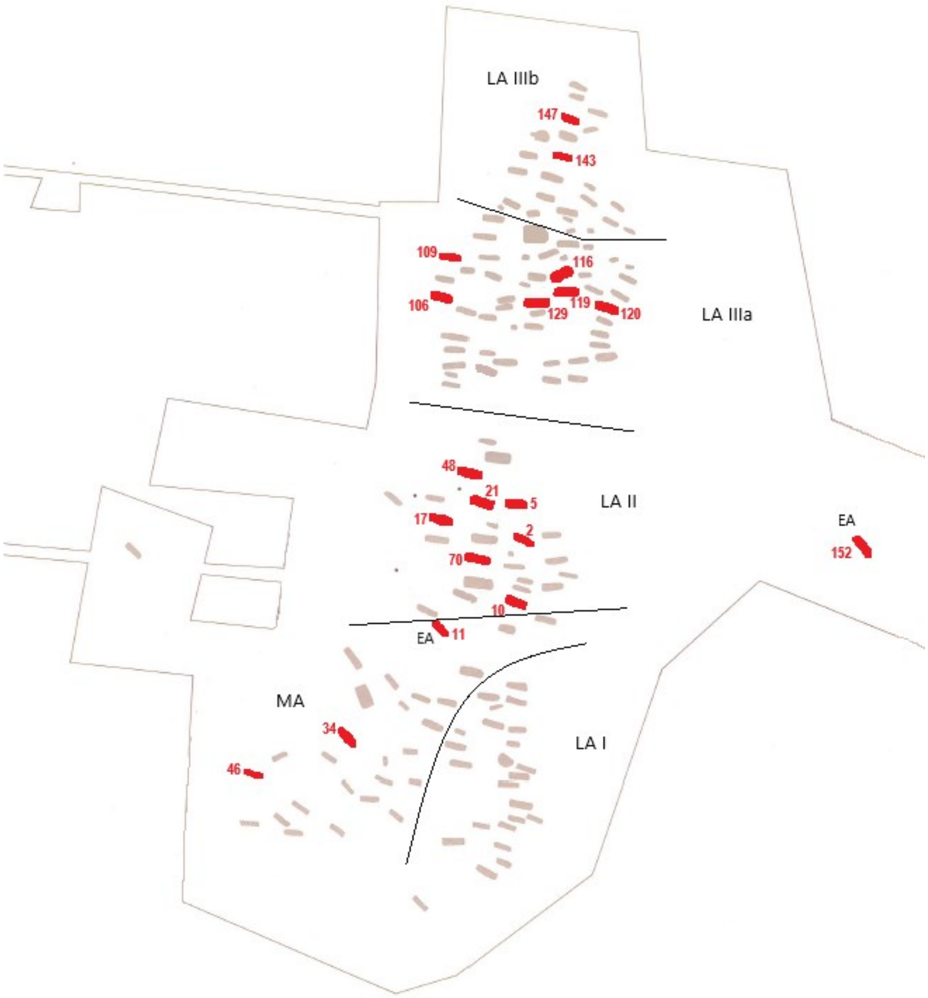

Figure 12. Map of the burial ground Leobersdorf; highlighted graves represent the 19 individuals showing fractures among the 129 examined herein (adapted from Daim, 1987).

Table 9. Individuals showing evidence of fractures.

Grave number	Period	Sex	Age	Site of injury	Fracture(s)	Proximate cause
2	Late Avar period II	Male	50+	Rib/ left	1 healed rib fracture (left middle rib, 5-7)	Direct blunt force trauma
5	Late Avar period II	Male	50+	Cranium/ left	1 healed cranial fracture (depression on left parietal)	Direct blunt force trauma
10	Late Avar period II	Female	20-34	Rib/ right	1 possible minor healed rib fracture (right lower rib)	Indirect trauma
11	Early Avar period	Male	50+	Ribs/ both sides	9 healed rib fractures (1 right lower rib, 6 left upper to middle ribs, 2 of them fractured twice)	Direct blunt force trauma + indirect trauma
17	Late Avar period II	Female	20-34	Rib/ right	1 healed rib fracture (right middle rib)	Indirect trauma
21B	Late Avar period II	Female	35-49	Rib/ left	1 healed rib fracture (left middle rib)	Direct blunt force trauma
34	Middle Avar period	Female	35-49	Ribs/ left	3 possible minor healed rib fractures (left upper ribs)	Indirect trauma
46*	Middle Avar period	Male	50+	Rib/ right	1 healed rib fracture (right upper rib)	Indirect trauma
48	Late Avar period II	Male	50+	Ribs/ left	4 ribs with inflammatory reactions, 2 of them with obvious fractures (left upper to middle ribs)	Direct blunt force trauma
70	Late Avar period II	Male	50+	Rib/ right	1 healed rib fracture (right lower rib)	Indirect trauma
106	Late Avar period IIIa	Female	50+	Rib/ right	1 healed rib fracture (right upper rib)	Direct blunt force trauma
109°	Late Avar period IIIa	Male	50+	Cranium + rib/ both sides	2 cranial fractures (1 healed depression on right parietal, 1 comminuted fracture of left facial skull) 1 healed rib fracture (left lower rib)	Direct blunt force trauma
116	Late Avar period IIIa	Male	35-49	Rib/ right	1 possible minor healed rib fracture (right upper rib)	Indirect trauma
119A	Late Avar period IIIa	Male	50+	Cranium/ centre	1 healed cranial fracture (shallow depression on sagittal suture)	Direct blunt force trauma
120	Late Avar period IIIa	Male	35-49	Rib/ left	1 healed rib fracture (left 2nd rib)	Direct blunt force trauma
129*	Late Avar period IIIa	Male	50+	Ribs/both sides	2 possible minor healed rib fractures (1 right, 1 left lower rib, same position)	Indirect trauma
143	Late Avar period IIIb	Female	50+	Cranium/ centre	1 healed cranial fracture (shallow depression on sagittal suture)	Direct blunt force trauma
147	Late Avar period IIIb	Male	< 20	Ribs/both sides	3 possible minor rib fractures (1 on 2nd left rib, 2 on both 1st ribs)	Indirect trauma
152	Early Avar period	Male	< 20	Rib/right	1 possible minor healed rib fracture (upper right rib)	Indirect trauma

* Individual also shows a fracture of the long bones
° Individual shows signs of myositis ossificans on the right clavicle

3.2.1. Detailed description of the individuals showing fractures

Grave number 2

Grave number 2 contained the remains of an older man (50 years or older) with a calculated body height of 170 cm. The grave was assigned to the Late Avar Period II.

One bone fragment belonging to one of the left middle ribs shows a healed transverse fracture. The barely visible fracture line on the radiograph indicates that it had already healed well a long time before the individual's death. The fragment originates from the anterior third of the rib and shows a regular and clearly recognisable callus formation as a result of non-displaced fracture ends (see Figure 13). The long bones of the individual show no fractures (N. Reiter, personal communication, 2022). The cause of the fracture can be assumed to have been a direct force acting on the left side of the thorax, like a hard punch with the fist.

The health problems caused by this fracture are likely to have been limited to the usual, temporary pain associated with a rib fracture. As grave goods, typical objects for male Avar graves were discovered. Among them were animal bones from a food offering, a simple earring, a belt buckle, an iron knife and two arrowheads (Daim, 1987).

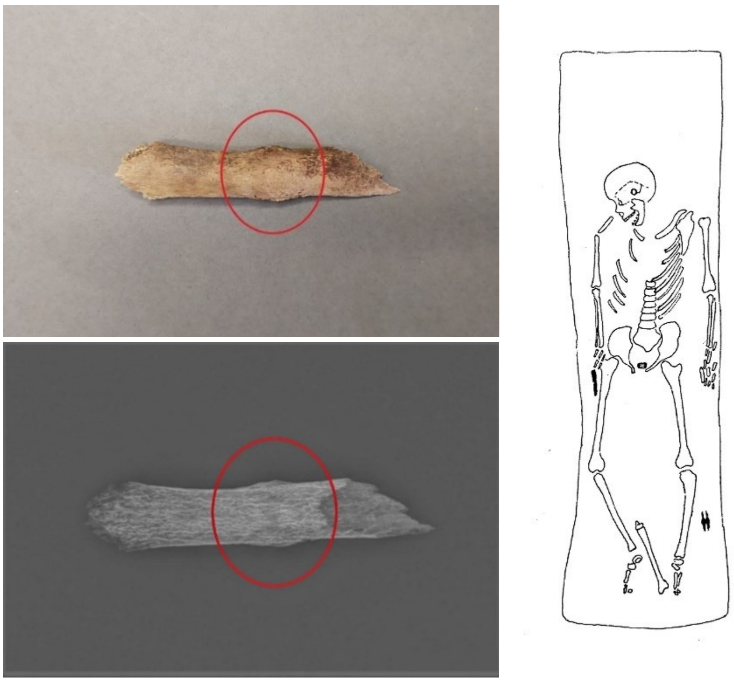

Figure 13. Grave number 2: Clearly recognisable, well healed transverse fracture of a left middle rib (left); position of the remains within the grave (right) (adapted from Daim, 1987).

Grave number 5

Grave number 5 also contained an older man (50 years or older). Since only the cranium and parts of the spine could be recovered, it was not possible to determine the body height. The grave was assigned to the Late Avar Period II as well.

The cranium of the individual shows a clearly recognisable depression with a diameter of about 1 cm. It is located on the left parietal, approximately 4 cm laterally to the middle of the sagittal suture (see Figure 14). Also, a small protuberance on the inner table of the cranium can be recognised. The impression is clearly visible on the CT scan, but the radiograph shows no sign of the depression (see Figure 15). The injury of the cranium can be categorised as a depressed (crush) fracture and was most likely caused by direct force applied to the neurocranium, such as a blow to the back of the head with a blunt object.

As indicated by the remodelling of the bone, the injury had probably healed well long before the individual's death and most likely did not cause any long-term damage. Since no long bones could be recovered from grave number 5 due to a disturbance of the grave, the long bones could not be examined for fractures. No grave goods were recovered, but discolorations suggestive of a right-angled coffin could be revealed (Daim, 1987).

Figure 14. Grave number 5: Depressed (crush) fracture of the left parietal with a diameter of about 1 cm (left); position of the remains within the grave (right) (adapted from Daim, 1987).

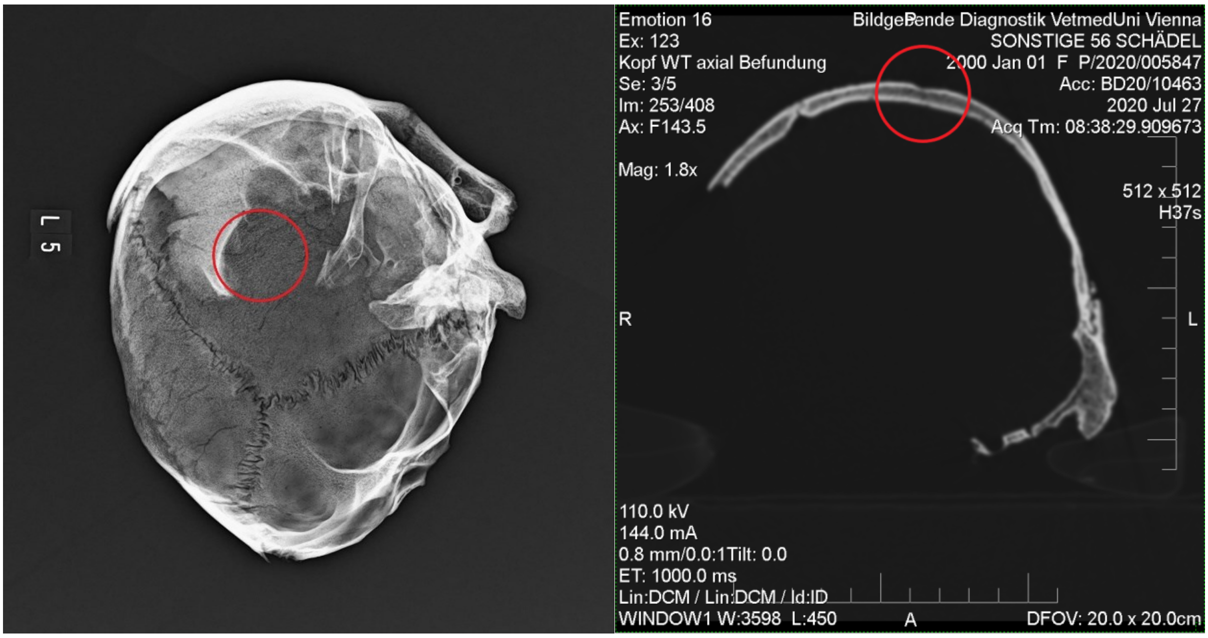

Figure 15. Grave number 5: The depressed (crush) fracture of the cranium is not visible on the radiograph (left), the CT scan however shows the cranial depression (right).

Grave number 10

The individual excavated from grave number 10 has been estimated to have been a young adult woman (20-34 years) with a calculated body height of 157 cm. The grave was assigned to the Late Avar Period II.

The affected bone fragment originates from the anterior third of what is probably a right lower rib. On the radiograph no fracture line is visible, only a slight thickening which indicates a minor injury of the rib rather than a complete fracture (see Figure 16). On the long bones no further fractures could be found (N. Reiter, personal communication, 2022).

The cause of the fracture was probably an indirect force that caused a bending of the affected rib and resulted in a greenstick fracture, such as a lateral compression of the rib cage. The injury had already healed well at the time of the individual's death and the individual probably had no persistent health problems after the temporary pain in the affected region had subsided. Grave number 10 also contained animal bones, earrings, the remains of a bead necklace, a spindle whorl, and an iron buckle (Daim, 1987).

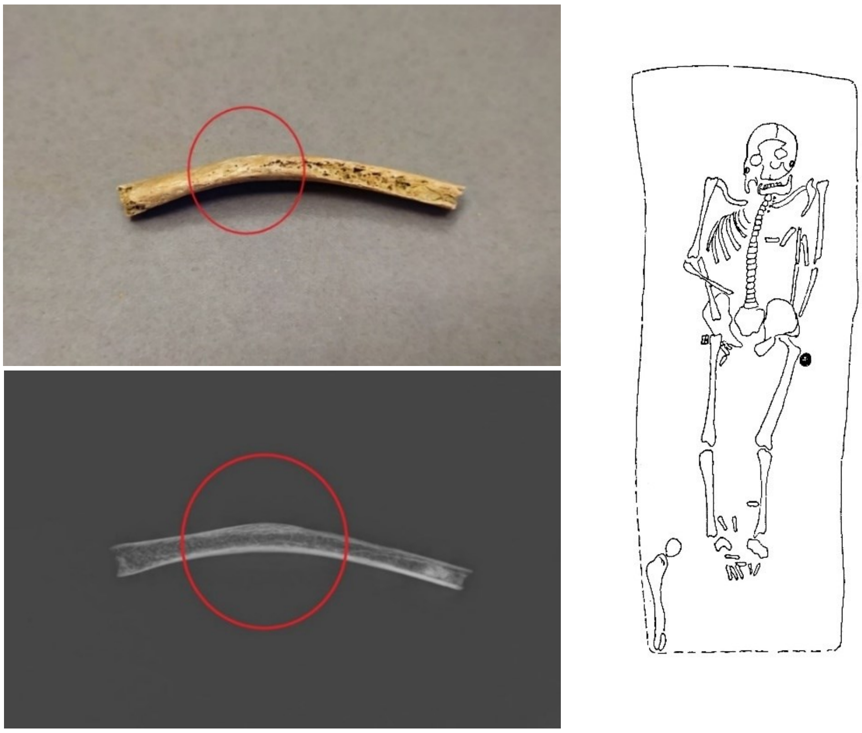

Figure 16. Grave number 10: Slight thickening of a right lower rib (left); position of the remains within the grave (right) (adapted from Daim, 1987).

Grave number 11

Grave number 11 contained an older man (50 years or older) with a calculated body height of 166 cm. The grave was assigned to the Early Avar Period and seemed to have been robbed, as the remains were in quite a disarranged position. The cranium was lying on the upper body and since the vertebrae show no signs of decapitation, the cranium was probably moved in the course of the robbery.

The individual suffered from nine rib fractures, mainly on the left back side of the rib cage, whereby transverse and oblique fractures could be found (see Figure 17).

On the right side, a non-displaced transverse rib fracture of presumably the eleventh rib can be found, located between the anterior and middle third of the rib. The fact that the radiograph shows no sign of the fracture line indicates, that the fracture had healed well long before the individual's death. The rib is almost completely preserved and shows an oblique postmortem fracture, located at the dorsal end of the healed fracture (see Figure 18).

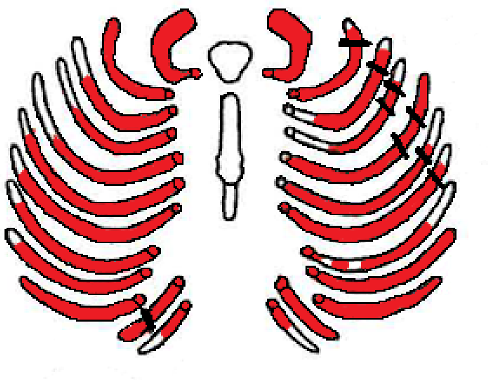

Figure 17. Grave number 11: Schematic drawing of the rib fractures (in black) the individual suffered from. In red, the preserved ribs.

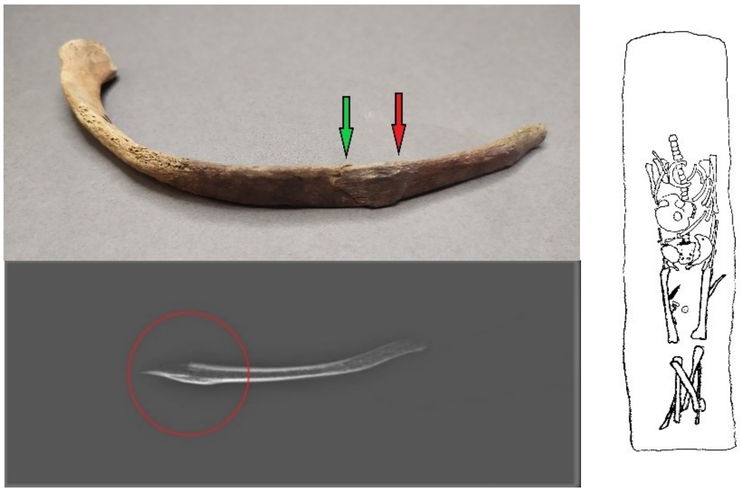

Figure 18. Grave number 11: Healed fracture (red arrow) and postmortem fracture (green arrow) on the eleventh right rib (left); position of the remains within the grave (right) (adapted from Daim, 1987).

Also, on the second and third rib of the left side, each in the anterior third, non-displaced transverse fractures are visible. They had probably healed well a long time before the individual died, as the radiographs show no signs of the fracture lines anymore. The third rib shows a postmortem fracture, located dorsal of the healed fracture (see Figure 19). Both ribs four and five of the left side show two fractures, each about 3 cm apart, in the anterior and middle thirds (Figure 20). The anterior transverse fracture of rib four may have been slightly displaced. In the case of rib five, both oblique fractures have been displaced, resulting in a somewhat wavy shape of the rib. The hardly visible fracture lines suggests that both ribs had healed relatively well at the time the individual died. Rib number four exhibits a postmortem fracture, located just dorsally of the posterior transverse fracture.

Figure 19. Grave number 11: Ribs number two (top) and three (bottom) of the left side show well healed fractures; rib number three shows a postmortem fracture (green arrow) dorsally of the healed fracture (red arrow).

Figure 20. Grave number 11: Ribs number four (top) and five (bottom) of the left side each show two partly displaced fractures; rib number four shows a postmortem fracture (green arrow) dorsally of the healed fractures (red arrows).

Ribs number six and seven each show a well healed fracture in the anterior third. The transverse fracture of rib number six was not displaced, whereas rib number seven shows a light upward displacement of the oblique fracture (see Figure 21). On the long bones of the individual excavated from grave number 11, no fractures could be found (N. Reiter, personal communication, 2022).

Figure 21. Grave number 11: Ribs number six (top) and seven (bottom) of the left side show well healed fractures in the anterior thirds.

