COSTAL CARTILAGE FRACTURES AMONG ARTIODACTYLES AND PERISSODACTYLES

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Abstract. In artiodactyles and perissodactyles the interior of the costal cartilages ossify, forming a spongy, osseous tissue. Recently, it has been discovered that such ossifications frequently display visible lines perpendicular to the curvature of the ossification. Such lines are not rare, and often several lines along the same costal cartilage are observed. Macerated ossified costal cartilages frequently, but not always, split into short, bony stabs with straight, cutoff ends, sometimes retaining organic matter encircled within a bony periphery. In archaeological materials such bony stabs are occasionally observed, and are just denoted "costal cartilages" if recognized. The cause of these structures is not clear. Some may be regarded as transverse splits of the ossifications along a weakness zone, but in other cases the cause is obviously a fracture with more or less extensive callus formation. The smooth surfaces are typical and cannot be confused with a secondary fracture, which occur after deposition or maceration. The smooth ends of a healed fracture always display a thin layer of compact tissue, while a secondary fracture is irregular and displays the spongy tissue. Thus, they may be considered as healed micro or macro fractures, where fusion of the fractured ends had occurred along the periphery of the ossification. In other cases, however, healing may involve dislocation prior to the healing process, extensive callus formation, lipping or formation of pseudoarthroses. How such an injury affected the animal is not generally known. However, in the cases of dislocation and extensive bony reaction to the fracture, it is highly probable that the wellbeing of the animal was influenced by the injury.
Key words: ossified costal cartilage, ossa sternocostalia, fractures, perissodactyles, artiodactyles.

ŠONKAULIŲ KREMZLIŲ PATOLOGIJOS ATVEJAI PORANAGIŲ IR NEPORANAGIŲ GRIAUČIUOSE

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Santrauka. Kaulinėse gyvūnų kolekcijose randami nedideli akytosios medžiagos lūžiai. Tokie atvejai pasitaiko sukaulėjusioje šonkaulio kremzlėje ir aptinkami poranagių bei neporanagių kauluose. Nustatyta, kad sukaulėjimai, kuriuos gyvūnui gyvam esant dengia plona šonkaulio kremzlė, dažnai lūžta. Iki šiol tokie lūžiai veterinarijos specialistams nebuvo žinomi. Straipsnyje pateikiami galimų tokių lūžių pavyzdžiai. Tyrimams naudota medžiaga – arklių bei tauriųjų ir šiaurės elnių skeletai iš Bergeno universiteto (Norvegija) Gamtos istorijos muziejaus. Panašūs pažeidimai rasti žirgui iš palaidojimo vikingų laive (Osebergo Vestfolde, Norvegija), kuris dendrochronologiškai datuojamas 834 m. Vienas ar daugiau lūžimų nustatyti visiems tirtiems arkliams bei daugeliui tirtų poranagių. Kai kurie lūžimai gerai sugiję, tačiau yra gana sunkių, su lūžgalių dislokacija ir susidariusiu dideliu randu, neretai susiformavus pseudoartrozėms nesant stabilumo ir fiksacijos gijimo metu. Kaip galimi šių lūžimų priežasčių paaiškinimai aptariamos traumos, kaulo silpnumo zonos bei degeneraciniai procesai.
Raktažodžiai: sukaulėjusios šonkaulių kremzlės, šonkaulių lūžiai, poranagiai, neporanagiai.

Introduction. From a zoological point of view it has been known for a long time that the interior of the costal cartilages in many mammals ossify. Remane (1936:162) stated that in adult artiodactyles, perissodactyles, *Xenarthra* (anteaters, armadillos and sloths) and in toothed whales veritable *ossa sternocostalia* are formed during life. Even the costal cartilage in humans may ossifiy in old age. Such ossifications are also mentioned in an extensive French zoological treaty by Lessertisseur and Saban (1967: 687), who added that the condition occurs in *Monotremata*, although the process of ossification may differ according to the vertebrate order.

In the horse and artiodactyles, at least, the ossifications are covered by a thin sheath of cartilage throughout life. In practice, the existence of these ossifications has facilitated the mounting of skeletons because of the osseous link between the sternal ribs and sternum. On the other hand, neither the costal cartilages nor their interior ossifications have been of any concern to veterinarians, as this kind of ossifications is only sporadically mentioned in veterinarian anatomy textbooks. For instance, they are not mentioned at all in the textbook by Nickel, Schummer, Seiferle (1961), and are only mentioned in connection with the horse by Getty (1975). It therefore seems that veterinarians are ignorant to the fact that the costal cartilages should be regarded as bones because of their internal structure (Sjøvold 2005).

