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Original article

Comparison of pathological lesions in navicular bone (*os sesamoideum distale*) and analysis of remodelling capacity in warmblood and coldblood horses

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Abstract

The problem of navicular bone lesions is better understood in warmblood horses. The aim of our research was to compare pathologic lesions of navicular bone of different types of horses divided into age groups. An extra goal was to compare radiographs with anatomical status of navicular bone dissected from the hoof capsule. The study group included 161 horses, out of which 100 individuals were warmbloods, and 61 – coldbloods. In total 280 navicular bones were analysed. The flexor surface, distal border fragments, enthesophytes and the process of obliteration of nutrient foramina were analysed. Some navicular bones were also subject to histology test. A greater tendency for the obliteration of nutrient foramina was observed in coldblood horses than in warmbloods. This fact can be explained as increased remodelling, covering the phenomenon of closure of synovial invaginations and canaliculi within the navicular bone. As a result, the synovial groove disappears and blood vessels cannot enter the distal border. New bone formation on the distal border is more frequently observed in coldblood horses. The development of enthesophytes both on the distal and proximal borders depends to a large extent on the age of horses of both types. Warmbloods, however, are more prone to have the lesions located on the flexor surface, leading as a consequence to deep erosions. They might be found even in very young horses in the form of grooves crossing the sagittal ridge. The frequency of lesions varies depending on the type of the horse. Post-mortem analysis of navicular bones helped interpret radiographs in a more precise manner.

Key words: navicular pathology, warmblood horses, coldblood horses, radiology

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Introduction

Research performed by numerous authors on the distal sesamoid bone, commonly called in horses the navicular bone, was usually prompted by the frequency of traumas of this structure and the associated lameness. It should be emphasised, however, that not every lesion found in diagnostic imaging is always related to lameness. Interestingly, this bone has been found to be capable of adapting to a certain extent to the strains exerted on it during the horse's work (Gabriel et al. 1999, Sandler et al. 2000, Bentley et al. 2007, Komosa et al. 2013). This problem is very broad, because lesions found on the navicular bone involve not only the osseous tissue, but also the associated anatomical structures. Therefore, the problem of pathologies related to the navicular bone should be analysed in a comprehensive way, as a problem of the whole navicular apparatus. Because of the frequency of injuries, radiographs of navicular bones have become a golden standard during the prepurchase examinations of sport and leisure horses. This examination, however, does not diagnose the problems of fibrocartilage and the surrounding soft tissues, such as the deep digital flexor tendon (DDFT), podotrochlear bursa and navicular ligaments. Moreover, in several cases it does not show smaller lesions of the navicular bone itself. Such situations have been reported especially in the case of distal border fragments (DBF) and small enthesophytes. This is why several authors emphasise the need to perform post-mortem studies as the conventional radiography is frequently misinterpreted (Wright et al. 1998, Dyson et al. 2011, Yorke et al. 2014). Anatomical analysis of animals that have been euthanized for various reasons might help describe the navicular apparatus in a more precise way and read radiographs more accurately (Cruz et al. 2001, van der Zaag et al. 2016). MRI and CT provide for much better interpreting possibilities of the condition of navicular apparatus; nevertheless, even in the case of these techniques it is worth referring to macro- and micro-anatomical analysis for comparison.

Analysis of the health status of the navicular bone is usually performed in sports horses because of the amount of strain on front limbs accumulated during the training process and competitions. Therefore, the problem of navicular lesions has been analysed more in warmblood horses, though many questions still remain unanswered because of the variety of pathologies of this area. Pathological lesions can affect different parts of the navicular bone, and this is why authors analysing the problems of this bone usually focus on some specific aspects thereof. These aspects usually include enlargement of nutrient foramina, DBFs, cyst-like lesions and enthesophytes on proximal or distal borders. Some of these lesions are frequently found to coexist (Doige and Hoffer 1983, Eliashar et al. 2004, Dyson et al. 2011).