The cause of these multiple rib fractures is likely to have been a considerable impact of force acting on the upper and middle parts of the left, as well as on the lower part of the right rib cage. The presence of transverse and oblique fractures suggests a combination of direct and indirect forces. As all fractures show the same degree of healing, it can be assumed that all injuries were caused simultaneously by a single incident, such as a fight or a fall from a horse. The slightly displaced fracture ends of the twice fractured ribs indicate an insufficient recovery period after the injury. Nevertheless, these, as well as all other fractures, healed well without signs of inflammation. This is why no serious long-term health problems are to be assumed, although the individual likely suffered massive pain for quite some time after the injury. The grave goods recovered were animal bones from a food offering, parts of a belt set, an iron knife, and an iron buckle. The tongue of the belt was certainly removed in the course of the robbery. Whether something else was taken from the grave is unclear (Daim, 1987).

Grave number 17

Grave number 17 contained a young adult woman (20-34 years) with a calculated body height of 155 cm. The grave was assigned to the Late Avar period II.

One bone fragment, probably belonging to a right middle rib, shows a healed oblique fracture with non-displaced fracture ends. The fragment probably stems from the anterior third of the rib and displays a macroscopically clearly recognisable callus (see Figure 22). The fracture line is only faintly visible on the radiograph, indicating a complete recovery before the death of the individual. The long bones of the individual excavated from grave number 17 showed no fractures (N. Reiter, personal communication, 2022). The cause of the rib fracture may have been an indirect force acting on the rib cage, like a compression. The injury probably caused no persistent health problems. A bronze ring, a spindle whorl and animal bones were also recovered from the grave (Daim, 1987).

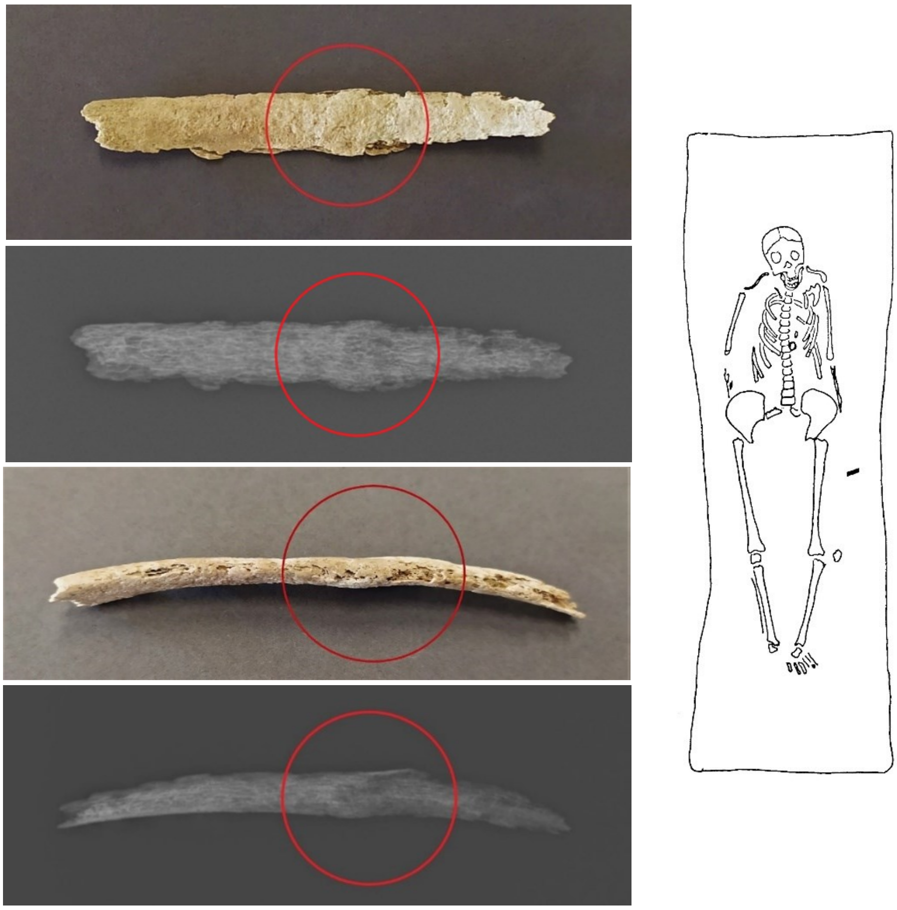

Figure 22. Grave number 17: A well healed oblique fracture on a right middle rib (left); position of the remains within the grave (right) (adapted from Daim, 1987).

Grave number 21B

Grave number 21 contained a triple burial. Here, a man (A: 50 years or older, lying in the middle in stretched back position), a woman (B: 35-49 years, lying on the right side of the man on her left side facing him) and a child (C: approx. 3 years, lying in stretched back position on the left lower half of the man's body) were buried in one common coffin (see Figure 23). The grave was assigned to the Late Avar Period II.

The woman (21B, with a calculated body height of 158 cm) suffered from a transverse rib fracture. The bone fragment of interest probably originates from the anterior third of a left middle rib. A relatively strong and rather irregular callus is clearly visible macroscopically. The fracture ends were probably not, or not significantly, displaced, which can also be seen on the radiograph. Unfortunately, the cranium of the individual was missing and could therefore not be examined in this work. When examining the long bones, no further fractures were found (N. Reiter, personal communication, 2022). The cause of the fracture can be assumed to have been a direct force acting on the left side of the rib cage, like a blow with a blunt object. The fracture had probably healed well not too long before the individual died, as the fracture line is still clearly visible on the radiograph. After the pain of the fracture had passed, the individual probably did not suffer any further health problems. The grave also contained animal bones, simple earrings (two found near the man, two near the child), a belt set and two iron knives, three iron arrowheads and a bead necklace found near the neck of the child (Daim, 1987).

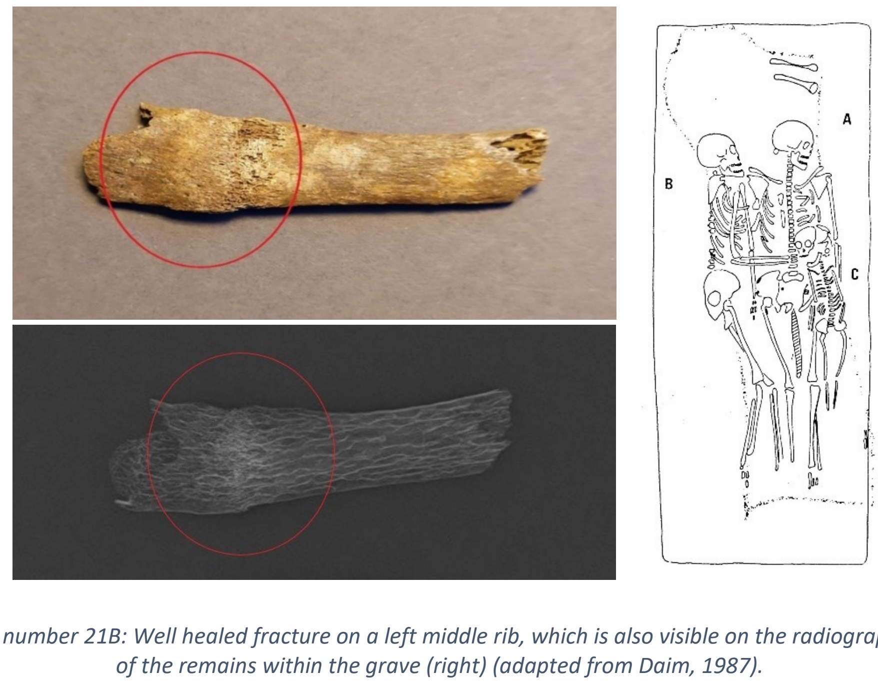

Figure 23. Grave number 21B: Well healed fracture on a left middle rib, which is also visible on the radiograph (left); position of the remains within the grave (right) (adapted from Daim, 1987).

Grave number 34

The individual recovered from grave number 34 was a middle aged woman (35-49 years) with a calculated body height of 156 cm. The grave was assigned to the Middle Avar Period.

The affected rib fragments belong to three left, probably upper ribs, with the anterior thirds being affected. There are thickenings, which are very faintly visible and are probably the result of minor injuries (see Figure 24). The radiographs show no signs of fracture lines. When examining the long bones, no fractures could be found (N. Reiter, personal communication, 2022). The cause of the thickenings could have been an indirect force, like a lateral compression of the thorax, that caused a bending of the affected ribs and resulted in multiple greenstick fractures. Since all ribs show the same degree of healing, a single incident, that caused the Injuries simultaneously, can be assumed. The injuries were already well-healed at the time the individual died and probably caused no persistent health problems. Also recovered from grave number 34 were animal bones from a food offering, a spindle whorl, a fragment of an earring and an iron buckle (Daim, 1987).

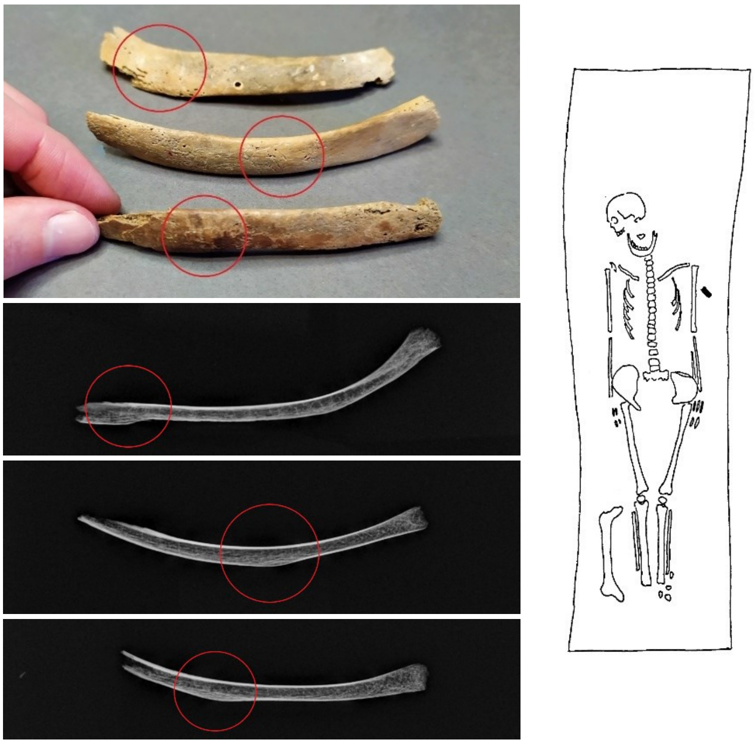

Figure 24. Grave number 34: Slightly visible thickenings on three left ribs, probably resulting from minor injuries, such as greenstick fractures (left); position of the remains within the grave (right) (adapted from Daim, 1987).

Grave number 46

Grave number 46 contained an older man (50 years or older). Due to the state of preservation of the long bones, it was not possible to calculate the body height. The grave was assigned to the Middle Avar Period.

The affected bone fragment seems to be the posterior third of a right upper (probably second) rib. The clearly recognisable callus and the hardly visible fracture line on the radiograph indicate a well-healed oblique fracture (see Figure 25).

Also, the left distal ulna shows a well-healed, non-displaced fracture, but due to the missing radius, it cannot be assessed whether it was also fractured (N. Reiter, personal communication, 2022). Assuming that the injuries occurred at the same time, the cause of the fractures could have been an indirect force, acting on the forearm and the upper thorax, like a fall. However, it cannot be said with certainty that one single event caused the fractures at the same time, since both injuries had already healed well when the individual died. The injuries probably did not cause any long-term health problems. Also recovered from the grave were animal bones from a food offering, a braid brace, an iron buckle, four iron arrowheads, an iron knife, and a bronze fitting (Daim, 1987).

Figure 25. Grave number 46: Callus formation on a right upper rib, which indicates a well healed oblique fracture (left); position of the remains within the grave (right) (adapted from Daim, 1987).

Grave number 48

Grave number 48 contained an older man (50 years or older) with a calculated body height of 174 cm. The grave was assigned to the Late Avar Period II.

There is evidence of fractures and inflammatory reactions on four rib fragments, which originate from the left upper to middle ribs. The position in the ribcage cannot be determined precisely, but it could have been ribs three to six or four to seven (see Figure 26). All rib fragments originate from the anterior half of the ribs. The two lower ribs clearly show transverse fractures with resulting inflammatory reactions (see Figure 27). The two upper ribs show obvious inflammatory reactions at the sternal ends, which are probably also caused by fractures or minor injuries, although fractures are not clearly recognisable in these two. The fracture on the lowest rib is located approximately at the transition from the anterior to the middle third of the rib and shows a slight upward displacement of the posterior fracture end. The fracture on the other rib is located in the anterior third of the rib and shows no displacement. The long bones of the individual showed no fractures (N. Reiter, personal communication, 2022).

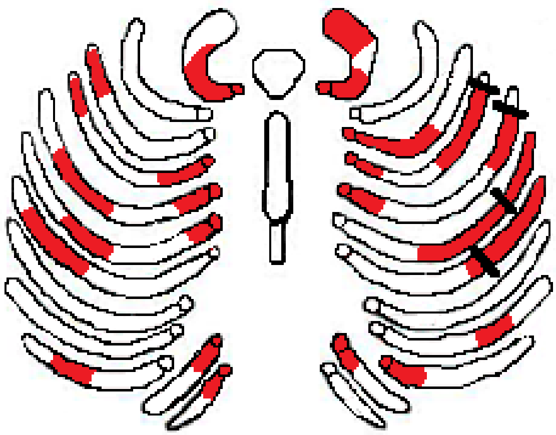

Figure 26. Grave number 48: Schematic drawing of the rib fractures (in black) the individual suffered from. In red, the preserved rib fragments.

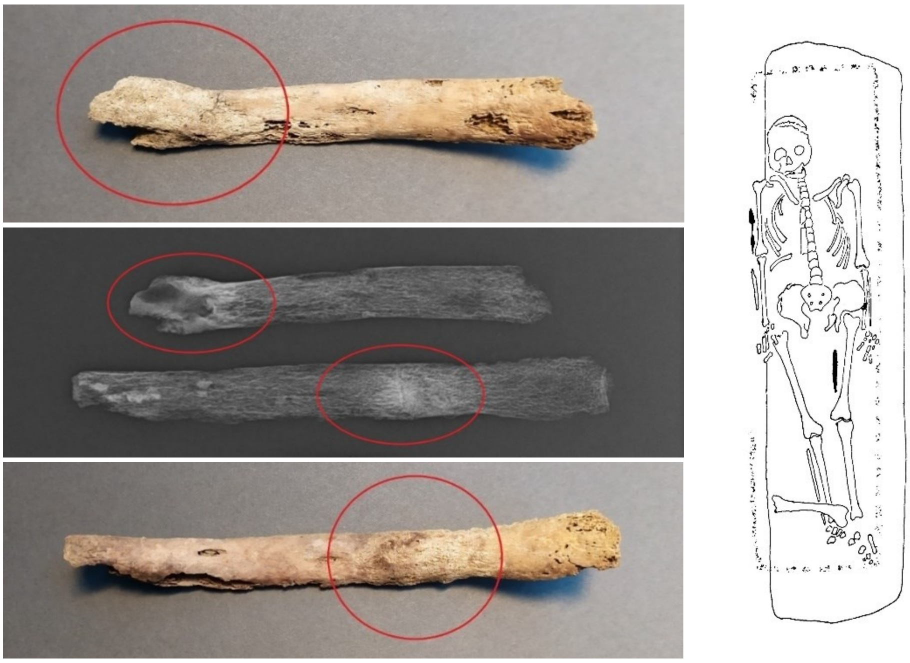

Figure 27. Grave number 48: Signs of fractures and inflammatory reactions on two left ribs (left); position of the remains within the grave (right) (adapted from Daim, 1987).

One of the fracture lines is still clearly visible on the radiograph, suggesting that the fracture was not able to heal completely before the death of the individual. All four ribs show the same degree of inflammation, which indicates that one single event caused the injuries at the same time. Also, the fractures of the two lower ribs and the inflammatory reaction of the adjacent rib can be aligned, suggesting a serial rib fracture of the anterior part of the left rib cage (see Figure 28).

The cause of the fracture can be assumed to have been a direct force applied to the anterior part of the left rib cage, whereby the two lower ribs may have been exposed to a greater force than the two upper ribs. For example, a fall onto an edge or a violent blow with a heavy, elongated object such as a wooden stick would be a possible scenario here. The displaced fracture ends of the upper rib indicate an insufficient recovery period after the injury and the poorly healed, inflamed fracture sites may have caused pain when breathing or performing certain movements even some time after the injury.

In the course of the examinations, this individual raised the suspicion of having suffered from a general disease due to various lesions (M. Berner, personal communication, 2022). However, as further examinations and examinations for pathogens had not yet been carried out at the time the present study was conducted, this individual was not excluded from the statistical trauma analyses in the present work. Also recovered from grave number 48 were animal bones from a food offering, two arrowheads, an iron buckle, and an iron knife (Daim, 1987).

Figure 28. Grave number 48: Fractures and inflammatory reactions on four ribs, probably resulting from a serial rib fracture of the left anterior rib cage.

Grave number 70

Grave number 70 contained an older man (50 years or older) with a calculated body height of 175 cm. The grave was assigned to the Late Avar period II.

One right, probably upper rib shows a bending in the posterior third, indicating a healed oblique fracture with displaced fracture ends (see Figure 29). There is no evidence of the fracture line on the radiograph, which points to a complete healing before the individual died.

The examined long bones showed no fractures (N. Reiter, personal communication, 2022). The cause of the rib fracture may have been an indirect force acting on the rib, like a compression of the ribcage that caused a bending of the affected site. The injury probably caused no persistent health problems after healing. The displaced fracture ends point to an insufficient recovery period after the injury. Also recovered from grave number 70 were animal bones of a food offering, iron buckles and other iron objects (Daim, 1987).

Figure 29. Grave number 70: Fracture with displaced fracture ends on a right rib (left); position of the remains within the grave (right) (adapted from Daim, 1987).

Grave number 82B

Grave number 82 contained a triple burial. Here, a boy (A: approx. 14 years), a woman (B: 35-49 years), and a younger child (C: approx. 5 years) were buried. The grave was assigned to the Late Avar Period IIIa.

The woman (82B, with a calculated body height of 160 cm) shows inflammatory reactions and bone remodelling on the first left rib and an overlying cervical rib (see Figure 30). Furthermore, a pseudo-articulation can be seen between the anterior parts of the two ribs (see Figure 31). The cause of the inflammation may have been an injury of the left upper thorax, but since no obvious signs of a fracture could be found, this case was excluded from the statistical trauma analysis. When examining the long bones, no fractures were observed (N. Reiter, personal communication, 2022). Among the grave goods that were found near the woman, animal bones from a food offering, earrings, a bead necklace, and a spindle whorl could be recovered (Daim, 1987).

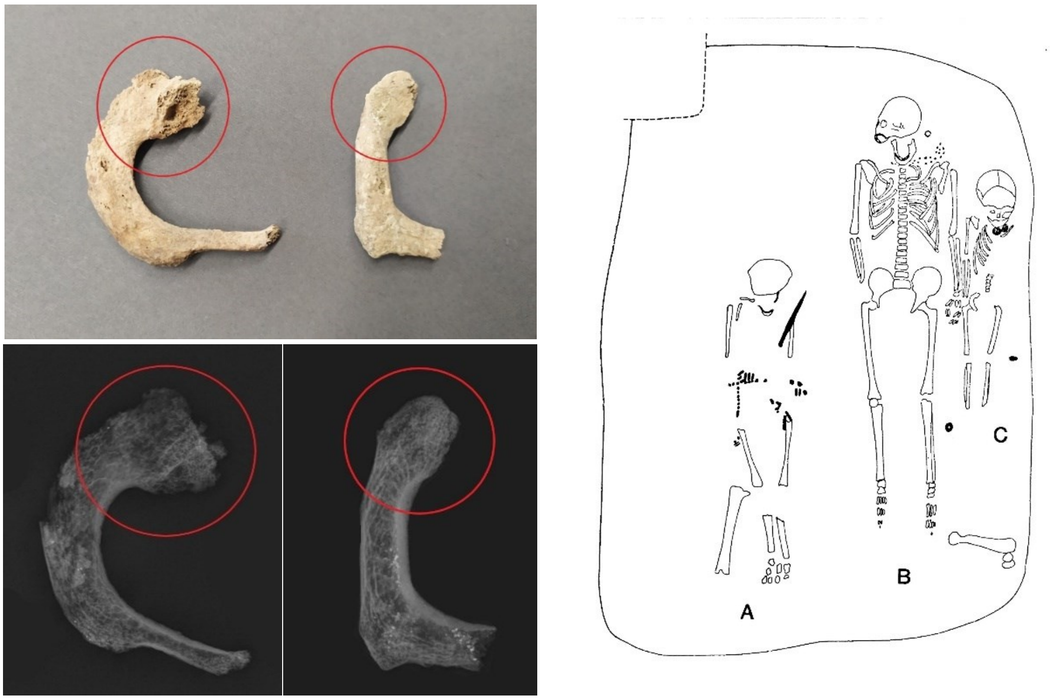

Figure 30. Grave number 82B: Inflammatory reactions and bone remodelling on first left rib and cervical rib (left); position of the remains within the grave (right) (adapted from Daim, 1987).