Typically, the ossifications are seen as more or less rod-like spongy, ossified tissue covered by a very thin layer of compact, osseous tissue bordering the surrounding sheath of cartilage in the living animal. The surface of the ossifications consists of a very thin osseous layer which is not quite smooth, but uneven, revealing the spongy character of the ossification. In comparison with the proper costae, which consist of a compact layer of bone surrounding interior spongy tissue, the costal cartilages eventually consist of a cartilaginous layer surrounding interior spongy tissue. Fragments of such ossifications are occasionally observed in faunal assemblages from archaeological sites, generally in the shape of short stabs with rather straight and smooth, cut-off ends. Since this kind of ossification has no particular diagnostic value apart from being recognized as ossified costal cartilages, they are at most noted as "costal cartilage" and are not given any further attention.

While studying a large collection of complete, disarticulated horse skeletons in the collections of the University Museum of Bergen, Natural History, attention was drawn to curious striations and deformations of these ossifications. At least in some cases they were clearly pathological. Occasionally there were fractured ossifications which displayed a fracture zone perpendicular to the curvature. Such fracture zones were sheathed by a thin layer of osseous tissue, which had obviously formed during the healing process. Search in the literature and consultation with veterinarians turned out negative, so apparently the feature was previously unnoticed and therefore deserved closer attention. A presentation of the pathologies observed given at the XXVth congress of the European Association of Veterinary Anatomists in July 2004 in Norway (Sjøvold 2005) supported this, as the features demonstrated were unknown to the roughly 100 veterinarians present.

Material and methods. The collection of disarticulated complete horse skeletons at the University Museum of Bergen, Natural History, consists of approximately 100 Norwegian Fjord horse and Døle horses, with some few representatives from other races. However, as the spongy ossifications are very brittle, during the preparation of the skeleton many of them crumbled during the process and had not been preserved. Therefore, only in exceptional cases did the complete number of 36 ossified cartilages exist among the 84 horses for which the ossifications could be studied. For all of these horses the breed, ancestry, size and date of birth and death are known. The age varied between 5 and 28 years, and ossified costal cartilages were observed for all ages.

The ossified costal cartilages were studied by visual inspection. At one stage of the study a Døle horse sternum from the Norwegian School of Veterinary Science in Oslo with attached costal cartilages cut out from the carcass was X-rayed. The specimen displayed soft tissue covering parts of the sternum, and also the costal cartilages proper surrounding the internal ossifications of the cartilages. In some cases local swelling of the cartilages were observed, revealing that extensive callus formation following healing of fractured ossifications had occurred. That the cartilaginous sheath had adapted itself to the swelling due to the callus was clearly visible on the X-ray, so that the cartilaginous sheath was shaped according to the shape of the interior ossifications. Other healed fractures which had not involved external callus formation were observed as straight, white lines across the ossifications.

Similar lesions have been observed in artiodactyles such as deer (*Cervus elaphus*), reindeer (*Rangifer tarandus*) and musk ox (*Ovibos moscatus*) in the collections of University Museum of Bergen, Natural History as well as in cattle (*Bos taurus*).

Results and discussion. The size of the ossifications depended on the race: the larger and heavier the horse the longer and thicker the ossifications. Those of the Døle horse are longer and thicker than those of the Fjord horse. Since the youngest horse studied was 5 years old with fully developed ossifications, it is clear that the ossification process is completed at a fairly young age.

The connection between the cartilage covered ossifications and the ribs is flexible. A short, proximal part of the ossification fuses with the distal end of the rib, apart from the caudal-most floating ribs, in which the ossification fuses directly with the distal end of the rib. As for the majority of the ribs, a flexible synchondrosis, denoted *genu costae*, exists between the short, fused, proximal part and the longer, distal part of the cartilage covered ossification. The sternal pairs form synchondroses with the sternum between the sternebrae. The first asternal pair (the 9th pair) forms immobile synchondroses along the last sternal pair (the 8th pair), whereas the remaining asternal pairs tend to overlap in a latero-ventral curve on each side.

The size and shape of the costal cartilages also change. The most anterior are shaped as short, rounded triangles with the base at the sternum and the tip at the *genu costae*, increasing in length in a posterior direction. The width at the sternum decreases and the costal cartilages become more cigar-shaped. The length of the ossifications increase until about the 10th pair, after which they become gradually shorter and more slender. All the asternal ossifications including the 9th, taper to a sharp point in a distal direction.