In the light of the data presented above, the condition of navicular bones in coldblood horses, which are much less frequently radiographed, is very interesting. Coldblood horses, because of their different use, are not subject to the same strain as saddle horses. Moreover, they have their own morphotype including different skeleton features. The bones of coldblood horses are more massive in respect to warmbloods; in many cases they have a different shape. Different proportions of the length to the width have been found particularly during the analysis of the third metacarpal bone and the phalanges (Dzierzęcka and Komosa 2013, Alrtib et al. 2014). Likewise, architectonics in the sense of the ratio of the cortical bone versus the calcaneus bone varies in horses of different morphotypes (Dzierzęcka and Charuta 2012). Some data on the anatomical structure of the navicular bone in horses of different breeds are included in the research of Gabriel et al. (1998), but still more studies are needed. The results of these authors suggest that the navicular bone in horses of different types or breeds might feature differences in its spatial structure and thus react differently to strain. For this reason we assume that learning about the differences of navicular bone lesions between warmblood and coldblood horses might lead to a better understanding of pathological lesions of the bone. The potential benefits of our research could be the opportunity to gain new data that can become the foundation for learning about the impact of different uses of the horse on the development of pathologies. Our anatomical observations can be considered as a tool for verifying the efficiency of diagnostic imaging and used to compare similar observations of other authors. The advantage of our research is a large study group, an aspect of great significance in anatomical veterinary analyses.

The most important aim of our research was to compare pathologic lesions of the navicular bone of different types of horses divided into age groups. An additional goal was to compare radiographs with the anatomical status of the navicular bone dissected from the hoof capsule. We also tried to analyse macroscopic changes resulting from adaptation to strain and to evaluate the possibilities of regeneration.

Materials and Methods

The study was conducted on 161 horses that were slaughtered for reasons not related to the study. The group consisted of 100 warmblood and 61 coldblood

Table 1. Statistical analysis.

Type of alterations	Type of horse		Age	
	Cramer's V Test	Jonckheere-Terpstra Test	Cramer's V Test	Jonckheere-Terpstra Test
Obliteration of nutrient foramina	0.34**	0.0001	0.15^{ns}	ns
Changes of flexor surface	0.19*	0.012	0.18^{ns}	ns
Enthesophytes on distal border	0.20*	ns	0.26**	0.0001
Enthesophytes on proximal border	0.14^{ns}	ns	0.19*	0.0004
Distal border fragments	0.09^{ns}	ns	0.20*	0.001
Synovial invaginations	0.12^{ns}	ns	0.17^{ns}	ns

ns – not significant, * $p \leq 0.05$, ** $p \leq 0.01$

horses. In total, 280 navicular bones were analysed, as in 119 cases navicular bones from both front limbs were analysed, while in the remaining 42 horses the bone was from one limb only. For technical reasons it was not always possible to obtain both front limbs; in such cases the left front limb was selected for analysis. Thus, 68 out of 100 warmblood horses had two navicular bones analysed, and 32 had only one, from the left front limb. Out of 61 coldblood horses, 51 had two navicular bones analysed, and 10 had one, from the left front limb.

Every limb was subjected to radiography. The radiographs were performed in lateromedial and dorsopalmar (A-P) view. The x-ray image evaluation procedure was carried out by a Doctor of Veterinary Medicine, a specialist in the field of surgery. The condition of the navicular bones was not known before the radiological examination.

Following the slaughter, the navicular bone was dissected from the hoof capsule, and its anatomical status and – in selected cases – the condition of fibrocartilage covering the flexor surface were described. In the case of five navicular bones a histology test was performed to complement the macroscopic observations. These selected navicular bones with adherent tissues and DDFTs were fixed in 10% formalin. The specimens were then collected and decalcified for 24 h in 5% nitric acid. The material was then embedded routinely in paraffin blocks. Preparations were stained with haematoxylin and eosin and evaluated under a light microscope.