Figure 31. Grave number 82B: Pseudo-articulation between first left rib and overlying cervical rib.

Grave Number 104

Grave number 104 contained a young adult woman (20-34 years) with a calculated body height of 156 cm. The grave was assigned to the Late Avar Period IIIa.

In this case, two right middle ribs are fused to each other at their posterior ends (see Figure 32). According to Grefen-Peters (1987), this individual suffered from tuberculous spondylitis of the thoracic spine (Pott's disease), with gibbus formation of seven segments. Therefore, the fusion of these two ribs can be assumed to be the result of a pathological fracture. According to Nina Reiter (personal communication, 2022) the long bones revealed no injuries. Since it cannot be considered exclusively traumatic, this case was excluded from the statistical trauma analysis. Also recovered from grave number 104 were animal bones from a food offering, earrings, a bead necklace, an iron knife, and a needle-like iron object (Daim, 1987).

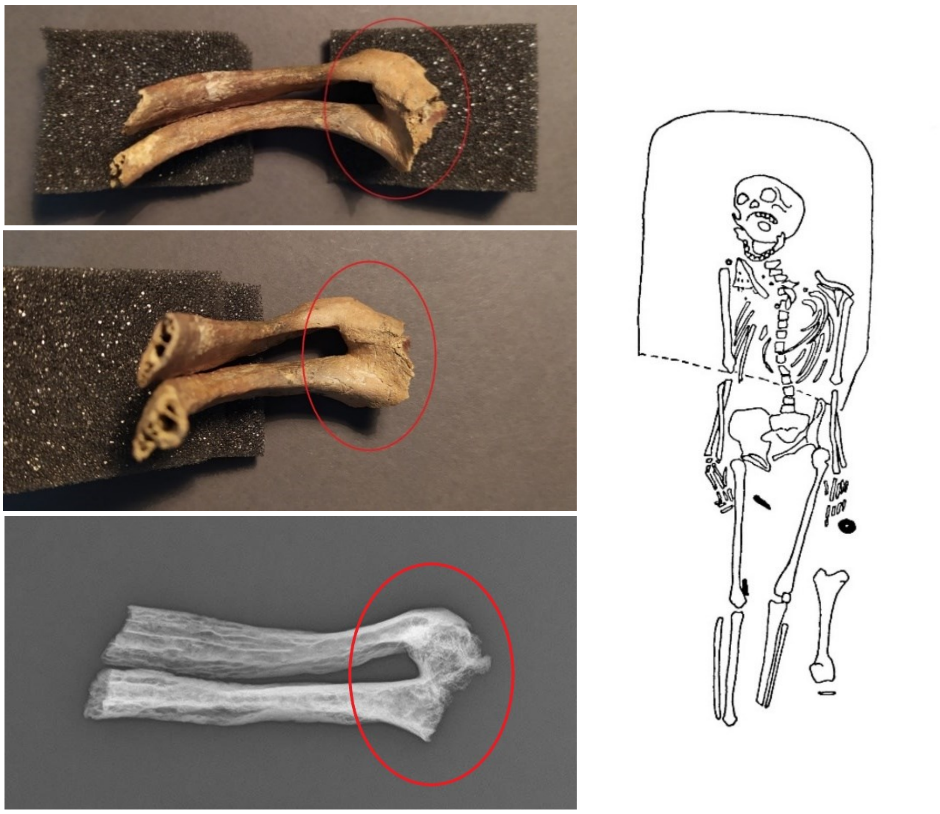

Figure 32. Grave number 104: Two fused ribs, probably resulting from a pathological fracture (left); position of the remains within the grave (right) (adapted from Daim, 1987).

Grave number 106

The individual recovered from grave number 106 was an older woman (50 years or older) with a calculated body height of 160 cm. The grave was assigned to the Late Avar Period IIIa.

The affected bone fragment seems to be the anterior third of a right, probably upper rib. Here, a well-developed, smooth callus is detectable. The ends of the transverse fracture may have been slightly displaced, as indicated by a small elevation on the cranial edge and a small indentation on the caudal edge of the rib (see Figure 33). On the long bones, no further fractures could be found during the examinations (N. Reiter, personal communication, 2022). The cause of the fracture can be assumed to have been a direct impact applied to the upper right thorax, like a punch. Although a slight displacement of the fracture ends is suspected, indicating inadequate sparing time after the injury, the fracture had already healed well at the time of the individual's death, which is also suggested by the hardly visible fracture line on the radiograph. The individual probably did not suffer from any long-term health consequences as a result of the injury. Earrings, a pearl necklace, and an iron fragment, which perhaps is the remain of a buckle, were also recovered from grave number 106 (Daim, 1987).

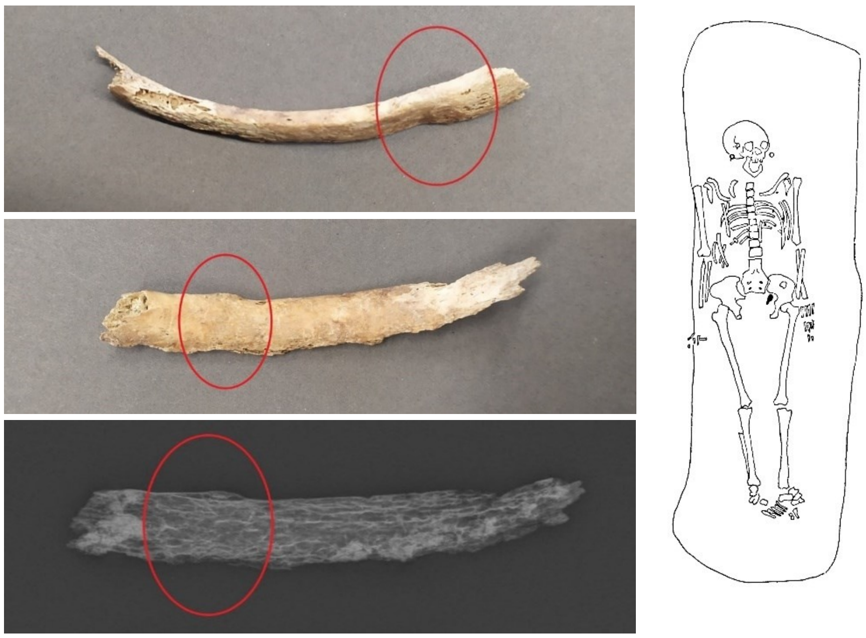

Figure 33. Grave number 106: Callus formation on a right upper rib, indicating a well-healed transverse fracture (left); position of the remains within the grave (right) (adapted from Daim, 1987).

Grave number 109

Grave number 109 contained an older man (50 years or older) with a calculated body height of 173 cm. The grave was assigned to the Late Avar Period IIIa.

The mortal remains of the individual show multiple fractures. On the cranium, a depression with a diameter of about 2 cm is visible on the right parietal, in the lateral, posterior region, above the lambdoid suture (see Figure 34). The depression has a more angular shape in the anterior region. On the inner surface of the cranium, an elevation is detectable. On the radiograph, the fracture is visible as a discrete shadow and on the CT scan, a gentle indentation is visible (see Figure 35). The notch suggests a depressed (crush) fracture, caused by direct blunt or semi-sharp force trauma to the neurocranium, such as a heavy strike with an angular object. When the individual died, the injury had already healed well.

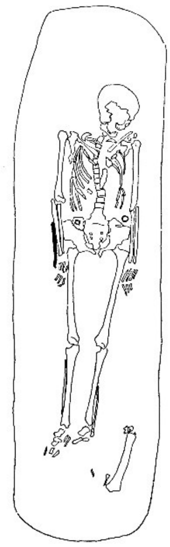

Figure 34. Grave number 109: Depressed (crush) fracture on the right parietal (left); position of the remains within the grave (right) (adapted from Daim, 1987).

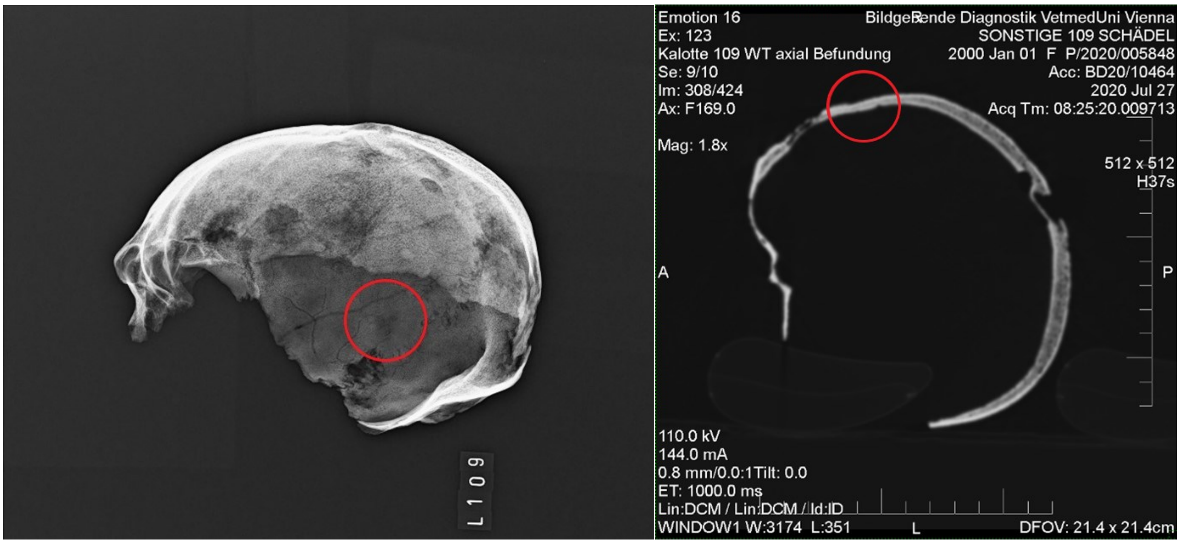

Figure 35. Grave number 109: The cranial fracture is visible as a discrete shadow on the radiograph (left) and as a gentle indentation on the CT scan (right).

The facial skull of the individual excavated from grave number 109 is affected as well. Here, the left frontal and lateral facial skull show bone remodelling indicative of a massive, comminuted fracture. The maxilla shows a fracture line running along the left side of the palatine process, as well as multiple areas affected from bone loss on the lateral side (Figure 36). Also, a reduction of the alveolar process due to a probably fracture-caused loss of the front teeth is observable.

Figure 38 shows a partial reconstruction of the frontal facial skull, showing the involvement of the orbit and the maxilla. Furthermore, the zygomatic bone is broken into several fragments, which can be observed in the partial reconstruction of the lateral facial skull (Figure 37).

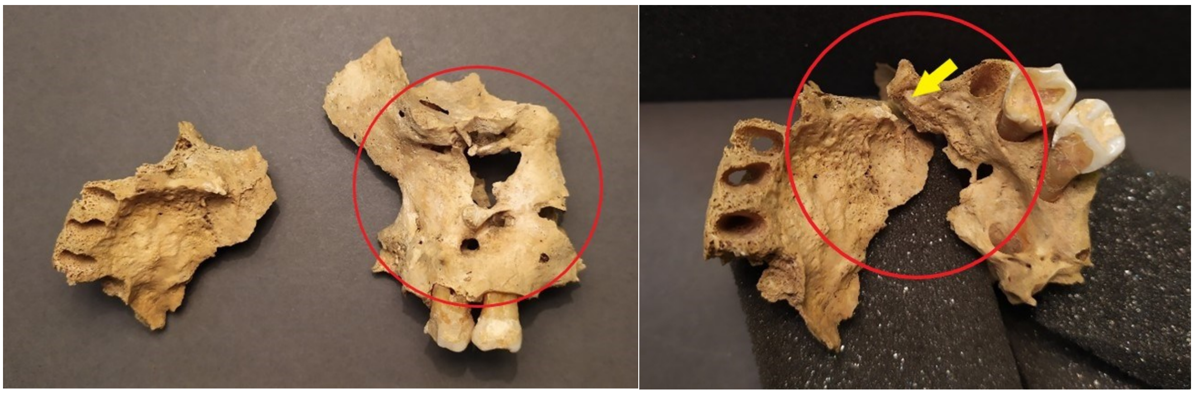

Figure 36. Grave number 109: Left maxilla with areas affected from bone loss (left); fracture line running along the left side of the palatine process (right); pseudo-articulation between fracture sites (arrow).

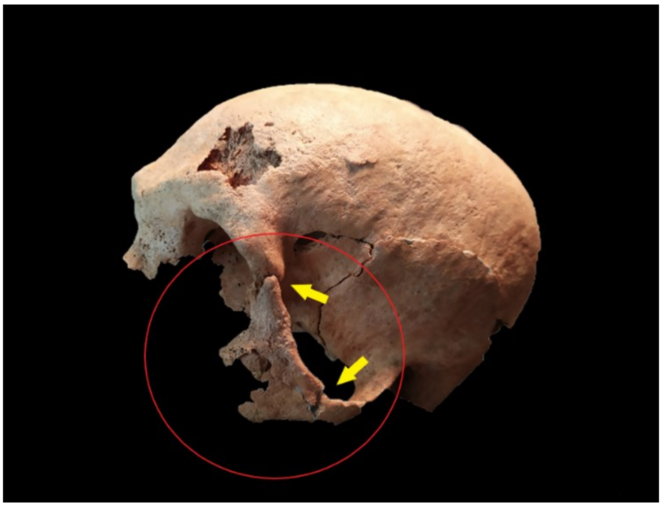

Figure 37. Grave number 109: Partial reconstruction of the lateral facial skull; fracture of the zygomatic bone, resulting in several fragments; pseudo-articulations between fracture sites (arrows).

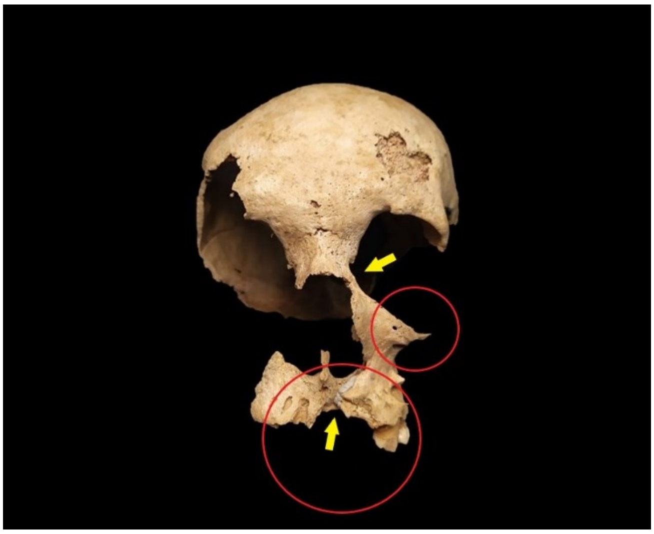

Figure 38. Grave number 109: Partial reconstruction of the frontal facial skull; sagging of the orbit and a reduction of the alveolar process; pseudo-articulations between fracture sites (arrows).

The mandible of the individual is also affected. In the region of the left coronoid process also bone loss can be observed. It probably resulted from a breaking-off and subsequent healing and re-attaching of the process. The newly fused fracture sites are clearly visible when looking at the medial side of the process (Figure 39). It can be assumed that such a severe fracture of the left frontal and lateral facial skull with involvement of the temporomandibular joint region was caused by a massive direct, blunt force trauma, such as a kick from a horse or a smashing of the face with a heavy object. Since there are multiple sites affected from bone loss and even small pseudo-articulations visible between the fracture sites, it cannot be stated that the fractures healed well, even though the healing process may have begun some time before the death of the individual.

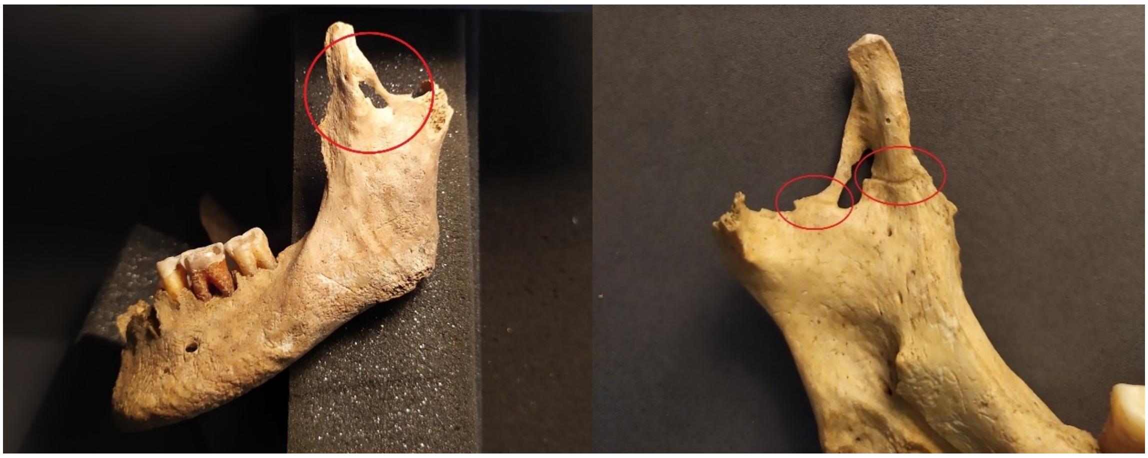

Figure 39. Grave number 109: Bone loss (left) and fracture lines (right) on coronoid process.

Moreover, the individual suffered from a transverse rib fracture. On the fragment of a left lower rib, which originates from the anterior third of the rib, a callus formation can be observed. A buckling of the rib can be recognised, which probably results from the displacement of the fracture ends. The callus formation is also visible on the radiographs (Figure 40). The cause of the fracture can be assumed to have been a direct force exerted on the left lower thorax, such as a heavy punch. As the hardly visible fracture line on the radiograph suggests, the fracture had probably healed long before the individual died. Furthermore, the individual excavated from grave number 109 also shows signs of (probably trauma-related) myositis ossificans on the right clavicle (N. Reiter, personal communication, 2022).

Although all injuries occurred a while before the death of the individual, it cannot be concluded with certainty that they resulted from the same incident. On close examination, the healing degrees of the neurocranium fracture and the rib fracture appear to be similar, whereas the facial skull fracture seems to have a shorter healing history. However, there is the possibility that all injuries occurred at the same time and only the generally poor healing of the facial skull fractures gives this impression. Assuming a common origin, an interpersonal confrontation with several strikes from the opponent could be a plausible scenario. For the facial skull fracture also a kick from a horse can be imagined.

The individual is unlikely to have had any persistent health problems caused by the neurocranial or the rib fracture. However, the situation is different for the fracture of the facial skull. Here, it is likely that massive ongoing complications occurred, such as pain when speaking and eating. A certain degree of disfigurement of the face can also be assumed, as a subsidence of the orbit can be observed. Furthermore, it cannot be ruled out that also the eyeball was affected and that there was a unilateral reduction of vision or even blindness. Also recovered from grave number 109 were animal bones from a food offering, an iron buckle, an iron ring, and a long iron knife (Daim, 1987).