No defect was observed on the five most anterior ossifications, which are shorter, broader and firmer than the posterior ossifications according to the general changes in length and shape from anterior to posterior. Minor or major defects, varying from whitish lines, which appear to be healed micro fractures to severe pathologies were observed in all specimens studied. Both stallions and mares were affected. As only a few complete sets of ossifications existed, it was difficult to determine how widespread the defects had been in any horse. Some examples are shown in figure 1. The horses represented are all from the larger of the two Norwegian races, the Døle horse: one mare (BM. 3889) aged 23; one stallion (BM. 4519) aged 16; and another stallion (BM. 4520) aged 13 years.

Figure 1. **Fractures of *ossa sternocostalia* in three Døle horses: mare aged 23 (BM. 3089); stallion aged 16 (BM. 4519) and stallion aged 13 (BM. 4520).** Note striation (healed micro fractures; BM 3089), extensive callus formation (BM. 4519, BM. 4520) and pseudoarthroses (BM. 4519, BM 4520 upper left), in some cases with callus formation. Scale 5 cm.

The ossifications from BM. 3889 included: the complete 9th; two of the 10th-16th of the *ossa sternocostalia* the uppermost of the two being more posterior than the lower one; and the 8th. The pair from BM. 4519 included the 8th and the 9th, although the middle part of the 8th was missing, and from BM. 4520 the top end of the 10th-16th, whereas the remaining two represent *ossa costalia* connected to floating ribs, most likely ribs 17-18.

The examples were selected in order to demonstrate the different kinds of lesions. In the mildest form, whitish lines are seen across the ossification. In BM. 3889 this is seen in the uppermost case, the 9th *os sternocostale*. The lines are interpreted as micro fractures which have subsequently healed. The whitish lines are interpreted as the result of osteoblastic activity causing fusion of the fractured ends. In X-ray this is seen as a straight, white line.

Such lines demonstrate the mildest of the lesions observed since they apparently healed with no complications. In fig. 1 they are seen some 4 cm from either end of the third *os sternocostale* from the top of horse BM. 3889 and 9 cm from the left of the topmost of BM. 4520. With few exceptions, they are straight, oriented at a right angle to the tangent of the curve following the outline of the ossification. Since in the living animal the ossifications are covered by a sheath of homogenous, hyaline cartilage, pressure asserted on the cartilage is distributed rather evenly. When the tensile strength of the cartilage is superseded, the interior ossification snaps, creating a straight fracture through the interior of the cartilage. Opposed to the fractures occurring *intra vitam* are *post mortem* fractures which have occurred after the cartilage has been removed or dissolved. The fractures created in such cases are irregular since they reflect the structure of the spongy ossifications, and not the flexible cartilage surrounding the ossification during life. Such post mortem fractures are seen at the right end of both the third *os sternocostale* from the top of BM. 3889 and the right side of the topmost of BM. 4520.

If the fracture is not sufficiently stabilized, which means that there is too much muscular movement in the area of the fracture for the ends to fuse, the fractured ends remain separated for the rest of the individual's life. Both the fractured ends heal because of osteoblastic activity, and some lipping along the margins of the fractured ends may develop. Such a condition is seen 10 cm from the left end of the uppermost "bone" of BM 4519. In some cases there may be a partial fusion of the fractured ends where callus formation may join the fractured ends together in the shape of a bony bridge.

One difference between the sternal and asternal ossifications is that the asternal, thinner *ossa sternocostalia* tend to curve and thicken in the vicinity of the *genu costae*, forming a small bend (e.g. the two middle cases of BM. 3889 and the three of BM.4520). This is particularly the case from the 10th through the 16th pairs, but less accentuated for the 17th-18th, which are often directly connected to floating ribs. Fractures are frequently observed some 2-3 cm distal to the proximal end of such bends.

In BM 4519 an approximately 10 cm long middle part of the 8th *os sternocostale* has been left out from the picture. The missing part has the shape of a 10 cm long, bony stab with straight ends with smooth, even surfaces. This is the kind of "costal cartilage" which is occasionally observed in zooarchaeological materials. The explanation for such "artefacts" is therefore that they represent ossified costal cartilages which have been fractured at two locations some centimetres apart, and the fractured ends have not fused during healing.