For the purposes of anatomical analysis, six types of lesions were taken into consideration: the condition of the flexor surface, the presence of DBFs, the presence of enthesophytes on the proximal border, the presence of enthesophytes on the distal border, the transformation of nutrient foramina into synovial invaginations and the process of obliteration of nutrient foramina on the distal border. For every type of lesion, a grading, consisting of four letters, from "a" to "d", depending on the severity, was introduced. Grade "a" meant no lesions, "b" – mild lesion, "c" – distinct lesion, and "d" – severe lesion. In the case of the flexor surface, the "d" grade meant deep erosions (cyst-like lesions). As far as obliteration of nutrient foramina is concerned, "d" grade meant closure of all foramina, or closure of almost all foramina and disappearance of the synovial groove on the distal border. In the case of navicular bones in which the obliteration of nutrient foramina and disappearance of synovial groove was found, X-ray images were taken again after hoof capsule isolation. This allowed for a more accurate description of the internal condition of the navicular bone.

The age of the studied animals was very diversified, ranging from 1.5 to 25 years. Therefore, to eliminate the impact of age, the navicular bones of warmblood and coldblood horses were compared in the relevant age groups. Five age groups were introduced: 1.5 – 4 years, 5 – 8 years, 9 – 12 years, 13 – 16 years and over 17 years of age. The first group was comprised of animals that had not yet been used by people, or just started to be used; the second group included horses that were becoming adults and were used more intensively; group 3 included horses at the peak of their careers and physical abilities; group 4 included horses that usually at this age are at the end of intensive use; and group 5 were animals considered to be old and usually working less or completely retired.

Statistical analysis was performed in SAS 9.2 software with the FREQ procedure. Contingency analysis with chi-squared test, and Monte Carlo evaluation for Fisher's exact test were applied. The relationship between variables was estimated by calculating Cramer's V and Jonckheere-Terpstra trend test.