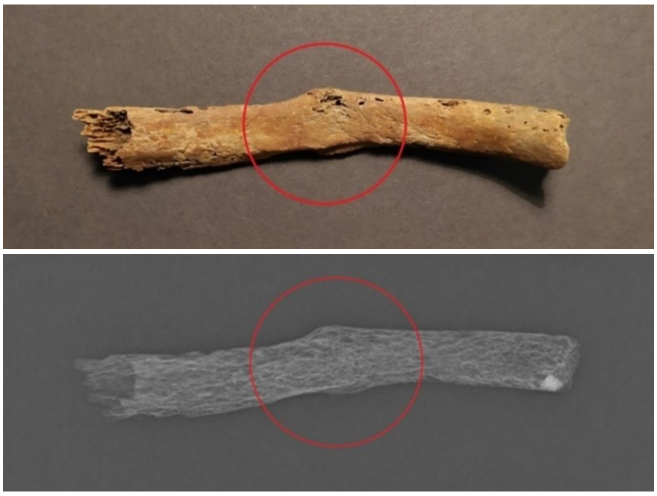

Figure 40. Grave number 109: Callus formation on a left lower rib with displaced fracture ends.

Grave number 116

Grave number 116 contained a middle-aged man (35-49 years), whose body height could not be determined due to the poor state of preservation of the long bones. The grave was assigned to the Late Avar Period IIIa.

The affected bone fragment appears to be the middle piece of a right upper (probably second) rib. Here, a subtle thickening can be noticed on the cranial surface of the rib, which might indicate a minor injury (see Figure 41). The examinations of the long bones revealed no further fractures (N. Reiter, personal communication, 2022). The fracture cause may have been an indirect force that caused a bending of the affected rib and resulted in a greenstick fracture, such as a lateral compression of the rib cage. The injury was already well-healed at the time the individual died and likely caused no persistent health problems. Grave number 116 also contained animal bones from a food offering, a bronze buckle, a long iron knife, an arrowhead, and a skewer-like iron object (Daim, 1987).

Figure 41. Grave number 116: Subtle thickening on a right upper rib, indicating a minor injury (left); position of the remains within grave (right) (adapted from Daim, 1987).

Grave Number 119A

Grave number 119 contained a double burial. Here, a man (A: 50 years or older) and a child (B: probably about 7 years) were buried in a common coffin, of which clearly visible, angular outlines could be identified. The grave was assigned to the Late Avar Period IIIa.

The man (119A, with a calculated body height of 170 cm) shows a small depression on the cranium with a diameter of about 1 cm (see Figure 42). The sagittal suture is hardly recognisable due to the advanced age of the individual and the state of preservation of the remains, but the depression is probably located directly on the posterior half of the suture. The anterior part of the depression shows a relatively sharp, angular edge. On the long bones no fractures could be found in the course of the investigations (N. Reiter, personal communication, 2022). The cause of the fracture was likely a direct impact to the neurocranium resulting in a depressed (crush) fracture. The sharp-edged border of the notch suggests a firm blow to the head with a blunt or semi-sharp object. There is no evidence of the injury on the radiograph, but the depression is clearly visible on the CT scan (see Figure 43). The fracture had already healed well when the individual died, and it can be assumed that the facture caused no long-term health problems. Grave number 116 also contained animal bones from a food offering, a belt set, an iron knife, two arrowheads and iron buckles (Daim, 1987).

Figure 42. Grave number 119A: Depressed (crush) fracture on the sagittal suture with sharp anterior edge (left); position of the remains within the grave (right) (adapted from Daim, 1987).

Figure 43. Grave number 119A: The radiograph (left) shows no sign of fracture, the cranial depression is, however, clearly visible on the CT scan (right).

Grave number 120

The individual recovered from grave number 120 was a middle aged man (35-49 years) with a calculated body height of 165 cm. The grave was assigned to the Late Avar Period IIIa.

In this case the left second rib is affected, which is relatively well preserved. In the middle third, a clearly recognisable callus formation can be observed, whereby the ends of the transverse fracture were probably not displaced (see Figure 44). The examinations of the long bones revealed no fractures (N. Reiter, personal communication, 2022). The cause of the fracture may have been a direct, forceful impact on the upper part of the left thorax, such as a hard stroke. As suggested by the hardly visible fracture line on the radiograph, the fracture probably healed well a long time before the death of the individual and likely did not cause any persistent health problems. From grave number 120, animal bones from a food offering, two iron buckles, arrowheads and an iron knife were recovered (Daim, 1987).

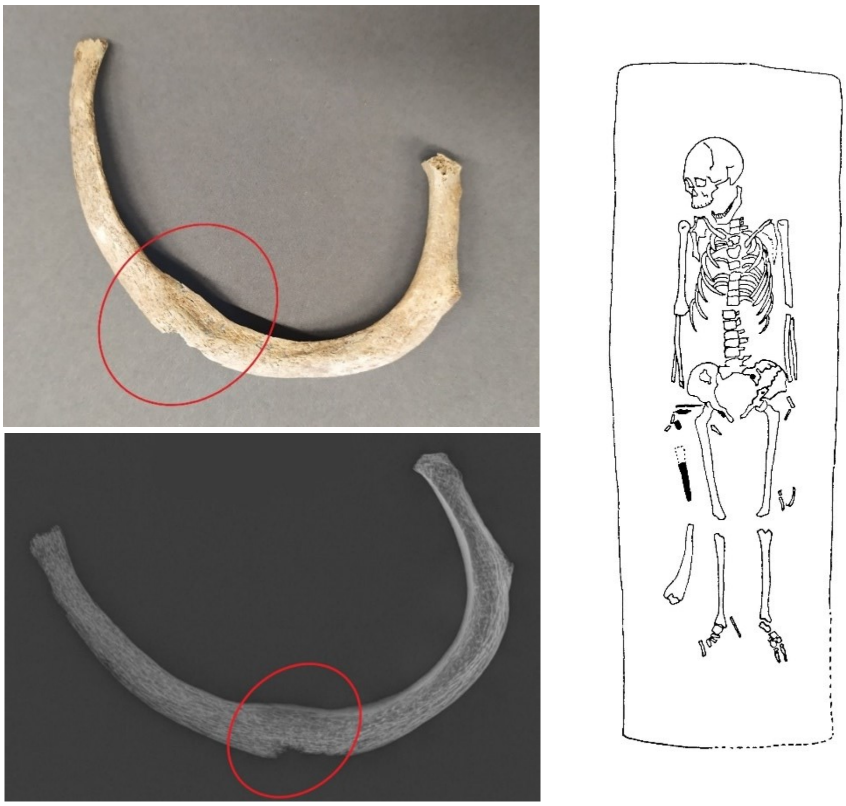

Figure 44. Grave number 120: Clearly visible callus on the left second rib (left); position of the remains within the grave (right) (adapted from Daim, 1987).

Grave number 129

The individual recovered from grave number 129 was an older man (50 years or older) with a calculated body height of 169 cm. The grave was assigned to the Late Avar Period IIIa.

The affected bone fragments seem to be the anterior parts of a left and a right rib of the same position within the ribcage. Both sides show subtle thickenings, which point to minor injuries rather than to complete fractures of the ribs (see Figure 45). The individual also shows evidence of a minor injury on the acromial third of the left clavicle (N. Reiter, personal communication, 2022). Due to the comparable degree of healing, it is assumed that the injuries occurred at the same time. The cause of the fractures may have been an indirect force that caused a compression of the ribcage and a bending of the affected ribs and the clavicle, resulting in greenstick fractures. The injuries had already healed well at the time the individual died and probably caused no persistent health problems. Also recovered from grave number 129 were animal bones from a food offering, a belt set, an iron buckle, wooden remains, arrowheads, and a long iron knife (Daim, 1987).

Figure 45. Grave number 129: Subtle thickenings on a left and a right rib indicating rather minor injuries (left); position of the remains within the grave (right) (adapted from Daim, 1987).

Grave number 143

The individual recovered from grave number 143 was an older woman (50 years or older). Here, a severely disturbed burial was discovered, with only the cranium, the right leg and the left lower leg being in their original position. Due to the poor preservation state of the long bones, no body height could be determined. The grave was assigned to the Late Avar Period IIIb.

In the posterior area of the sagittal suture, a shallow cranial depression with a diameter of about 3 cm can be observed (see Figure 46). The sagittal suture, which is well visible elsewhere, is hardly visible in the depression due to bone remodelling. On the long bones no fractures could be found (N. Reiter, personal communication, 2022). The injury, which can be classified as a depressed (crush) fracture, is most likely the result of direct blunt force trauma to the neurocranium, such like a heavy strike to the head. On the radiograph no signs of the injury can be found, whereas the CT scan makes the depression visible (Figure 47). The fracture had already healed well some time before the death of the individual and probably caused no persistent health problems. Animal bones from a food offering, an earring and a spindle whorl were also recovered from grave number 143 (Daim, 1987).

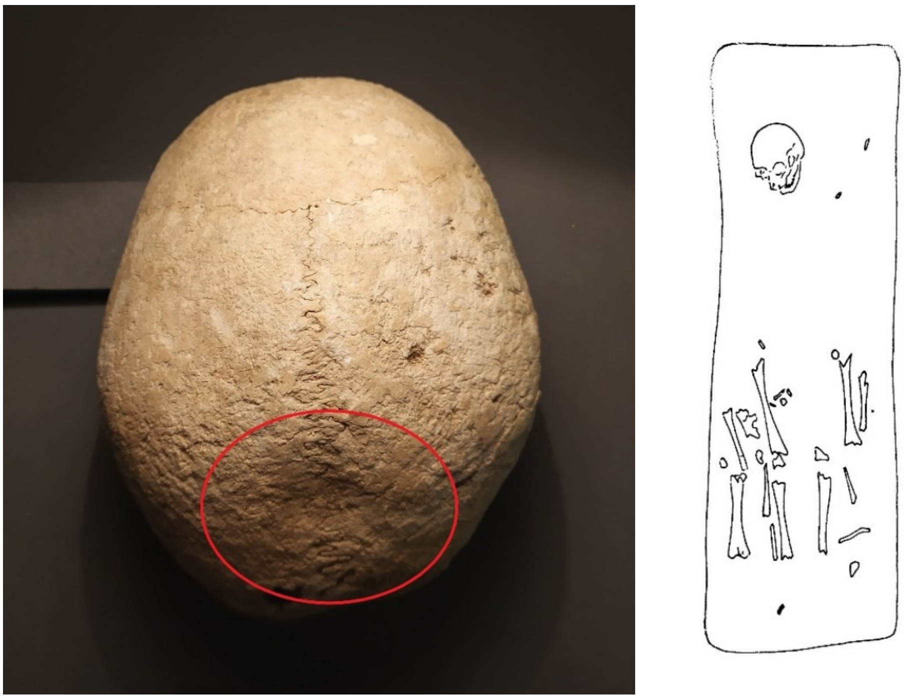

Figure 46. Grave number 143: Depressed (crush) fracture in the posterior region of the sagittal suture, with a diameter of about 3 cm (left); position of the remains within the grave (right) (adapted from Daim, 1987).

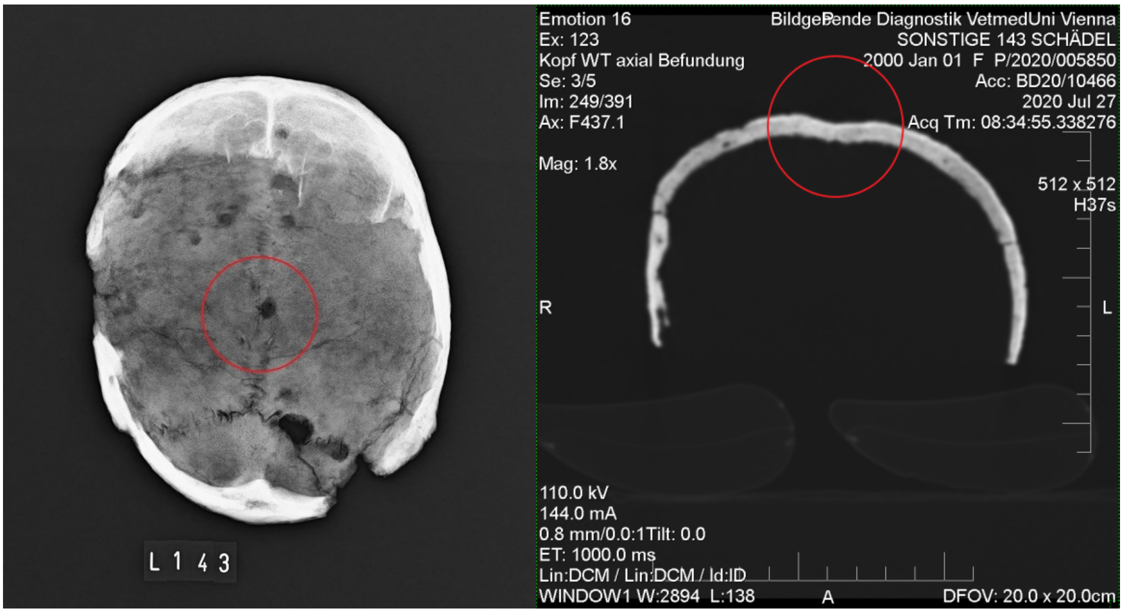

Figure 47. Grave number 143: The radiograph (left) shows no sign of fracture, the depression is, however, visible on the CT scan (right).

Grave number 147

Grave number 147 contained a subadult man (younger than 20 years). Due to the state of preservation of the long bones, no body height could be determined. The individual was buried lying on his right side with his legs slightly drawn up. The grave was assigned to the Late Avar Period IIIb.

On the second left rib, which is relatively completely preserved, a slightly pronounced, evenly formed callus can be observed, suggesting a minor fracture with non-displaced fracture ends (see Figure 48). Likewise, the two first ribs, which are as well relatively completely preserved, show irregularities which may also point to rather minor injuries than to complete fractures (see Figure 49). On the long bones, no fractures could be found during the examinations (N. Reiter, personal communication, 2022). Due to the comparable degree of healing, it can be assumed that all fractures occurred at the same time. The cause of the fractures may have been an indirect force that caused a compression of the ribcage and a bending of the affected ribs, resulting in greenstick fractures. The injuries had already healed well at the time the individual died and presumably caused no persistent health problems. An iron buckle and an iron ring were also recovered from grave number 147 (Daim, 1987).

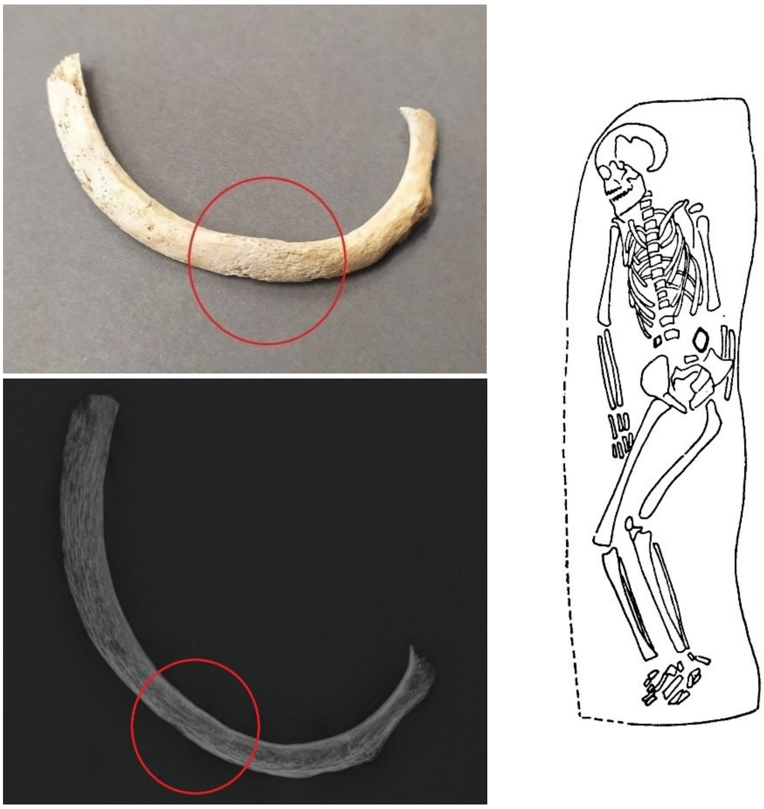

Figure 48. Grave number 147: Thickening on the left second rib, probably resulting from a minor fracture (left); position of the remains within the grave (right) (adapted from Daim, 1987).

Figure 49. Grave number 147: Irregularities on the two first ribs, which may point to greenstick fractures.

Grave number 152

Grave number 152 also contained a subadult man (younger than 20 years). Here, a completely disturbed burial was discovered with only parts of the spine and the lower legs being in their original position. Due to the poor state of preservation of the long bones, no body height could be determined. The grave was assigned to the Early Avar Period.

The affected bone fragment seems to be the middle third of an upper right rib. Here, a slightly pronounced, irregularly formed callus was built, likely due to a minor fracture, resulting in a broadening of the rib at the medial edge. On the radiograph, no signs of the fracture could be found (see Figure 50). The investigations revealed no fractures of the long bones (N. Reiter, personal communication, 2022). The fracture cause may have been an indirect force that led to a compression of the ribcage, and the bending of the affected rib may have resulted in a greenstick fracture. At the time the individual died the fracture had already healed well and probably caused no persistent health problems. Also recovered from grave number 152 were animal bones from a food offering, a silver earring, a pocket clasp made of bone, parts of a belt set, richly ornamented fittings of a quiver made of bone, remains of a compound reflex bow, some iron fragments, an iron buckle, and a silver-plated bronze sheet fragment (Daim, 1987).

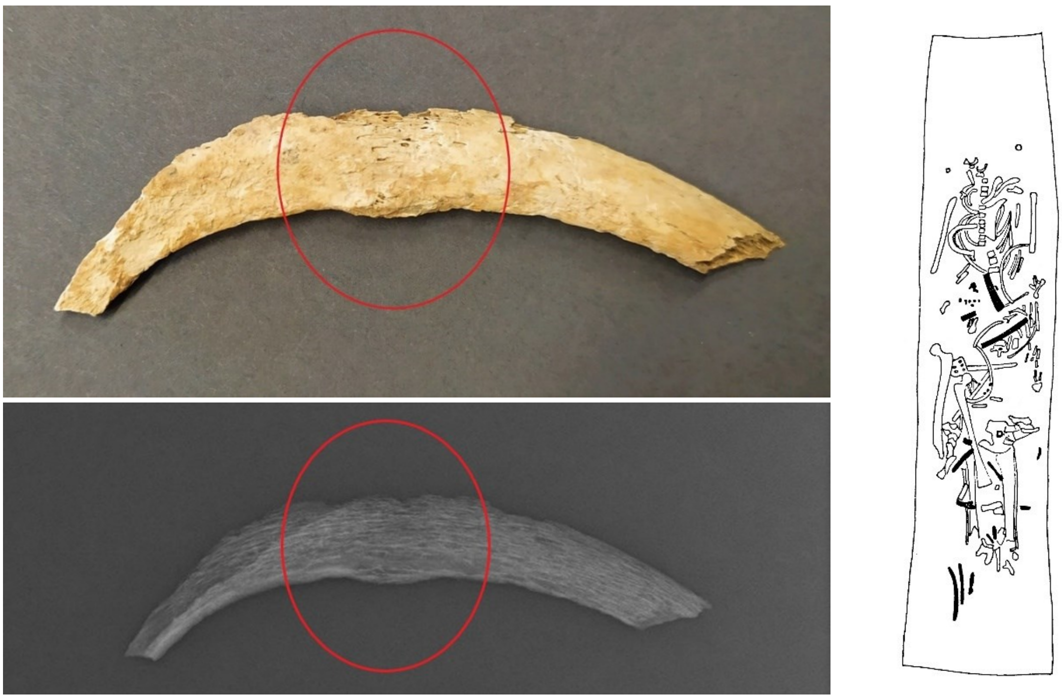

Figure 50. Grave number 152: Broadening of an upper right rib, probably resulting from a minor injury, such as a greenstick fracture (left); position of the remains within the grave (right) (adapted from Daim, 1987).