So far nobody has cared about using or interpreting these fragments for any purpose. However, such fractures also occurred in the past. One example is dated to AD 834, which is the dendrochronological dating of the Viking Age ship burial from Oseberg (Christensen, Ingstad and Myhre,1992). Within and about the ship the carcasses of 15 sacrificed horses were deposited.

Figure 2. ***Ossa sternocostalia* from one of the horses sacrificed at the Viking Age ship burial at Oseberg, Vestfold, Norway, dated dendrochronologically to AD 834**. A number of healed micro fractures and pseudoarthroses exist, but with little callus formation and no dislocation. Scale 5 cm.

Fig. 2 shows ossified costal cartilages from one of the horses. The three cases in the middle are from the 3rd to the 5th pairs and show no pathologies. Because they are short and stout fractures are hardly ever observed at these positions. The middle case displays a *post mortem* fracture at the proximal end which is typically irregular, opposed to those which has occurred and healed during life. Two other cases of *post mortem* fractures are observed among the short stabs to the right. This is the kind of short, osseous stabs which are occasionally observed in faunal remains from archaeological excavations. The three slender cases to the right are from the asternal ossifications and show healed fractures which have resulted in pseudoarthroses, because the fractured ends have not fused again during the healing process.

Among the remaining five larger ossifications all but one display between one and three pseudoarthroses, ten pseudoarthroses altogether. In five cases it has been possible to add the adjoining parts so that the pseudoarthrosis is complete, whereas the remaining five are situated at one end of each of them, but the adjoining parts of the pseudoarthroses are missing.

Furthermore four of the larger *ossa sternocostalia* display several examples of healed micro fractures or fractures that have healed neatly. The leftmost displays five, the next at least two, of which one is only partially fused, and the third displays three. The one to the right of the three anterior ones show clearly two healed micro fractures.

Healed fractures of ossified costal cartilage have on the other hand not only been observed in horse, but also in several artiodactyles, including wild species. In the collection at the University Museum of Bergen, Natural History, there are also a series of disarticulated skeletons of reindeer (*Rangifer tarandus*) and red deer (*Cervus elaphus*). Like for horse, many ossifications were missing in the skeletal collections. But in 14 reindeer skeletons, nine females and five males, as well as and two male red deer, some *ossa sternocostalia* were preserved.