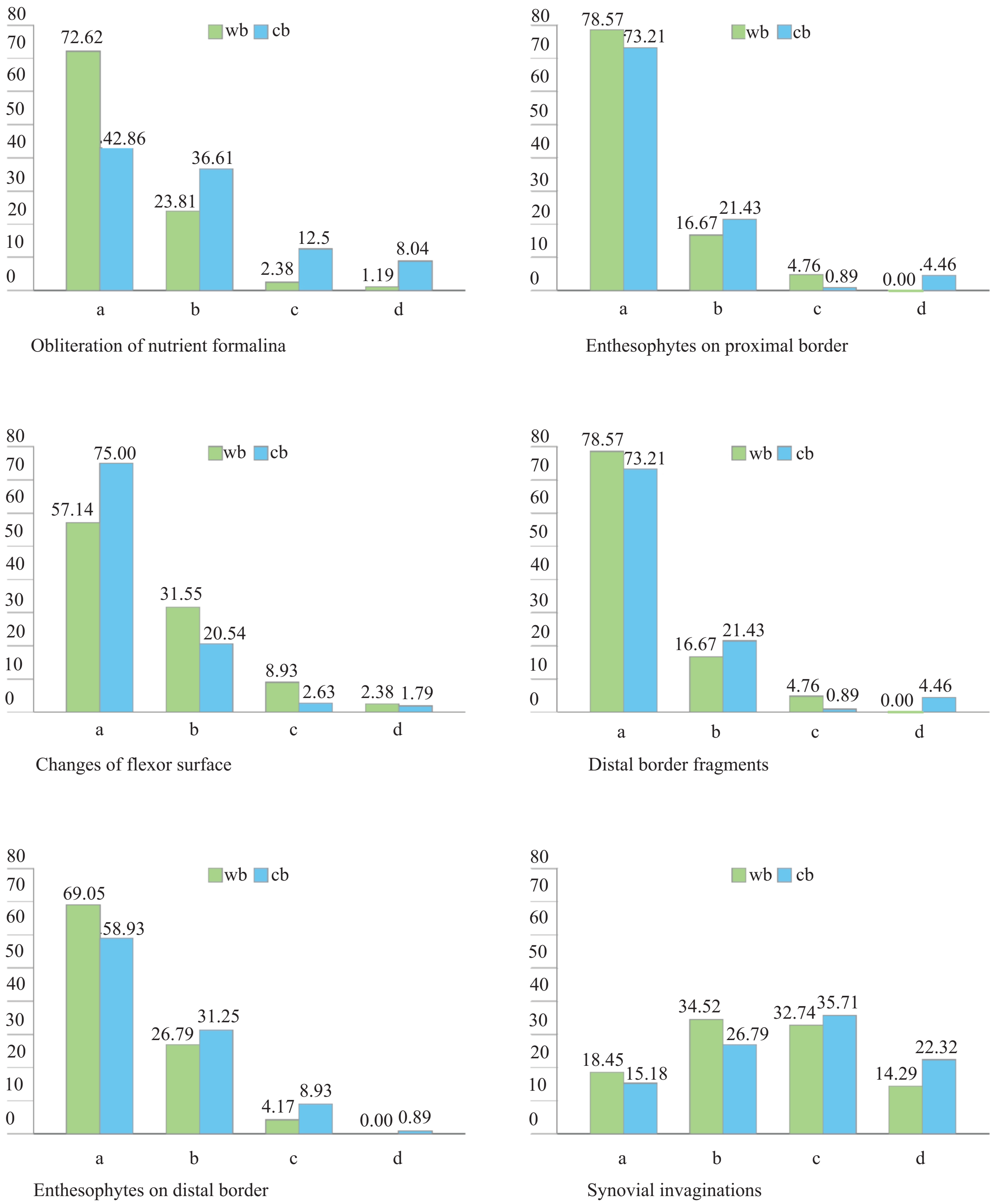

Fig. 1. Frequency diagrams of pathological lesions in warmblood (wb) and coldblood (cb) horses.

Results

Statistical analysis

The statistical analysis showed that out of all studied types of lesions, three are significantly related to the type of horse (Table 1). We found that obliteration of nutrient foramina on the distal border happens more frequently in coldblood horses. Warmblood horses, on the other hand, suffer more frequently from lesions on the flexor surface. Formation of enthesophytes to a large extent depends on the

Fig. 2. Process of gradual obliteration of nutrient foramina and disappearance of synovial groove. Specimens of navicular bones subject to lesions: **Top** – navicular bones graded as “b”. **Middle** – navicular bones graded as “c”. **Bottom** – navicular bones graded as “d”.

age and progresses as the horse becomes older. Enthesophytes seem to form more frequently on the distal border of coldblood horses.

In the case of distal border fragments, the type of horse has not been found to be of relevance; the only significant influence was the age and this was confirmed by the existence of a trend. This means that in older horses large fragments detach much more frequently in this area of the bone. As regards synovial invaginations, the statistical tests did not show any relationship with the type or the age of the horse (Fig. 1).

Anatomical and radiologic analysis

Description of the distal border of navicular bones dissected from the hooves *post mortem* showed a large variety of lesions related to the form of the synovial groove and the number of nutrient foramina. The development of synovial invaginations was a common process. Besides these lesions, as much as 57.14% of navicular bones in coldbloods and 27.38% of navicular bones in warmbloods had nutrient foramina of distal border obliterated to some extent. Our observations show that initial stages of the process develop in those navicular bones that had already developed synovial invaginations. In the first stage, nutrient foramina are gradually covered by new osseous tissue, and the synovial groove becomes more shallow, while the articular surface contacting the coffin bone increases in area. In the next stage, nutrient foramina begin to close, which decreases their number, or even leads to their complete disappearance. Such navicular bones completely lose their synovial groove (Fig. 2).