3.3. Prevalence of fractures

In the course of the examinations 129 individuals were systematically checked for the presence of fractures of the cranium, the ribs and the first four cervical vertebrae. Of these, 19 individuals (14.7% of the total sample) showed evidence of at least one injury. Six of those individuals (4.7%) showed evidence of more than one injury, whereby the maximum number of observed fractures in one individual was 9 (grave number 11). Rib fractures were found in 16 individuals (12.4%) and cranial fractures were found in four (3.1%), whereby one individual (0.8%) showed both types of fractures. None of the examined individuals showed vertebral fractures. Table 10 shows the distribution of individuals with rib fractures, cranial fractures, and fractures in general, divided by sex, age at death, and historical period in absolute (n) and relative (% of the total) numbers. More males than females, more individuals aged 35 years or older than individuals younger than 35 years, and more individuals assigned to the Late Avar period I-IIIa than individuals assigned to the other two periods were affected with fractures. In the Early and Middle Avar period 16.7% of the examined individuals showed fractures, whereby in the Late Avar period I-IIIa 14.9% of the examined individuals showed fractures. In the Late Avar period IIIb 11.8% showed fractures. These differences between the periods concerning the occurrence of fractures were not statistically significant (p = 0.932, Fisher's Exact Test).

Table 10. Prevalence of rib fractures, cranial fractures, and fractures in general, divided by sex, age at death, and historical period in absolute (n) and relative (% of the total) numbers.

	Total number of examined individuals	Individuals with fractures	Individuals with rib fractures	Individuals with cranial fractures
Sex				
Male	62 (48.1%)	13 (10.1%)	11 (8.5%)	3 (2.3%)
Female	67 (51.9%)	6 (4.7%)	5 (3.9%)	1 (0.8%)
Age				
<35	57 (44.2%)	4 (3.1%)	4 (3.1%)	0 (0.0%)
>35	70 (54.3%)	15 (11.6%)	12 (9.3%)	4 (3.1%)
?	2 (1.6%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Historical period				
Early + Middle Avar period	24 (18.6%)	4 (3.1%)	4 (3.1%)	0 (0.0%)
Late Avar period I-IIIa	87 (67.4%)	13 (10.1%)	11 (8.5%)	3 (2.3%)
Late Avar period IIIb	17 (13.2%)	2 (1.6%)	1 (0.8%)	1 (0.8%)
?	1 (0.8%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Total	**129 (100.0%)**	**19 (14.7%)**	**16 (12.4%)**	**4 (3.1%)**

Overall, out of 48 crania that showed a preservation status of 50-100%, four (8.3%) showed fractures. One individual showed a fracture that was located clearly on the left parietal (grave number 5). One individual showed a fracture that was located clearly on the right parietal, whereby this individual also showed a fracture of the left facial skull, affecting the zygomatic bone, the maxilla, and the ramus of the mandible (grave number 109). Two individuals showed a fracture that was located on the sagittal suture (graves number 119A and 143). Since these fractures could not be clearly assigned to one side, they were counted for both sides. Table 11 shows the distribution of individuals with fractures of the right parietal, the left parietal, the left zygomatic bone, the left maxilla, as well as the left ramus mandibulae, divided by sex, age at death, and historical period in absolute (n) and relative (% of the examined individuals in each case, considering preservation status 25-100%) numbers. More males than females, only individuals aged 35 years or older, and mainly individuals assigned to the Late Avar Period I-IIIa showed evidence of cranial fractures.

Table 11. Prevalence of fractures of the right parietal, the left parietal, the left zygomatic bone, the left maxilla, and the left ramus mandibulae, divided by sex, age at death, and historical period in absolute (n) and relative (% of the examined individuals in each case, considering preservation status 25-100%) numbers.

	Fracture of right parietal	Fracture of left parietal	Fracture of left zygomatic bone	Fracture of left maxilla	Fracture of left ramus mandibulae
Sex					
Male	2 (2.8%)	2 (2.7%)	1 (1.6%)	1 (2.0%)	1 (1.3%)
Female	1 (1.4%)	1 (1.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Age					
<35	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
>35	3 (4.2%)	3 (4.0%)	1 (1.6%)	1 (2.0%)	1 (1.3%)
?	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Historical period					
Early + Middle Avar period	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Late Avar period I-IIIa	2 (2.8%)	2 (2.7%)	1 (1.6%)	1 (2.0%)	1 (1.3%)
Late Avar period IIIb	1 (1.4%)	1 (1.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
?	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Total number of individuals with fractures	**3 (4.2%)**	**3 (4.0%)**	**1 (1.6%)**	**1 (2.0%)**	**1 (1.3%)**
Total number of examined individuals	**72 (100.0%)**	**75 (100.0%)**	**64 (100.0%)**	**49 (100.0%)**	**80 (100.0%)**

Of 65 individuals of whom the first right rib could be examined and of 67 individuals of whom the first left rib could be examined, one individual each (1.5%) showed an injury (grave number 147). Of 82 individuals of whom the ribs of the right side could be at least partially examined 10 individuals (12.2%) showed fractures. Of 83 individuals of whom the ribs of the left side could be at least partially examined, 9 individuals (10.8%) showed fractures.

Table 12 shows the distribution of individuals showing fractures of the right first rib, the left first rib, and the right and left side of the rib cage in general, divided by sex, age at death, and historical period in absolute (n) and relative (% of the examined individuals in each case, considering preservation status 0-100%) numbers. More males than females, more individuals aged 35 years or older than individuals younger than 35 years, and more individuals assigned to the Late Avar period I-IIIa than individuals assigned to the other historical periods showed evidence of rib fractures.

Table 12. Prevalence of fractures of the right first rib, the left first rib, and the right and left side of the rib cage in general, divided by sex, age at death, and historical period in absolute (n) and relative (% of the examined individuals in each case, considering preservation status 0-100%) numbers.

	Fracture of right first rib	Fracture of left first rib	Fracture of ribs right side	Fracture of ribs left side
Sex				
Male	1 (1.5%)	1 (1.5%)	7 (8.5%)	7 (8.4%)
Female	0 (0.0%)	0 (0.0%)	3 (3.7%)	2 (2.4%)
Age				
<35	1 (1.5%)	1 (1.5%)	4 (4.9%)	1 (1.2%)
>35	0 (0.0%)	0 (0.0%)	6 (7.3%)	8 (9.6%)
?	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Historical period				
Early + Middle Avar period	0 (0.0%)	0 (0.0%)	3 (3.7%)	2 (2.4%)
Late Avar period I-IIIa	0 (0.0%)	0 (0.0%)	6 (7.3%)	6 (7.2%)
Late Avar period IIIb	1 (1.5%)	1 (1.5%)	1 (1.2%)	1 (1.2%)
?	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Total number of individuals with fractures	1 (1.5%)	1 (1.5%)	10 (12.2%)	9 (10.8%)
Total number of examined individuals	65 (100.0%)	67 (100.0%)	82 (100.0%)	83 (100.0%)

3.4. Test of hypotheses

3.4.1. Hypothesis 1

The first hypothesis, which states that men show a generally higher frequency of fractures than women, was tested using the Chi-Squared Test. Here, no statistically significant sex difference could be found (X^2 (1, N = 129) = 3.700, p = 0.080). Figure 51 and Table 13 show the distribution of the individuals without and with fractures, divided by sex. In both sexes, there were much more individuals without fractures than individuals with fractures. Thirteen male individuals showed fractures (10.1% of the total; 21.0% of all examined males), whereby only six female individuals showed fractures (4.7% of the total; 9.0% of all examined females).

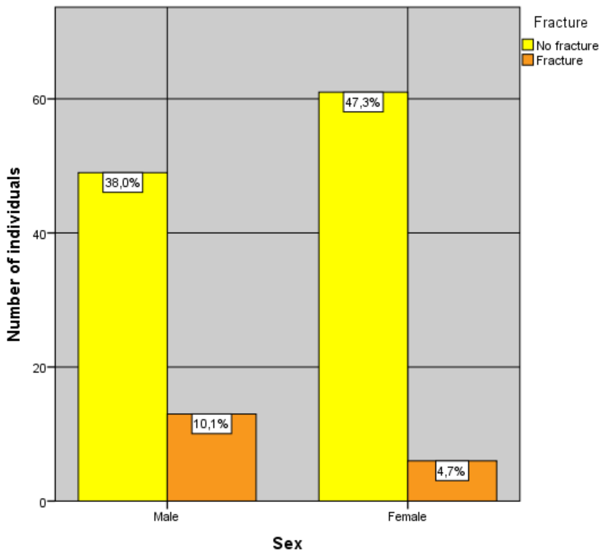

Figure 51. Distribution of individuals without and with fractures in relative (% of the total) numbers, divided by sex.

Table 13. Distribution of individuals without and with fractures in absolute (n) and relative (% of the total) numbers, divided by sex.

Sex	No fracture	Fracture	Total
Male	49 (38.0%)	13 (10.1%)	62 (48.1%)
Female	61 (47.3%)	6 (4.7%)	67 (51.9%)
Total	110 (85.3%)	19 (14.7%)	129 (100.0%)

When testing the hypothesis per age group, again no significantly higher frequency of fractures in males could be found in individuals younger than 35 years (p = 0.594, Fisher's Exact Test) or individuals aged 35 years or older (X^2 (1, N = 70) = 1.142, p = 0.376). In the group of individuals younger than 35 years, two males (3.5% within age group; 10.5% of the examined young males) and two females (3.5% within age group; 5.3% of the examined young females) showed fractures. In the group of individuals older than 35 years, eleven males (15.7% within age group; 25.6% of the examined older males) and four females (5.7% within age group; 14.8% of the examined older females) showed fractures. Figure 52 and Table 14 show the distributions of individuals without and with fractures for both age groups, divided by sex.

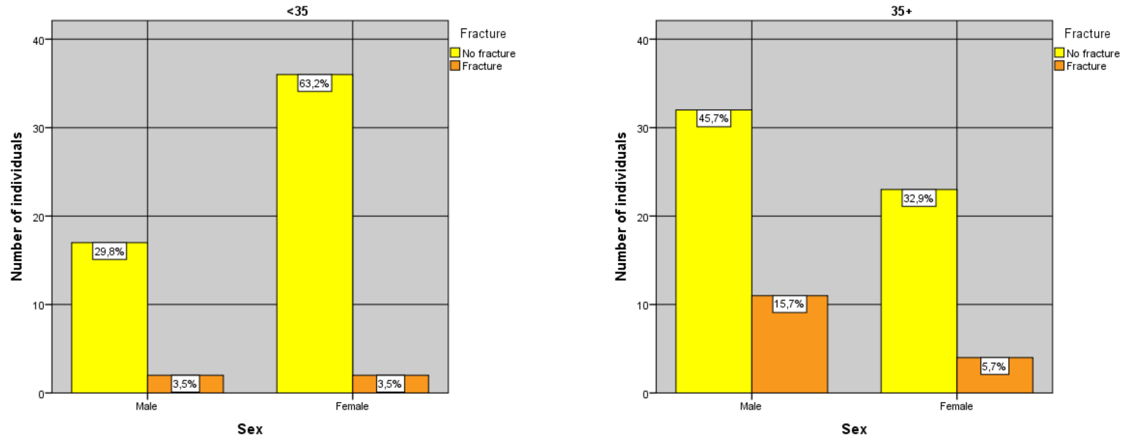

Figure 52. Distribution of individuals without and with fractures in relative (% within age group) numbers, divided by sex, for individuals younger than 35 years (left) and older than 35 years (right).

Table 14. Distribution of the individuals without and with fractures in absolute (n) and relative (% within age group) numbers, divided by age group and sex.

<35			
Sex	No fracture	Fracture	Total
Male	17 (29.8%)	2 (3.5%)	19 (33.3%)
Female	36 (63.2%)	2 (3.5%)	38 (66.7%)
Total	53 (93.0%)	4 (7.0%)	57 (100.0%)

35+			
Sex	No fracture	Fracture	Total
Male	32 (45.7%)	11 (15.7%)	43 (61.4%)
Female	23 (32.9%)	4 (5.7%)	27 (38.6%)
Total	55 (78.6%)	15 (21.4%)	70 (100.0%)

In summary, the first hypothesis, stating that male individuals generally show significantly more fractures than female individuals, could not be confirmed. However, among the individuals with fractures, more males than females could be observed. Even though the differences were not statistically significant (X^2 (1, N = 129) = 3.700, p = 0.080), more than twice as many males than females showed fractures when considering the entire sample (21.0% of males vs. 9.0% of females).

When testing the hypothesis per age group, again no significant results could be found (p = 0.594, Fisher's Exact Test for younger individuals; X^2 (1, N = 70) = 1.142, p = 0.376 for older individuals). In both groups, however, more males than females showed fractures (10.5% of males vs. 5.3% of females in the group of younger individuals and 25.6% of males vs. 14.8% of females in the group of older individuals).

3.4.2. Hypothesis 2

The second hypothesis, which states that older individuals generally show more fractures than younger individuals, was tested using a Chi-Squared Test. Here, a significant effect could be found (X^2 (1, N = 127) = 5.128, p = 0.026). Figure 53 and Table 15 show the distribution of individuals without and with fractures, divided by age groups. Individuals older than 35 years showed significantly more fractures than individuals younger than 35 years. In the group of individuals younger than 35 years, four individuals showed fractures (3.1% of the total; 7.0% of the younger individuals). In the group of individuals aged 35 years or older, 15 individuals showed fractures (11.8% of the total; 21.4% of the older individuals).

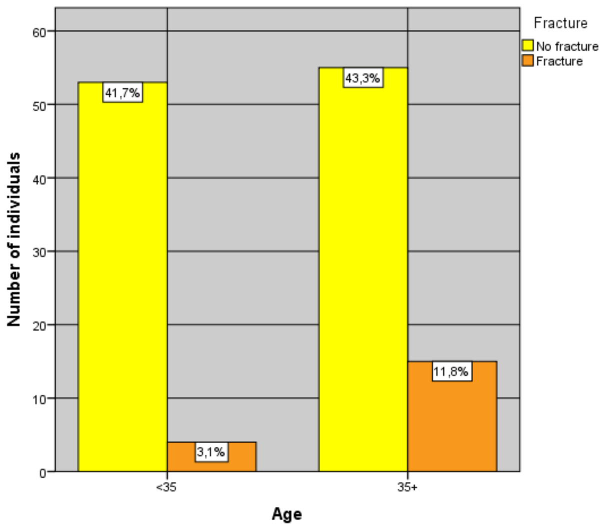

Figure 53. Distribution of individuals without and with fractures in relative (% of the total) numbers, divided by age groups.

Table 15. Distribution of individuals without and with fractures in absolute (n) and relative (% of the total) numbers, divided by age group.

Age group	No fracture	Fracture	Total
<35	53 (41.7%)	4 (3.1%)	57 (44.9%)
35+	55 (43.3%)	15 (11.8%)	70 (55.1%)
Total	108 (85.0%)	19 (15.0%)	127 (100.0%)

Furthermore, the two age groups were examined for differences regarding fracture type and severity of the occurring fractures. Figure 54 and Table 16 show the occurrence of rib and cranial fractures and the occurrence of minor and severe fractures, divided by age groups.

When examining the fracture type per age group, statistically significant differences could be found ($p = 0.028$, Fisher's Exact Test). Here it was observed that in the group of individuals younger than 35 years only four individuals (21.1% of individuals with fractures; 7.0% of the younger individuals) showed rib fractures, whereas in the group of individuals aged 35 years or older eleven individuals showed rib fractures (57.9% of individuals with fractures; 15.7% of the older individuals). Also, it was observed that none of the younger individuals showed cranial fractures, whereas four of the older individuals did (21.1% of individuals with fractures; 5.7% of the older individuals). The individual excavated from grave number 109, which showed both rib and cranial fractures, was assigned to the "cranial fracture" group only for statistical analyses of fracture types. Therefore, Figure 54 and Table 16 only show 15 individuals suffering from rib fractures.

When examining the severity of the occurring fractures per age group, no statistically significant result could be found, even though one could speak of a trend ($p = 0.071$, Fisher's Exact Test). Here, it was shown that in the group of younger individuals only one individual showed a severe fracture (5.3% of individuals with fractures; 1.8% of the younger individuals), whereas in the group of older individuals twelve showed severe fractures (63.2% of individuals with fractures; 17.1% of the older individuals). Furthermore, in both age groups three individuals each showed minor fractures (15.8% of individuals with fractures; 5.3% of the younger individuals; 4.3% of the older individuals).

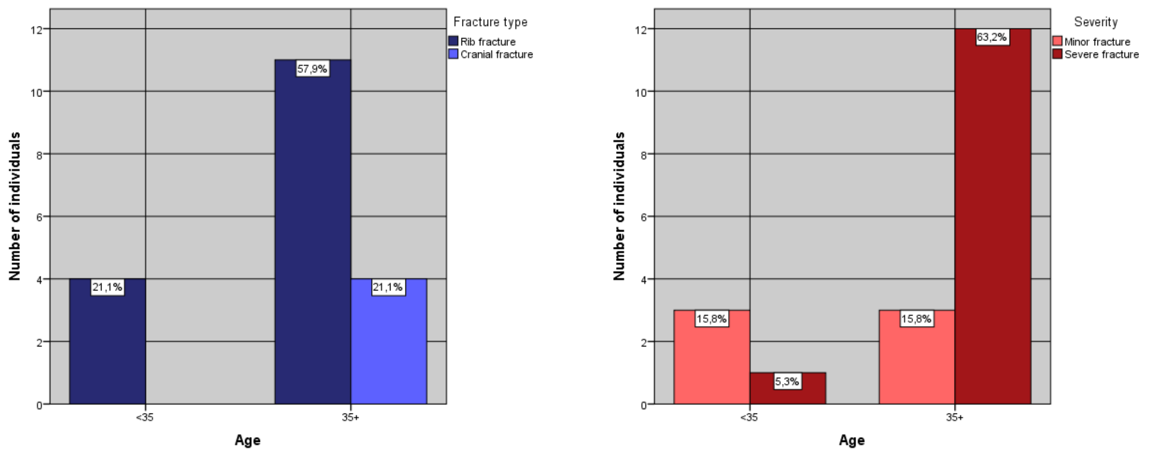

Figure 54. Distributions of fracture type (left) and severity (right) in relative (% of individuals with fractures) numbers, divided by age groups.

Table 16. Distributions of fracture type and severity, divided by age groups in absolute (n) and relative (% of individuals with fractures) numbers.

Age group	Rib fracture	Cranial fracture	Total
<35	4 (21.1%)	0 (0.0%)	4 (21.1%)
35+	11 (57.9%)	4 (21.1%)	15 (78.9%)
Total	15 (78.9%)	4 (21.01%)	19 (100.0%)

Age group	Minor fracture	Severe fracture	Total
<35	3 (15.8%)	1 (5.3%)	4 (21.1%)
35+	3 (15.8%)	12 (63.2%)	15 (78.9%)
Total	6 (31.6%)	13 (68.4%)	19 (100.0%)

To sum up, the second hypothesis, stating that older individuals show significantly more fractures than younger individuals, could be confirmed (X^2 (1, N = 127) = 5.128, p = 0.026). Only 7.0% of the younger individuals showed fractures, whereas 21.4% of the older individuals did.

Significant results could also be observed when examining the fracture type per age group (p = 0.028, Fisher's Exact Test). Of the younger individuals only 7.0% showed rib fractures, whereas of the older individuals 15.7% did. Also, none of the younger individuals showed cranial fractures, in contrast to 5.7% of the older individuals.

No significant results, but a trend could be found, when examining the severity of the occurring fractures per age group (p = 0.071, Fisher's Exact Test). Here, only 1.8% of the younger individuals showed severe fractures, whereas 17.1% of the older individuals did. Minor fractures were recorded for 5.3% of the younger individuals and 4.3% of the older individuals.

3.4.3. Hypothesis 3

The third hypothesis, which states that sex-specific differences can be found when examining the fracture patterns, was tested using Fisher's Exact Test. Here, no significant sex differences could be found regarding the prevalence of rib and cranial fractures (p = 1.000) or the more frequently affected side of the body (p = 0.596), when considering the sample of individuals showing fractures.

Likewise, no significant results could be found when examining sex differences regarding the occurrence of single and multiple fractures (p = 0.605) or the severity of the occurring fractures (p = 1.000). Figure 55 and Table 17 show the distributions of fracture type, affected side of the body, single and multiple fractures, and severity within the individuals showing fractures, divided by sex.