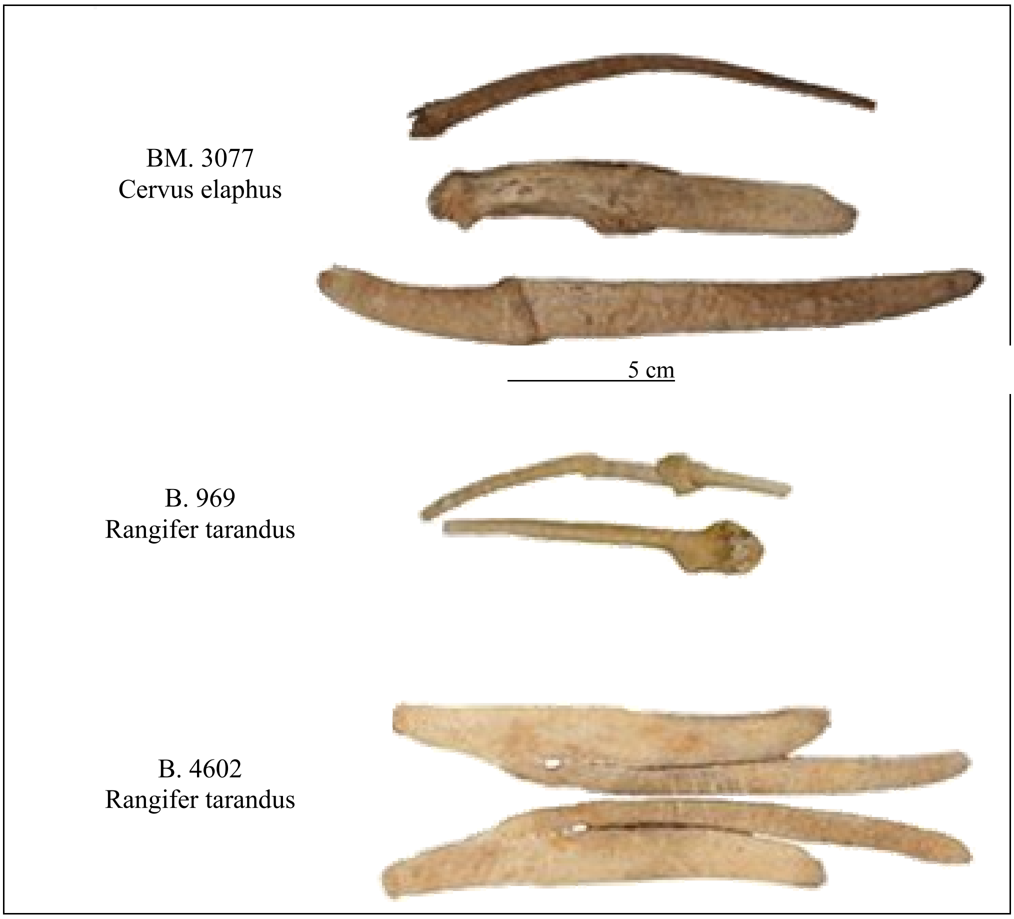

Figure 3. ***Ossa sternocostalia*** **from a male red deer (BM. 3077) and a male reindeer (BM. 909) with evidence of healed fractures.** The red deer specimen shows callus formation around a pseudoarthrosis at the left end (adjoining the part missing); both species show evidence of dislocation and callus formation. Scale 5 cm.

Fig. 3 demonstrates *ossa sternocostalia* from a male red deer and a male reindeer with evidence of fractures among the sternal as well as the asternal ossified cartilages. In fig. 3 the three top bones are from a male red deer (BM. 3077) and the two lowermost (BM. 909) are from male reindeer.

The uppermost of the red deer is an asternal ossification, which has had a fracture some centimetres distal to the *genu costae*. Callus formation has created a sheath around the fracture zone, but that was apparently not sufficient to stabilize the fractured ends. Consequently, the two parts have been separated throughout the rest of the individual's life. The middle specimen represents the 6th or 7th *os sternocostale*. This has also succumbed to a fracture which has healed, as demonstrated by the callus sheath about the middle of the ossification. This proves that the ossification has been fractured. The dislocation between the part to the left and the part to the right indicates that there has been a slight dislocation between the fractured ends before they started fusing again. The apparent callus at the distal end has in fact nothing to do with a fracture, it is actually the shape of the ossification at the junction between the costal cartilage and the sternum. Finally, among the red deer specimens, an example of a fractured 8th *os sternocostale* is demonstrated with a dislocation, after which the two fractured ends have fused together in the dislocated state (fig. 3).

The two lowermost specimens on fig. 3 are reindeer. The upper of the two represent asternal *ossa sternocostalia* which has been fractured, dislocated and fused during healing in the dislocated position. The lower represents an ossified costal cartilage from a floating rib, showing that even in this position fractures may occur.

As for the prevalence of fractures to the ossified costal cartilages among red deer and reindeer, both red deer observed were males, and both displayed fractures. Among reindeer, only one of nine females displayed fractures, opposed to three out of five males. The fact that about 10 percent of females and 60 percent of males display fractures indicates a higher prevalence among males than females. For red deer no conclusions can be drawn due to the small sample size.

Both in red deer as well as reindeer severe dislocation and extensive callus formation are rare, in contrast to what was observed in the horse. The lesions in the red deer and the reindeer were most frequently displayed as whitish, transverse lines, which implied healed micro fractures. Furthermore, healed fractures of different kinds were observed in every horse skeleton that has been scrutinized so far. In particular, this includes every skeleton where the *ossa sternocostalia* could be observed in other races than the Fjord horse and the Døle horse. It has been observed both in articulated as well as disarticulated skeletons, both at the skeletal collections in Bergen and elsewhere. This may indicate that human handling of the horse may be a factor of concern for causing fractures to the *ossa sternocostalia*.

Fractured *ossa sternocostalia* among modern perissodactyles and artiodactyles and from the Viking Age ship burial at Oseberg in Norway demonstrates that such short stabs may occasionally turn up in zooarchaeological assemblages. The ends of these stabs are normally smooth because of the healing process during the animal's life, as opposed to secondary fractures which are irregular. If regarded carefully, even examples of micro fractures and fractured ends fused during healing may be observed and may reveal aspects of the life history of the animal.

Conclusion. The frequency or prevalence of the different kinds of fused or unfused fractures is difficult to quantify. Smaller or greater numbers of traces of such pathologies have been observed in all horse skeletons with preserved costal ossifications studied and in many cases in red deer and reindeer. It is evident that some are caused by traumatic factors, but since they occur in other species and may be quite numerous in some individuals, trauma may not be the only agent causing costal ossifications to snap. Other possible factors may be zones of weakness in the ossification, or degenerative changes of the osseous tissue.

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