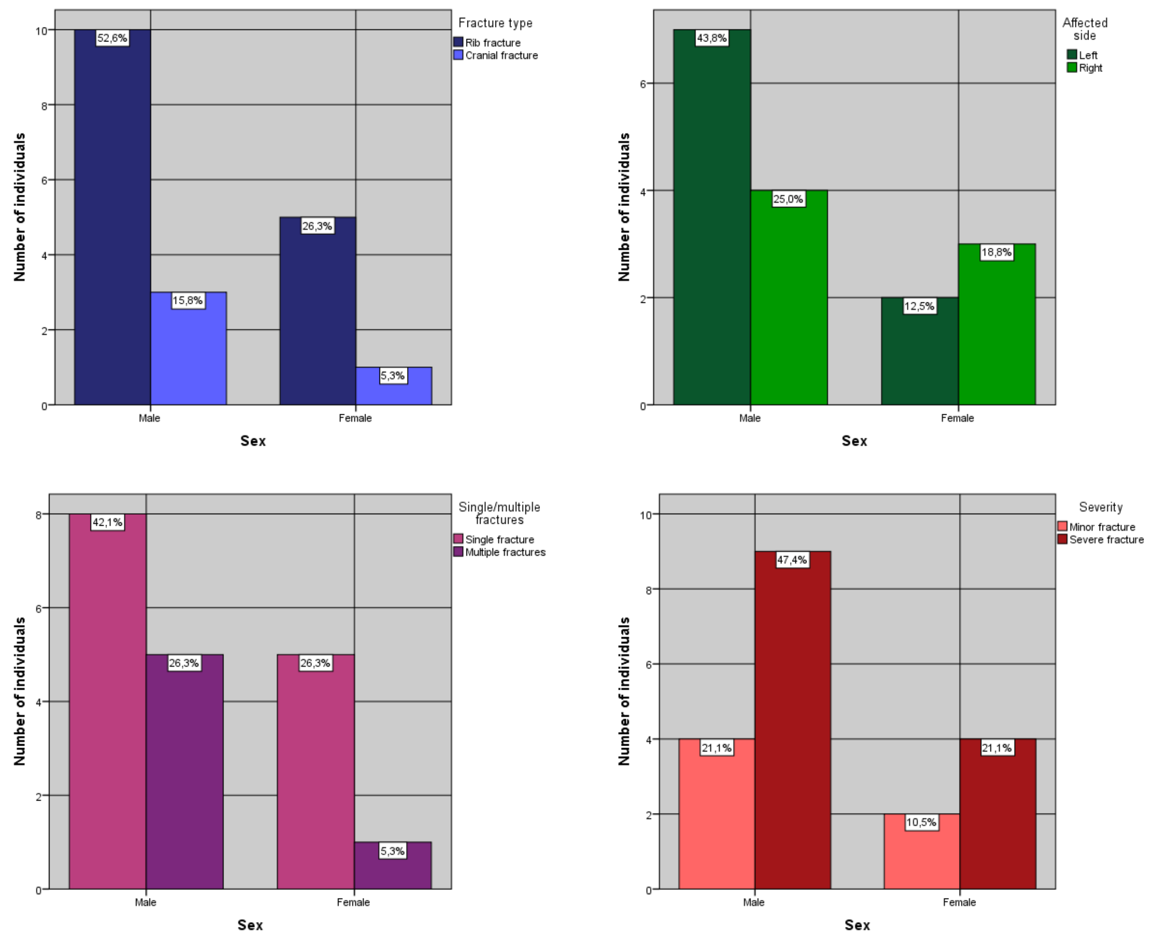

Figure 55. Distributions of fracture type (top left), affected side of the body (top right), single and multiple fractures (bottom left), and severity of the occurring fractures (bottom right) in relative (% of the individuals showing fractures) numbers, divided by sex.

Although no statistically significant results could be found, more males than females were affected by both rib and cranial fractures. Also, rib fractures occurred more frequently than cranial fractures in both sexes. Ten males (52.6% of individuals showing fractures; 16.1% of all males) and five females (26.3% of individuals showing fractures; 7.5% of all females) only showed rib fractures.

Three males (15.8% of individuals showing fractures; 4.8% of all males) and one female (5.3% of individuals showing fractures; 1.5% of all females) showed cranial fractures, whereby one individual (grave number 109, male) showed a rib fracture in addition. This individual was assigned to the “cranial fracture” group only for the statistical analyses. Thus, Figure 55 and Table 17 only show 15 individuals suffering from rib fractures.

In male individuals, the left side of the body was more often affected. Seven individuals only showed fractures on the left side of the body (43.8% of individuals showing fractures; 11.3% of all males) and four individuals only showed fractures on the right side of the body (25.0% of individuals showing fractures; 6.5% of all males). In female individuals, however, the right side of the body was affected slightly more often. Three individuals only showed fractures on the right side of the body (18.8% of individuals showing fractures; 4.8% of all females) and two only showed fractures on the left side of the body (12.5% of individuals showing fractures; 3.0% of all females). Three individuals were excluded from the examinations, because they either showed fractures on both sides of the body or the fracture could not be clearly assigned to one side.

Table 17. Distributions of fracture type, affected side, single and multiple fractures, as well as severity of the occurring fractures in absolute (n) and relative (% of individuals showing fractures) numbers, divided by sex.

Sex	Rib fracture	Cranial fracture	Total
Male	10 (52.6%)	3 (15.8%)	13 (68.4%)
Female	5 (26.3%)	1 (5.3%)	6 (31.6%)
Total	15 (78.9%)	4 (21.1%)	19 (100.0%)

Sex	Left side	Right side	Total
Male	7 (43.8%)	4 (25.0%)	11 (68.8%)
Female	2 (12.5%)	3 (18.8%)	5 (31.3%)
Total	9 (56.3%)	7 (43.8%)	16 (100.0%)

Sex	Single fracture	Multiple fractures	Total
Male	8 (42.1%)	5 (26.3%)	13 (68.4%)
Female	5 (26.3%)	1 (5.3%)	6 (31.6%)
Total	13 (68.4%)	6 (31.6%)	19 (100.0%)

Sex	Minor fracture	Severe fracture	Total
Male	4 (21.1%)	9 (47.4%)	13 (68.4%)
Female	2 (10.5%)	4 (21.1%)	6 (31.6%)
Total	6 (31.6%)	13 (68.4%)	19 (100.0%)

Furthermore, in both sexes single fractures were recorded more frequently than multiple fractures. Among the male individuals, eight showed single fractures (42.1% of individuals showing fractures; 12.9% of all males) and five showed multiple fractures (26.3% of individuals showing fractures; 8.0% of all males). Among the female individuals, five showed single fractures (26.3% of individuals showing fractures; 7.5% of all females) and one showed multiple fractures (5.3% of individuals showing fractures; 1.5% of all females).

Also, in both sexes severe fractures were recorded more frequently than minor fractures. Nine male individuals showed severe fractures (47.4% of individuals showing fractures; 14.5% of all males) and four showed minor fractures (21.1% of individuals showing fractures; 6.5% of all males). Four female individuals showed severe fractures (21.1% of individuals showing fractures; 6.0% of all females) and two showed minor fractures (10.5% of individuals showing fractures; 3.0% of all females).

Although the results were statistically not significant, the analyses further indicated that in male individuals multiple fractures appeared to be more common on the left side ($p = 0.194$, Fisher's Exact Test), whereas in female individuals single fractures were slightly more common on the right side ($p = 0.400$, Fisher's Exact Test; see Figure 56 and Table 18).

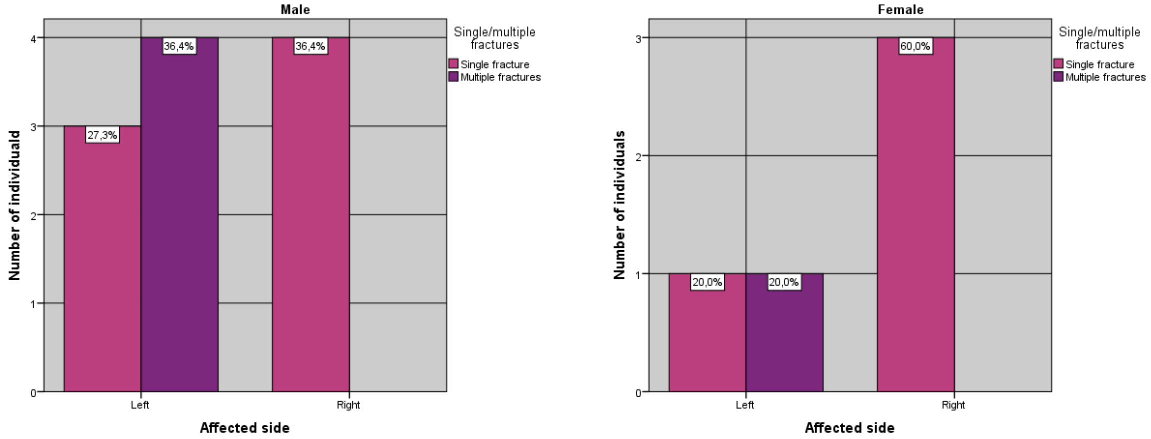

Figure 56. Distributions of single and multiple fractures, divided by affected side of the body in relative (% of individuals showing fractures) numbers, for males (left) and females (right).

Table 18. Distributions of single and multiple fractures, divided by affected side of the body in absolute (n) and relative (% of individuals showing fractures) numbers, for males and females.

Male			
Side	Single fracture	Multiple fractures	Total
Left	3 (27.3%)	4 (36.4%)	7 (63.6%)
Right	4 (36.4%)	0 (0.0%)	4 (36.4%)
Total	7 (63.6%)	4 (36.4%)	11 (100.0%)

Female			
Side	Single fracture	Multiple fractures	Total
Left	1 (20.0%)	1 (20.0%)	2 (40.0%)
Right	3 (60.0%)	0 (0.0%)	3 (60.0%)
Total	4 (80.0%)	1 (20.0%)	5 (100.0%)

Furthermore, in male individuals severe fractures appeared to be more likely to occur on the left side (p = 0.491, Fisher's Exact Test), whereas in female individuals severe fractures appeared to be more likely to occur on the right side (p = 1.000, Fisher's Exact Test), whereby again no statistically significant results were found here (see Figure 57 and Table 19).

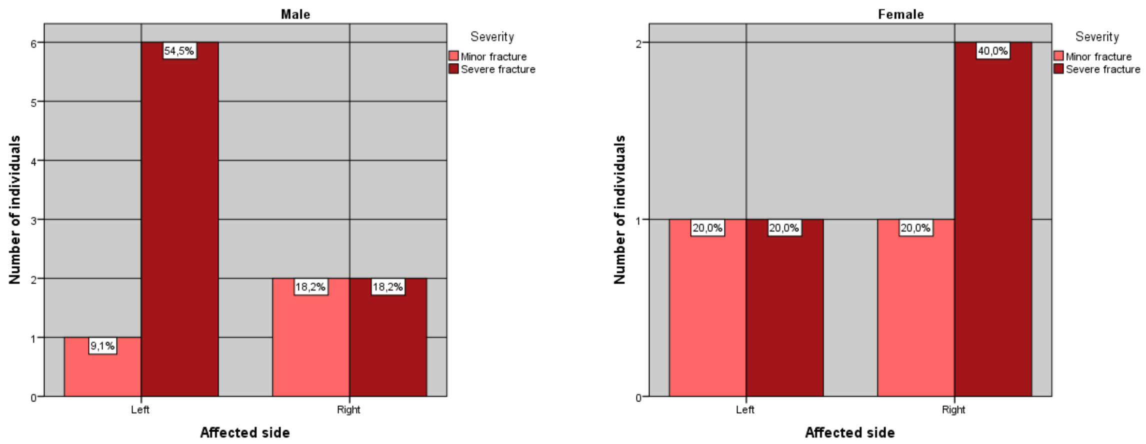

Figure 57. Distributions of minor and severe fractures, divided by affected side of the body in relative (% of individuals showing fractures) numbers, for males (left) and females (right).

Table 19. Distributions of minor and severe fractures, divided by affected side of the body in absolute (n) and relative (% of individuals showing fractures) numbers, for males and females.

Male			
Side	Minor fracture	Severe fractures	Total
Left	1 (9.1%)	6 (54.5%)	7 (63.6%)
Right	2 (18.2%)	2 (18.2%)	4 (36.4%)
Total	3 (27.3%)	8 (72.7%)	11 (100.0%)

Female			
Side	Minor fracture	Severe fractures	Total
Left	1 (20.0%)	1 (20.0%)	2 (40.0%)
Right	1 (20.0%)	2 (40.0%)	3 (60.0%)
Total	2 (40.0%)	3 (60.0%)	5 (100.0%)

In conclusion, the third hypothesis, stating that male and female individuals show different fracture patterns, could not be confirmed. In both sexes rib fractures occurred more frequently than cranial fractures and even though more than twice as many males than females showed rib fractures (16.1% of males vs. 7.5% of females) and cranial fractures (4.8% of males vs. 1.5% of females), these results were statistically not significant (p = 1.000, Fisher's Exact Test).
When examining the more frequently affected side of the body, also no statistically significant results could be found (p = 0.596, Fisher's Exact Test), although the findings indicated that in males the left side was more frequently affected (11.3% left vs. 6.5% right) and in females the right side was more frequently affected (4.8% right vs. 3.0% left).
Furthermore, both sexes showed more single fractures (12.9% of males and 7.5% of females) than multiple fractures (8.0% of males and 1.5% of females), whereby also no statistically significant sex differences could be found here (p = 0.605, Fisher's Exact Test).
The higher frequency of severe fractures (14.5% of males and 6.0% of females) compared to minor fractures (6.5% of males and 3.0% of females) in both sexes, also produced no significant results (p = 1.000, Fisher's Exact Test).
Furthermore, although again no statistically significant results could be found, it was observed that in males multiple fractures (p = 0.194, Fisher's Exact Test) and severe fractures (p = 0.491, Fisher's Exact Test) were more likely to occur on the left side. In contrast to this, females were more likely to show single fractures (p = 0.400, Fisher's Exact Test) and severe fractures (p = 1.000, Fisher's Exact Test) on the right side.

4. Discussion

From the 129 adult individuals of the graveyard Leobersdorf, which were examined herein for the presence of fractures of the cranium, the ribs and the first four cervical vertebrae, 19 individuals (14.7%) showed at least one injury. Cranial fractures were found in four individuals (3.1%) and rib fractures were found in 16 individuals (12.4%). Fractures of the cervical vertebrae could be found in none of the examined individuals. These results are consistent with the findings of other authors studying populations with similar living conditions.

For example, in his study of a burial ground, which was uncovered in Privlaka (Croatia) and dated to the Avaro-Slav period in the early Middle Ages (between 700 and 800 CE), Šlaus (1996) observed similar numbers of fractures, in terms of the crude prevalence rate. Of 144 examined adult individuals, 26 (18.1%) showed fractures. Cranial fractures were found in two individuals (1.4%).

However, in his study, Šlaus also examined the occurrence of long bone fractures, whereas the occurrence of rib fractures was not discussed. Since the individuals examined by Šlaus were classified as members of an Avaro-Slav population and were assigned to the Late Avar period, like the majority (80.6%) of the herein examined individuals, a settled way of life with a combination of livestock farming and agriculture can be assumed.

Megan Brickley (2006) reported similar results for the crude prevalence rate of rib fractures to those observed in the present work when examining the English burial ground of St. Martin's Church in Birmingham. The majority (77.6%) of the examined individuals was buried in earth-cut graves and was classified as being part of the working class, which makes the living conditions of these individuals in a broader sense comparable to those of the individuals examined in the present study. The rest of the examined individuals was buried in vaults and assigned to the slightly wealthier class. Her investigations showed that out of 352 individuals, mainly buried between 1750 and 1850, 55 individuals (15.6%) showed rib fractures. Although individuals assigned to the working class showed more rip fractures (17.6%) than individuals assigned to the wealthier class (8.9%), Brickley could not observe statistically significant differences here.

Hypothesis testing

Hypothesis 1

Men have a higher chance of being injured in accidents, interpersonal conflicts, or warfare, as they are in general more physically aggressive and risk-taking than women (Eagly & Steffen, 1986; Pawlowski et al., 2008). Thus, the first hypothesis predicted that men generally show a higher frequency of fractures than women. This hypothesis could not be confirmed.

When examining the first hypothesis it turned out that, when considering the whole sample, 21.0% of males and 9.0% of females showed fractures, however these differences were statistically not significant. When splitting the sample into age groups (individuals younger and individuals older than 35 years), it was found that in the group of younger individuals 10.5% of males and 5.3% of females showed fractures. In the group of older individuals 25.6% of males and 14.8% of females showed fractures, whereby these differences were also not statistically significant.

These results are in line with those of other studies. For example, Šlaus (1996) also found no significant sex differences when examining the frequency of fractures in his sample of 144 adult individuals excavated from the burial ground Privlaka, dated to the Late Avar period. However, in accordance with the results of the present study, he also reported that more males (19.7%) than females (16.4%) showed fractures.

Matos (2009) as well reported similar results when examining the prevalence of rib fractures in a sample of 197 individuals from the Human Identified Skeletal Collection of the Museu Bocage in Portugal, dated between the late 19th and the middle 20th century CE. He reported that more males (36.7%) than females (32.7%) with fractures were found in the group of older individuals, when splitting the sample in two age groups (individuals younger and older than 40 years), whereby these results were statistically not significant.

Other authors, for example Novak & Šlaus (2012), found statistically significant results. In their study of 119 adult crania recovered from the burial ground Dugopolje in Croatia, which was dated between the 13th and the 16th century CE, they reported significantly higher craniofacial fracture frequencies in males (31.7%) than in females (10.7%). They also reported that most of the indicators for interpersonal aggression, such as perimortem injuries and sharp force trauma, were observed in males. In their work, Novak & Šlaus stated that historical sources point to a persistent presence of violent behaviour in the examined region during the late medieval period, since an embattled strategic important fortress lies in the immediate vicinity. They argued that the significantly higher prevalence of fractures in males may result from a strict sexual labour division, with men performing task which were evaluated as riskier and physically more demanding, such as horse riding, hunting, agricultural work, and interpersonal conflicts, including warfare (Novak & Šlaus, 2012; Djurić et al., 2006; Standen & Arriaza, 2000).

Although the sex differences found in the present work were not statistically significant, numerically the trend goes in that direction, and the origin of these can probably also be attributed to a combination of men being in general more risk-taking than women, higher levels of physical aggression in males, and sexual division of labour (Campbell, 2007; Eagly & Steffen, 1986; Pawlowski et al., 2008; Redfern, 2016).

At this point it should be mentioned that in the present study significantly more men than women were in the group of older individuals (35 years or older), which generally indicates better living conditions for men. Sex differences like these are relatively common and have been reported for skeletal samples in various countries, such as Croatia (Šlaus, 1996), Turkey (Angel, 1966), Hungary (Acsádi & Nemeskéri, 1970) and North America (Blakely, 1971) (Šlaus, 2000). These differences are frequently associated with deaths during pregnancy and childbirth in younger women, but also with a higher social status of men and a resulting better access to food resources, based on the above-mentioned sexual division of labour (Šlaus, 2000).

In her doctoral thesis, Herold (2008) examined individuals from five early medieval cemeteries from Lower Austria and Vienna (Leobersdorf, Zwölfaxing, Pottenbrunn, Pitten and Wien-Csokorgasse) for sex-specific differences in life expectancy and reported a significantly higher life expectancy in men. Based on mortality profiles, macroscopic examinations, and isotope analyses, it became evident that the differences were at least partly the result of women's limited access to food resources. She stated that a reduced intake of iron, amino acids, protein, and vitamin D in women, in addition to presumably at least some pregnancy- and childbirth-related deaths, which, however, can only in rare cases be proved in archaeological contexts, likely led to the higher life expectancy in men in the graveyard Leobersdorf and the other graveyards she examined (Herold, 2008).

In summary, the first hypothesis, stating that men show more fractures than women, could not be confirmed for the present work. Although more males than females showed fractures, these differences were not statistically significant. However, when considering the entire sample, more than twice as many males (21.0%) than females (9.0%) showed fractures.

Hypothesis 2

The second hypothesis tested if older individuals generally show more fractures than younger individuals, since fractures accumulate with increasing age of an individual (Roberts & Manchester, 2010) and age-related osteoporosis may increase the probability of fractures, especially in women (Roberts & Manchester, 2010; Sahlin, 1990).

When examining the second hypothesis, it turned out that older individuals (35 years or older) showed significantly more fractures than younger individuals (younger than 35 years), which was also found in other studies.

For example, when examining 783 crania from the osteological collection of the Tel Aviv University, which were dated between 4300 BCE and 1917 CE, Cohen et al. (2014) reported that mature and old individuals (19 years or older) showed significantly higher frequencies of cranial injuries than young individuals (1-18 years old).

Brickley (2006) found similar results when examining the prevalence of rib fractures in 352 adult individuals excavated from the English burial ground of St. Martin’s Church, dated between 1750 and 1850 CE. She observed an increasing prevalence of fractures with increasing age of the examined individuals. In the group of young adults (20-35 years), only one individual (out of 62) showed rib fractures (1.6%). In the group of older individuals (35 years or older), out of 245 individuals 51 showed rib fractures (20.8%). The remaining 45 adult individuals could not be assigned to one of the age categories with certainty.

These herein observed sex differences may be explained by the fact that the older the examined individuals are, the longer they were exposed to the risk of being injured and fractures accumulate over the course of a lifetime (Cohen et al., 2014). Also, bones of younger individuals show different characteristics than bones of older individuals. Due to a higher level of collagen and faster metabolic processes, bones of younger individuals are more flexible, harder to break, and heal faster than those of older individuals. This can make it difficult to detect fractures in younger individuals (Lewis, 2007).

Furthermore, age-related bone loss may have played a role in the occurrence of fractures in older individuals. In general, the loss of bone mass with increasing age is a natural process observed in both sexes, although in women it is enhanced through menopause. However, whether an individual develops osteoporosis depends on many different factors, such as genetic predisposition, other pathologies, physical activity, diet, and general lifestyle. Osteoporosis is common in modern populations, especially in Western and Asian societies (Brødholt et al., 2021; Agarwal & Stout, 2003; Agarwal & Glencross, 2010).

The extent to which the prevalence of osteoporosis today can be compared with the prevalence in earlier times is, however, difficult to assess (Brødholt et al., 2021; Agarwal & Stout, 2003; Agarwal & Glencross, 2010). Although some authors suggest that osteoporosis is unlikely to have played a major role in ancient times, due to the lower life expectancy and high levels of physical activity (Roberts & Manchester, 2010), some researchers have found evidence of osteoporosis in earlier populations.

Foldes et al. (1995), for example, examined the remains of a woman which were discovered in the Negev Desert in Israel and dated to the 6th century CE. The observed compression fractures of the spine, which were examined with X-ray, bone densitometry and histomorphometry, were indicative of osteoporosis.

Mays et al. (2006) examined bone mineral density and the prevalence of osteoporosis in Norwegian and English individuals of the medieval period. Here, similar levels of age-related loss of bone mineral density were observed and osteoporotic fractures were found in both groups. Among female individuals, the Norwegian group showed a higher frequency of osteoporotic fractures than the English group. These differences can also be observed between modern Norwegian and English populations. The reasons for these differences are unknown, but it is suspected that lower temperatures and the occasionally harder underground may lead to more fall-related injuries.

In the present study, significant results were found, when examining the fracture type per age group. Most of the occurring rib fractures and all of the occurring cranial fractures were found in the group of older individuals. Also, nearly all of the occurring severe fractures were found in the group of older individuals, whereby here no significant results but a trend could be observed. These results may also be explained by a combination of faster bone repair mechanisms in younger individuals, which may complicate the identification of fractures, and the generally weaker bones of older individuals (Brødholt et al., 2021; Lewis, 2007; Roberts & Manchester, 2010).

In conclusion, the second hypothesis, stating that older individuals generally show more fractures than younger individuals, could be confirmed. In the group of older individuals 21.4% showed fractures, whereas in the group of younger individuals only 7.0% did. The examinations also showed that significantly more rib and cranial fractures were found in older individuals, and it was also found that older individuals tended to show more severe fractures than younger individuals.

Hypothesis 3

The fact that Avar cemeteries show sex-specific differences in grave goods leads to the assumption of differing lifestyles and tasks within society and differing physical burdens and risks in everyday life (Bott, 1988). Hypothesis three expected sex-specific differences when examining the fracture patterns. This hypothesis could not be confirmed.

The examinations revealed that there are more individuals with rib fractures (12.4%) than individuals with cranial fractures (3.1%) to be found in the cemetery population Leobersdorf, in both men (16.1% and 4.8% respectively) and women (7.5% and 1.5% respectively). Although these results were not statistically significant, they were not surprising, since rib fractures are among the most commonly reported fractures in archaeological human remains (Brickley, 2006).

For example, the results of Roberts & Cox (2003) showed that rib fractures were the most frequently occurring of all fracture types when examining more than 200 different British sites, dated between 43 to 1850 CE, and containing over 32,000 individuals from both rural and urban societies and a vast variety of different lifestyles.

When examining the more frequently fractured side of the body, it was found that more male individuals showed fractures on the left side (11.3%) than on the right side (6.5%). On the contrary, more female Individuals showed fractures on the right side (4.8%) than on the left side (3.0%). These differences were not statistically significant due to the overall small number of individuals with fractures present in the sample altogether.

That in both sexes more individuals with severe fractures (14.5% of males and 6.0% of females) than with minor fractures (6.5% of males and 3.0% of females) were found may be explained by the fact that minor fractures, such as greenstick fractures, are generally more difficult to detect in archaeological settings. They are easier to be missed, for example, due to taphonomic processes or the general state of preservation of the remains, than severe fractures with obvious callus formations.

In all male individuals with multiple fractures the left side of the body was affected (4/4), whereas in nearly all female individuals with single fractures the right side was affected (3/4). Most of the affected male individuals showed severe fractures on the left side of the body (6/8), while most of the affected female individuals showed severe fractures on the right side (2/3).

That in men the severe and the multiple fractures were more likely to occur on the left side might indicate that men were more often engaged in interpersonal conflicts while facing a right-handed attacker who, for example, landed several forceful strikes. That in women the severe and the single fractures were more likely to occur on the right side might indicate that these injuries occurred during escape or in prone position (Larsen, 1997).

The fact that most of the affected individuals display single, non-lethal fractures (8/13 males and 5/6 females with fractures) may indicate that the injuries were more likely the result of accidents or interpersonal conflicts than of warfare. In warfare, a number of multiple and deadly injuries produced by sharp force trauma would have been observed (Jordana et al., 2009).

Scaffidi & Tung (2020), for example, examined violence-related trauma in the Peruvian cemetery of Uraca, which was dated between 200 and 750 CE and reported a very high prevalence of cranial injuries: of 145 examined crania 67% showed trauma, whereby 61% of those showed more than one injury. Especially males who were assigned to the elite showed multiple injuries and perimortem trauma, as well as sharp force and penetrating injuries, which was attributed to warlike encounters with competing groups.

Rubini & Zaio (2011) also linked the occurrence of sharp force trauma injuries with warlike encounters in their study of the early mediaeval cemetery of Campochiaro in Central Italy, dated between the 6th and 8th century CE. The cemetery was attributed to local groups, as well as Lombard and Avar groups, and probably represented the presence of a military outpost against Byzantine groups in Southern Italy. Graves of warriors buried with their horses, but no evidence of a permanent settlement could be found, which points to an occupation mainly by semi-nomadic groups of the Early Avar period. The observed injuries pointed to a spiked mace, a battle axe and a sword or dagger, which were weapons used by the Byzantine armies. Although the observed injuries were not fatal, they were interpreted as evidence for warfare.

Among the individuals examined in this work, four (three males and one female) were assigned to the Early Avar period. Of these, two males showed fractures. One of them (grave number 11) showed a total of nine healed rib fractures, eight of them on the left side. The other one (grave number 152) showed a probable minor fracture on an upper right rib.

The majority of the herein examined individuals was assigned to the Late Avar period (80.6%), and thus were probably mainly occupied with agricultural work (Pohl, 2002). This also seems to be reflected by the observed fracture patterns, since none of the affected individuals showed lethal injuries.

However, it is important to consider the possibility that individuals who were involved in warfare may have been buried elsewhere. For example, it is possible that those killed in war were buried near the battlefield and not in the cemetery of Leobersdorf. It seems reasonable to assume that a higher number of individuals from the Early Avar period would have led to a higher frequency of fractures and to different fracture patterns in general, since those individuals were thought to be more engaged in raids and warlike conflicts than individuals of the later periods (Pohl, 2002).

In conclusion, the third hypothesis, stating that male and female individuals show different fracture patterns, could not be confirmed. Although males showed more than twice as many rib and cranial fractures than females, the results were statistically not significant. While fractures generally occurred more often on the left side in males and on the right side in females, again no significant differences were found here. In both sexes more single than multiple fractures and more severe fractures than minor fractures could be found. Furthermore, it could be observed that in males all multiple fractures and most severe fractures occurred on the left side, whereas in females most single fractures and most severe fractures occurred on the right side, whereby these results were also not significant.

Cranial fractures

Of the four individuals that showed cranial fractures, three were male and one was female. Three individuals (two males, one female) showed a single fracture. One male individual (grave number 109) showed two different cranial fractures. All four individuals showed a depression (crush) fracture of the neurocranium, whereby the individual excavated from grave number 109 showed a comminuted facial skull fracture in addition. These findings point to accidents or interpersonal violence as fracture causes rather than to warfare, as the latter would have resulted in more multiple and fatal injuries caused by sharp force trauma (Jordana et al., 2009; Scaffidi & Tung, 2020).

For example, Filer (1992), who examined cranial fractures in Egyptian and ancient Nubian skulls, found that the two groups studied showed different types of injuries, which was attributed to different behavioural patterns. The group from ancient Nubia showed predominantly oval depression fractures, which were associated with attacks using stones and clubs and were assessed as resulting from civil or domestic disputes. In contrast to this, the group from Egypt showed a higher frequency of severe injuries, such as deep cuts, which were attributed to attacks with swords and axes in warfare.

All of the herein observed depression fractures had already healed well by the time the individuals died. In contrast to this, the facial skull fracture showed numerous hole formations and pseudo-articulations, which is why it cannot be stated that it was well-healed when the individual died. Yet, none of the cranial fractures was lethal, which together with the overall rather low prevalence of cranial fractures in the whole sample (3.1%) also points against a war-related cause for the occurring cranial injuries.

In contrast to this, Scaffidi & Tung (2020) found, when examining human remains excavated from the burial ground Uraca in Peru, that 5% of the examined individuals showed lethal cranial fractures, whereby all of them were males assigned to the elite. Due to the overall high number of individuals with cranial fractures in the sample altogether (67%), the authors suggest that the Uraca cemetery may have been reserved for high-ranking men who engaged in battles.

All of the herein observed depression fractures involved the parietal bones, with all fractures being located in the lateral to posterior part of the parietals. One depression fracture each was clearly located on the left and the right side (both in male individuals). The two remaining depression fractures (in one male and one female individual) were located exactly on the sagittal suture and thus could not be clearly assigned to one side. The locations of the depression fractures indicate injuries due to accidents or interpersonal violence while the affected individuals were turning away or lying on the ground. Interpersonal violence in face-to-face encounters would probably have produced more injuries in the left anterior regions of the cranium, like the frontal bone (Larsen, 1997).

Brink et al. (1998) classified in a study of 1481 assault victims from Denmark 69% of all occurring injuries as craniofacial. Most of the injuries were caused by blunt force, whereby 54% of all fractures were produced by punches with the fist, and in both sexes the craniofacial injuries were found significantly more often on the left side. Men showed significantly more fractures in the nasal and oral regions than women, whereas women showed significantly more injuries to the back of the head.

In the herein observed case of the facial fracture which was found in the individual excavated from grave number 109 the results point to a violent face-to-face dispute as origin. Here, the anterior and lateral parts of the left side of the face were affected, whereby an involvement of the zygomatic bone, the maxilla, and the ramus of the mandible was observed.

In contrast to the results of Brink et al. (1998) no fractures of the nasal bone could be found in the herein examined individuals. Cohen et al. (2014) point out, that fractures of the facial skull are especially difficult to determine in archaeological contexts, as the nasal bone and the zygomatic bone, which are frequently affected, are often lacking.

This was probably also the reason for the absence of nasal bone fractures in the herein examined sample, since only few individuals showed well-preserved nasal bones. In 13.1% of the individuals the left nasal bone was preserved well (75-100%) and only in 11.5% of the individuals the right nasal bone was preserved well.

The higher prevalence of fractures to the posterior parts of the cranium in females, which Brink et al. (1998) described could also not be found due to the small number of cranial fractures in the sample. From the four individuals that showed cranial fractures only one was female, but this individual indeed showed a cranial depression fracture in the posterior area of the sagittal suture. However, it has to be stated that also the other depression fractures were located rather in the lateral and posterior areas of the crania, as already mentioned above.

Rib fractures

Of the 16 individuals showing rib fractures, eleven were male and five were female. In most of the affected individuals (11/16, seven males, four females) only one fractured rib could be found. Five individuals (four males, one females) showed multiple rib fractures.

In one male individual (grave number 129) a fracture of the long bones could be found in addition to the observed multiple rib fractures. Also, the male individual excavated from grave number 46 showed a fracture of the long bones in addition to a single rib fracture. The individual excavated from grave number 109 (also male) showed, as already mentioned above, two cranial fractures, as well as signs of myositis ossificans on the right clavicle in addition to a single rib fracture (Nina Reiter, personal communication, 2022). Thus, out of the 16 individuals showing rib fractures, seven individuals (six males, one female) showed multiple fractures, when also considering fractures of the long bones.

Most of the individuals with rib injuries displayed well-healed fractures (15/16), which proves that those injuries were not lethal. One individual (grave number 48, male) also showed non-lethal but rather poorly healed rib fractures and probably suffered from long-term health problems, like pain when breathing or performing certain movements. Six individuals with complete rib fractures displayed transverse fractures. Such rib fractures are usually caused by direct blunt force acting to the chest, like a punch with the fist or a strike with a blunt object, whereby the number of fractured ribs varies with the dimension of the affected area (Galloway, 1999).

Three individuals with complete rib fractures showed oblique fractures. Fractures like these are commonly caused by indirect forces, such as crushing or bending of the rib cage, as it occurs for example when a person falls from a height (Galloway, 1999). The individual excavated from grave number 11 displayed complete transverse and oblique rib fractures, which points to a combination of direct and indirect forces. In the remaining six individuals, evidence for possible incomplete fractures was found. This could, for example, point to greenstick fractures caused by indirect forces, like a slight compression of the rib cage due to a fall. In none of the affected individuals, evidence for rib injuries caused by sharp force, such as cut marks, could be found. The non-lethal nature of the occurring rib fractures together with the rather low prevalence of multiple fractures in the sample altogether also points to accidents or interpersonal conflicts as fracture causes, rather than to warfare. As in the case of cranial fractures, warlike conflicts would have resulted in more individuals with multiple injuries and sharp force trauma (Jordana et al., 2009; Scaffidi & Tung, 2020).

Lockau et al. (2013), for example, examined the human remains of the Smith's Knoll collection, which were attributed to at least 24 individuals killed in the battle of Stoney Creek in Canada in the War of 1812 (1812-1814). Replicas of contemporary weapons were used to produce cut marks on animal models which were then compared to lesions found on several of the examined human rib fragments. The results showed that some of the lesions likely mirror perimortem injuries produced by sharp force trauma. The cut marks that were produced in the experiments using the model of a bayonet showed similarities to 14 of the 38 lesions observed in the remains and thus point to perimortem injuries caused by stabbing wounds.

Most of the herein examined individuals that showed rib injuries displayed fractures on the left side of the thorax (9/16, seven males, two females). Also, in most of the affected individuals with multiple rib fractures, the fractures were either located entirely on the left side or affected the left side more severely (4/5, three males, one female). This may point to interpersonal violence, for example a confrontation with a right-handed opponent (Larsen, 1997).

As Lovell (1997) states, rib fractures, as well as fractures of the (facial) skull and the bones of hands and feet, are more likely to result from interpersonal conflicts than other fractures, such as fractures of the forearm. When examining the fracture causes in 548 individuals, who were hospitalised after thoracic trauma and suffered from rib fractures, Sirmali et al. (2003) observed that apart from road traffic accidents (60%), falls (22%), assaults (10%), and work-related accidents (8%) were the most common causes for rib fractures. These results support the evidence found in the present study which suggest interpersonal violence or accidents as most probable causes for the observed rib fractures.

In three individuals (graves number 11, 120, and 147, all males), injuries on clearly identified upper ribs could be observed. The individuals excavated from the graves 11 and 120 each showed a fracture of the second left rib. The individual excavated from grave number 147 shows signs of minor injuries on the second left rib, as well as on both first ribs. In three more individuals (grave numbers 46, 116, and 152, all male), the affected rib fragments may originate from second ribs, but in these cases an assignment was not possible without doubt. In general, healed fractures of the first to third ribs are relatively rare in archaeological human remains. Since they are located underneath the shoulder girdle, fractures of the upper ribs are usually attributed to severe violent impact and are often associated with life-threatening injuries, as such strong forces may involve important underlying vessels or the trachea (Brickley, 2006; Lovell, 1997; Galloway, 1999). Apart from direct trauma to the upper part of the ribcage, fractures of the upper ribs may also be produced by hard manual work, such as lifting heavy objects (Brickley, 2006; Galloway, 1999; Pavlov & Freiberger, 1978). Thus, the observed injuries of the upper ribs might indicate interpersonal conflicts or an engagement in heavy physical work, which would be consistent with the assumption that most of the studied individuals were likely occupied with agricultural work (Pohl, 2002).

Vertebral fractures

Of the 129 individuals examined in the present work, none showed fractures of the first four cervical vertebrae. In some cases where the position or the absence of the cranium could have been interpreted as indicator for decapitation at the first glance (graves number 5, 11, 137, 143 and 152), the circumstances of excavation and/or discovery largely ruled out this possibility in addition to the absence of vertebral fractures (Daim, 1987). In the case of grave number 5, for example, only the cranium and parts of the cervical spine were recovered, likely due to an almost complete destruction of the grave. Daim (1987) stated that the originally well-preserved remains had probably been destroyed by visitors during the excavations.

In the case of grave number 11, where the position of the cranium on the lower spine of the individual could point to a decapitation, a rolling of the cranium during a robbery is much more likely, since the rich Early Avar grave was severely disturbed and obviously robbed and the cranium was found at the lowest point of the grave (Daim, 1987). From grave number 137, no cranium is preserved and thus a decapitation may be suspected. However, as Daim (1987) mentions, the cranium was stolen during the excavations. In the case of grave number 143, where the isolated position of the cranium might indicate a beheading, a severe disturbance of the grave is assumed, which only left the skull and parts of the lower extremities in place (Daim, 1987).

In the case of grave number 152, which, like grave number 11, was a rich Early Avar grave, also severe disturbance and robbery can be assumed as cause for the apparent absence of the cranium (Daim, 1978).

Beheadings were probably not very common among Austrian populations living during the Avar period, as Wiltschke-Schrotta & Stadler (2005) state. Nevertheless, three male individuals displaying cut marks on the cervical vertebrae were found when examining the Avar time burial ground Mödling - Goldene Stiege in Lower Austria, which comprised a total of 540 individuals. Two of the individuals were probably regularly decapitated with an axe, with a complete severance of the head. The other individual that also showed cut marks was probably attacked with a smaller weapon, whereby the head was likely not completely separated (Wiltschke-Schrotta & Stadler, 2005). Also, Pany-Kucera & Wiltschke-Schrotta (2017) found cut marks on the cervical vertebrae of a male individual, which were interpreted as signs for a decapitation, when examining the Avar time burial ground Vösendorf in Lower Austria, which comprised a total of 443 individuals.

In the present study only the first four cervical vertebrae were examined, as evidence for interpersonal violence, for example in the form of decapitation, strangulation or hanging, is mainly found in the upper cervical spine (Maples, 1986; Spence et al., 1999; Waldron, 1996). However, it must be mentioned that also the lower cervical vertebrae or even the first thoracic vertebra may be affected (Waldron, 1996). Also, in the case of strangulation or hanging with a running noose, where no drop is used, the cervical vertebrae may display no or only hardly visible signs of injury. Furthermore, the already mentioned "hangman's fracture", a fracture of the C2, may also be caused by other mechanisms. For example, nowadays, such fractures are usually the result of car accidents (ElMiligui et al., 2010; Waldron, 1996).

Prevalence of fractures within the three historical periods

Within the category “Early + Middle Avar period” 16.7% of the individuals showed fractures, whereas in the category “Late Avar period I-IIIa” 14.9% did. In the category “Late Avar period IIIb” 11.8% of the individuals showed fractures. These results show a decrease in fracture prevalence with the later periods, although no statistically significant differences were found here ($p = 0.932$, Fisher's Exact Test). The slight decrease in the occurrence of fractures with the later periods may be related to the gradual transition from a nomadic to a settled way of life, which probably took place progressively from about 710 CE onwards (Pohl, 2002).

This would match the dating of Late Avar period I-IIIa (710-800 CE) and Late Avar period IIIb (after 800 CE; after Daim, 1987) and may reflect the "calmer" life of the individuals of the Late Avar periods, where agricultural work played a more important role, in contrast to the Early and Middle Avar period where military campaigns and raids were more common (Pohl, 2002). In this context it has to be stated that the total absence of fatal injuries and injuries produced by sharp force trauma within the examined sample may suggest that individuals killed in warlike conflicts were buried elsewhere.

Implications for the injured individuals

As discussed earlier, the majority of the occurring fractures probably did not cause any long-term health problems for the injured individuals. Most individuals with rib and cranial injuries (15/16 and 3/4 respectively) showed fractures that had already healed well long before the death of the individuals and the pain was probably limited to the time of the fracturing event and the time of healing. Regarding the consequences for the affected individuals, there are of course differences due to the severity of the fractures. For example, a single, slightly cracked rib is less disturbing in everyday life than a serial rib fracture with several multiple fractured ribs that cause considerable pain with the slightest movement.

Nevertheless, even a single broken rib can cause considerable pain and affect the person's respiration, ability to work and general quality of life during the healing phase (Kara et al., 2003; Brickley, 2006). In a study by Kerr-Valentic et al. (2003) for example, it was observed that in a sample of 40 individuals who suffered from rib fractures, it took them an average of 70 days before they could return to work or their usual activities.

Although no evidence for infections could be found in the cranial depression fractures occurring in the herein studied group, and other severe complications, such as brain damage or intracranial haemorrhages, seem unlikely due to the rather mild manifestations of the fractures, temporary disabilities, such as concussions, cannot be ruled out. In contrast to this, the facial skull fracture observed in the individual excavated from grave number 109 likely caused severe and lasting disabilities. It must be stated, however, that the possible complications of cranial injuries are in general difficult to assess in archaeological contexts, as they are complex and influenced by many different factors (Roberts, 1991).

Out of 10 individuals with complete rib fractures, five individuals showed a displacement of the fracture ends, which suggests that these individuals continued to perform their daily tasks despite the pain and did not spend enough time on recovery after being injured. Five individuals, however, showed no signs of displaced fracture ends, which indicates that they had the opportunity to adequately spare themselves. This in turn suggests that in some cases the daily tasks of the individuals were at least partially taken over by other members of the society for the duration of the healing process. In the case of the individual excavated from grave number 109, who suffered from considerable impairment due to the poorly healed facial skull fracture, also care provided by others can be assumed. He likely suffered from problems and pain when speaking, chewing, and swallowing, and was probably also disfigured to some degree. Despite this, he survived the injury for a long time and reached old age. Thus, it can be assumed that he was provided with suitable food and that his daily duties were at least temporarily taken over by others.

Body posture of the examined individuals

In the burial ground Leobersdorf, the stretched back position represents the usual burial type, with the arms stretched out beside the body. However, in grave number 147, as well as in the graves 42 and 75, individuals buried in squatting positions could be observed (Daim, 1987). Commonly, these postures are linked with burials with few grave goods and are in general associated with carelessness during the burial or with burials after the onset of rigor mortis (Čilinská, 1968; Daim, 1987). Especially graves where the length of the grave pit exactly matches the required length of the squatting individual suggest poor graves, as a smaller pit means less effort. The fact that all three graves are located in the peripheral areas of the cemetery and do not contain special grave goods (grave number 75 even contained no grave goods at all) also points to rather poor graves (Daim, 1987; Meyer-Orlac, 1982).

The individuals excavated from grave number 42 and 75 showed no fractures of the cranium, ribs, first four cervical vertebrae or long bones. The individual excavated from grave number 147, however, showed thickenings on both first ribs and on the second left rib, which may indicate well-healed minor injuries, such as greenstick fractures. As already mentioned above, healed fractures of the first to third ribs are in general relatively rare in archaeological human remains as they are protected by the shoulder girdle (Brickley, 2006; Lovell, 1997; Galloway, 1999). Minor injuries in this area may be produced by hard manual work, such as lifting heavy objects (Brickley, 2006; Galloway, 1999; Pavlov & Freiberger, 1978) and thus might indicate engagement in heavy physical work. These findings suggest that the individual from grave number 147 could have been a hard-working member of the society with low status within the examined group.

Radiographs and CT scans

For complementing the macroscopic fracture analyses, radiographs and CT scans seemed to be differently suited depending on the examined region. When investigating the ribs of the studied individuals, the radiographs proved to be very useful for the assessment of fracture patterns, making it unnecessary to take additional CT scans. During the examinations of cranial fractures, on the other hand, the radiographs were not very supportive. In three of four cases, no indications of the depression fractures could be seen on the radiographs, at least not from the chosen perspective. Only in one case the impression was detectable as a subtle shadow. However, it would have been impossible to identify the fracture here without prior macroscopic examination. In contrast to this, the produced CT scans showed a clearly recognisable indentation in all four cases of depression fractures.

In the case of the facial skull fracture, the regions of new bone formation were clearly visible on both radiographs and CT scans. Thus, it may be concluded that, at least in the case of well-healed depression fractures of the cranial vault, CT scans are more suitable in supplementing the macroscopic examinations than radiographs. However, it must be considered that the possibility of taking radiographs and CT scans is not always given, for example due to restricted access to the equipment or due to limited financial resources. Also, the interpretation of radiographs and CT scans in archaeological human remains can sometimes be difficult since, for example, soil deposits may affect the density of the examined bones (Grauer & Roberts, 1996; Roberts, 1991; Lovell, 1997).

Limitations of the study

- When examining the frequency of fractures, it is important to bear in mind that the bones of younger individuals are generally more resistant to fractures. Also, with fractures that healed long before the death of the individual, there is the possibility that no more signs of the injury can be seen macroscopically or on the radiographs (Roberts, 1991). In addition, grave disturbances or robberies may lead to bones or bone parts being lost and taphonomic changes may contribute to fractures being overlooked. Thus, it can be assumed that the frequency of recorded fractures never represents the total number of injuries that occurred in the population and is usually an underestimation (Djurić et al., 2006). A renewed examination of the remains would have reduced the risk of overlooking fractures, but due to limited time resources, this was not possible for the present study.

- Only the cranium, the ribs, and the first four cervical vertebrae were examined herein. Although the long bones were examined in parallel to this work by Nina Reiter and fractures of these were mentioned in this study, individuals who only showed fractures of the long bones were not discussed. Furthermore, it must be stated that even if both studies were combined, fractures of the thoracic and lumbar vertebrae or the bones of hands and feet, for example, would not have been detected, whereby especially fractures of the hands are often associated with interpersonal conflicts (Lovell, 1997). Consequently, the individuals were not examined in their entirety and a complementary analysis of the rest of the available remains would likely reveal higher frequencies of fractures.

- Furthermore, it is important to mention that there are various pathological conditions that may mimic traumatic injuries. For example, certain infectious diseases, such as tuberculosis, can produce circular pits on the cranium which may be confused with cranial trauma (Cohen et al., 2014). Also, some diseases, such as metastatic types of cancer or Paget disease, can cause osseus changes on the ribs that may be mistaken for fractures (Davies-Barrett et al., 2019; Talbot et al., 2017). Although most of the herein described fractures have been classified as obvious, and were also discussed with colleagues, the possibility of pathological conditions being mistaken for fractures cannot be completely ruled out.

- Although fractures of the cranium and the ribs are in general frequently associated with interpersonal conflicts, one should be aware of the fact that a precise identification of the ultimate fracture cause is only possible in rare cases in archaeological contexts. Although the herein observed fracture patterns tend to exclude warlike conflicts as a cause, it is impossible to reliably assign the observed fractures to accidental or intentional causes. Whereas in some cases of sharp and semi-sharp force the injuries can be attributed to specific weapons and thus intention can be assumed (Filer, 1992; Lockau et al., 2013; Rubini & Zaio, 2011), this is hardly possible in the case of injuries caused by blunt force, as the fractures patterns produced by blunt objects may be very divers and sometimes do not represent the dimension of the object that caused the injury (Cohen et al., 2014). Thus, the present study focused on the proximate causes of the fractures and only suggested possible scenarios that may have led to the observed injuries.

- In archaeological contexts, ribs are often only partially preserved and/or highly fragmented and assembling these ribs is a difficult and time-consuming task, which is not always carried out in the course of anthropological examinations (Matos, 2009). The rib fragments of the herein examined individuals were only partially assembled due to limited time resources. This might have increased the chance of missing perimortem and serial rib fractures and a higher prevalence of such fractures may have had an impact on the observed sex differences in fracture patterns.

Conclusion

The first hypothesis, stating that men generally show a higher prevalence of fractures than women, could not be confirmed for the 129 individuals from the graveyard Leobersdorf, whose crania, ribs and first four cervical vertebrae were examined in the present work. No significant differences were observed between the sexes regarding the occurrence of fractures.

The second hypothesis, stating that older individuals generally show more fractures than younger individuals, could be confirmed. Individuals aged 35 years or older showed significantly more fractures than individuals younger than 35 years.

Finally, the third hypothesis, stating that sex-specific differences can be found when examining fracture patterns, could not be confirmed. Between males and females no significant differences were observed regarding the fracture type, the more frequently affected side of the body, the occurrence of single and multiple fractures, or the severity of the observed fractures.

In general, the examined individuals seem to have lived relatively peacefully. Evidence suggesting warlike conflicts, such as fatal injuries and/or injuries caused by sharp force trauma, could not be found. Most of the observed injuries were single, non-lethal fractures caused by blunt force trauma and are likely to have been caused by accidents, interpersonal disputes, or heavy manual work. The majority of the fractures had healed well before the occurrence of death and only a small part of the examined individuals likely suffered from persistent health problems.

Considering that the Avars are frequently portrayed as generally hostile and violent people, who often engaged in raids and warfare, these results seem surprising. The present study contributes to a more differentiated perception of the Avars in general and allows a more realistic picture of the investigated population and their former way of life. This especially applies to individuals assigned to the Late Avar periods, who were probably mainly engaged in agricultural work, and not so much in nomadism and looting anymore, which also seems to be reflected by the herein described injuries.

Zusammenfassung

Bei der Untersuchung menschlicher Überreste ist die Analyse von Frakturen von größter Bedeutung und kann wertvolle Informationen über Herausforderungen liefern, denen sich die Verstorbenen stellen mussten. In dieser Arbeit wurden menschliche Überreste von 129 Individuen aus dem awarischen Gräberfeld Leobersdorf, welche hauptsächlich in das 7. und 8. Jhd. n. Chr. datiert wurden, auf Frakturen des Schädels, der Rippen und der ersten vier Halswirbel untersucht. Neunzehn Individuen (14,7%) wiesen mindestens eine Verletzung auf. Hypothese eins, die besagt, dass Männer mehr Frakturen zeigen als Frauen, konnte nicht bestätigt werden, obwohl Männer tatsächlich häufiger betroffen waren. Hypothese zwei, die besagt, dass ältere Individuen mehr Frakturen aufweisen als jüngere, konnte bestätigt werden. Hypothese drei, die besagt, dass Männer und Frauen unterschiedliche Frakturmuster aufweisen, konnte nicht bestätigt werden. Es wurden keine signifikanten Geschlechtsunterschiede in Bezug auf Frakturtyp, häufiger betroffene Körperseite, das Auftreten von einzelnen und multiplen Frakturen oder den Schweregrad beobachtet. Die in dieser Arbeit beschriebenen Frakturen deuten im Allgemeinen eher auf Unfälle, zwischenmenschliche Konflikte oder Verletzungen aufgrund schwerer körperlicher Arbeit hin, als auf kriegerische Auseinandersetzungen. Dies lässt auf ein eher friedliches Leben der untersuchten Gruppe schließen. In Anbetracht der Tatsache, dass Awaren häufig als feindseliges und gewalttätiges Volk dargestellt werden, scheinen diese Ergebnisse überraschend. Die vorliegende Studie trägt zu einer differenzierteren Wahrnehmung der Awaren bei und ermöglicht ein realistischeres Bild der untersuchten Gruppe und ihrer Lebensweise. Insbesondere der späten Awarenzeit zugeordnete Individuen waren wahrscheinlich hauptsächlich mit landwirtschaftlicher Arbeit beschäftigt und weniger mit Nomadentum und Plünderungen, was sich in den hier beschriebenen Verletzungen widerzuspiegeln scheint.

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Appendix

Table 1. List of all 131 adult individuals excavated from the burial ground Leobersdorf, with grave number, associated time period, sex, age at death and description of eventual fractures.

Grave number	Period	Sex	Age (Years)	Fracture(s) (Number/Type/Side/Severity)
1	Late Avar period II	Female	20-34	None
2	Late Avar period II	Male	50+	Single/Rib/Left/Severe
3	Late Avar period II	Female	50+	None
5	Late Avar period II	Male	50+	Single/Cranium/Left/Severe
6	Late Avar period II	Female	< 20	None
7	Late Avar period II	Male	35-49	None
9	Late Avar period II	Female	20-34	None
10	Late Avar period II	Female	20-34	Single/Rib/Right/Minor
11	Early Avar period	Male	50+	Multiple/Rib/Both sides/Severe+Minor
12	Middle Avar period	Male	35-49	None
13	Middle Avar period	Female	20-34	None
16A	Late Avar period II	Female	20-34	None
17	Late Avar period II	Female	20-34	Single/Rib/Right/Minor
18	Late Avar period II	Female	20-34	None
19	Middle Avar period	Female	< 20	None
20	Middle Avar period	Female	< 20	None
21A	Late Avar period II	Male	50+	None
21B	Late Avar period II	Female	35-49	Single/Rib/Left/Severe
22	Late Avar period II	Male	< 20	None
ä23A	Late Avar period II	Male	< 20	None
25	Late Avar period I	Female	20-34	None
26	Middle Avar period	Female	35-49	None
28	Late Avar period I	Female	35-49	None
30	Middle Avar period	Female	< 20	None
33	Middle Avar period	Male	20-34	None
34	Middle Avar period	Female	35-49	Multiple/Rib/Left/Minor
35A	Middle Avar period	Female	35-49	None
35B	Middle Avar period	Male	50+	None
36	Middle Avar period	Male	35-49	None
37	Late Avar period I	Female	35-49	None
38A	Early Avar Period	Male	< 20	None
40	Middle Avar period	Female	20-34	None
41	Middle Avar period	Male	35-49	None
42	Middle Avar period	Female	< 20	None
44	Middle Avar period	Male	50+	None
45	Middle Avar period	Female	20-34	None
46	Middle Avar period	Male	50+	Single/Rib/Right/Minor
47	Middle Avar period	Female	35-49	None
48	Late Avar period II	Male	50+	Multiple/Rib/Left/Severe
49	Middle Avar period	Female	< 20	None
50	Late Avar period I	Female	20-34	None
51	Late Avar period I	Male	50+	None
53B	Late Avar period I	Female	35-49	None
54	Late Avar period I	Male	50+	None
55	Late Avar period I	Female	20-34	None
56	Late Avar period I	Male	20-34	None
57A	Late Avar period I	Male	35-49	None
60	Late Avar period I	Female	20-34	None

61	Late Avar period I	Female	20-34	None
62	Late Avar period I	Female	50+	None
64	Late Avar period I	Female	35-49	None
65	Late Avar period I	Male	20-34	None
66	Late Avar period I	Male	20-34	None
67A	Late Avar period I	Female	20-34	None
69	Late Avar period II	Male	50+	None
70	Late Avar period II	Male	50+	Single/Rib/Right/Minor
71	Late Avar period II	Male	35-49	?
72	Late Avar period II	Female	50+	None
73	Late Avar period II	Male	50+	None
74A	Late Avar period II	Female	20-34	None
76	Late Avar period II	Female	< 20	None
77	Late Avar period II	Male	< 20	None
78	Middle Avar period	Male	20-34	None
79A	Late Avar period IIIa	Female	50+	None
79B/B	Late Avar period IIIa	Female	< 20	None
79B/C	Late Avar period IIIa	Female	50+	None
79B/D	Late Avar period IIIa	Male	50+	None
81	Late Avar period IIIa	Male	20-34	None
82A	Late Avar period IIIa	Male	< 20	None
82B	Late Avar period IIIa	Female	35-49	None
86A	Late Avar period IIIa	Female	20-34	None
86B	Late Avar period IIIa	Male	35-49	None
87	Late Avar period IIIb	Female	50+	None
91	Late Avar period IIIb	Female	35-49	None
93A	Late Avar period IIIa	Male	50+	None
95	Late Avar period IIIb	Male	50+	None
97	Late Avar period IIIa	Female	35-49	None
99	Late Avar period IIIa	Male	35-49	None
100A	Late Avar period IIIa	Male	35-49	None
100B	Late Avar period IIIa	Female	< 20	None
101	Late Avar period IIIa	Male	50+	None
102	Late Avar period IIIa	Male	35-49	None
103A	Late Avar period IIIa	Female	< 20	None
103B	Late Avar period IIIa	Female	< 20	None
104	Late Avar period IIIa	Female	20-34	?
105B	Late Avar period IIIa	Female	< 20	None
105C	Late Avar period IIIa	Female	35-49	None
106	Late Avar period IIIa	Female	50+	Single/Rib/Right/Severe
107	Late Avar period IIIa	Female	< 20	None
109	Late Avar period IIIa	Male	50+	Multiple/Cranium+Rib/Both sides/Severe
110	Late Avar period IIIa	Female	< 20	None
112	Late Avar period IIIa	Female	20-34	None
114A	Late Avar period IIIa	Male	35-49	None
114B	Late Avar period IIIa	Female	35-49	None
116	Late Avar period IIIa	Male	35-49	Single/Rib/Right/Minor
118	Late Avar period IIIa	Female	35-49	None
119A	Late Avar period IIIa	Male	50+	Single/Cranium/Centre/Severe
120	Late Avar period IIIa	Male	35-49	Single/Rib/Left/Severe
121	Late Avar period IIIa	Male	< 20	None
122A	Late Avar period IIIa	Male	20-34	None
122B	Late Avar period IIIa	Male	35-49	None
123	Late Avar period IIIa	Male	50+	None
124	Late Avar period IIIa	Female	< 20	None

126	Late Avar period IIIa	Male	50+	None
127	Late Avar period IIIa	Male	50+	None
128	Late Avar period IIIa	Male	50+	None
129	Late Avar period IIIa	Male	50+	Multiple/Rib/Both sides/Minor
131	Late Avar period IIIa	Male	20-34	None
132	Late Avar period IIIa	Female	?	None
133	Late Avar period IIIa	Male	35-49	None
134A	Late Avar period IIIa	Female	20-34	None
134B	Late Avar period IIIa	Male	35-49	None
135	Late Avar period IIIa	Male	< 20	None
136	Late Avar period IIIa	Male	20-34	None
137	Late Avar period IIIb	Male	50+	None
139	Late Avar period IIIb	Female	?	None
140A	Late Avar period IIIb	Female	20-34	None
141	Late Avar period IIIb	Male	< 20	None
142	Late Avar period IIIb	Female	35-49	None
143	Late Avar period IIIb	Female	50+	Single/Cranium/Centre/Severe
144A	Late Avar period IIIb	Male	50+	None
144B	Late Avar period IIIb	Male	35-49	None
146	Late Avar period IIIb	Female	35-49	None
147	Late Avar period IIIb	Male	< 20	Multiple/Rib/Both sides/Minor
148	Late Avar period IIIb	Female	< 20	None
149	Late Avar period IIIb	Female	20-34	None
150	Late Avar period IIIb	Female	50+	None
151	Late Avar period IIIb	Male	50+	None
152	Early Avar Period	Male	< 20	Single/Rib/Right/Minor
153	Early Avar Period	Female	50+	None
Ohne Nummer	?	Female	< 20	None