These observations have been confirmed by radiographic analysis of navicular bones dissected *post mortem* in order to determine the intensity of remodelling within the bone. We saw that besides the external obliteration process, the canaliculi inside the navicular bone are also closed with osseous tissue. Therefore, the process could be considered as opposite to the development of synovial invaginations. This situation can happen already at an early stage, where several nutrient foramina are still visible on the distal border. As the synovial groove closes, the internal canaliculi become more and more obliterated, until they become completely closed with new osseous tissue. This process can be observed when comparing right with left limbs in horses which developed this problem (Fig. 3). In most cases, in one of the limbs remodelling was slightly more advanced than in the contralateral limb; this could mean that eventually in both limbs complete obliteration would take place later on in the animal’s life. Interestingly, the remodelling process seems to cover also DBFs that had developed earlier. In horses with accumulation of a few lesions, including DBF, this process might fill up the missing fragment. As a consequence, irregularities of the distal border might become even again.

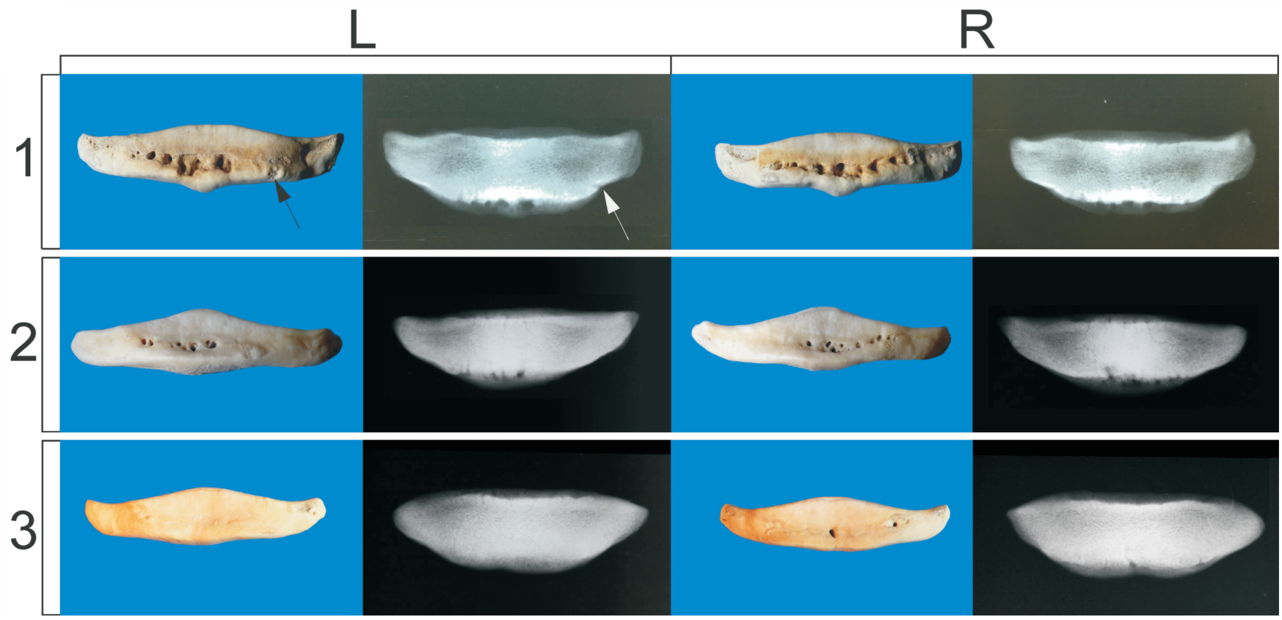

Fig. 3. External and internal process of disappearance of synovial invaginations on navicular bones of left and right limb of three horses. **Top** – a clear radiopaque zone immediately by the enlarged nutrient foramina, remaining parts of the navicular bone with increased radiolucency. The arrow points to the area of detachment of a DBF. **Middle** – partly closed internal canaliculi, a large radiopaque area in the centre of the navicular bone. **Bottom** – left navicular bone with completely obliterated foramina and canaliculi; right navicular bone with less advanced remodelling, with traces of canaliculi.

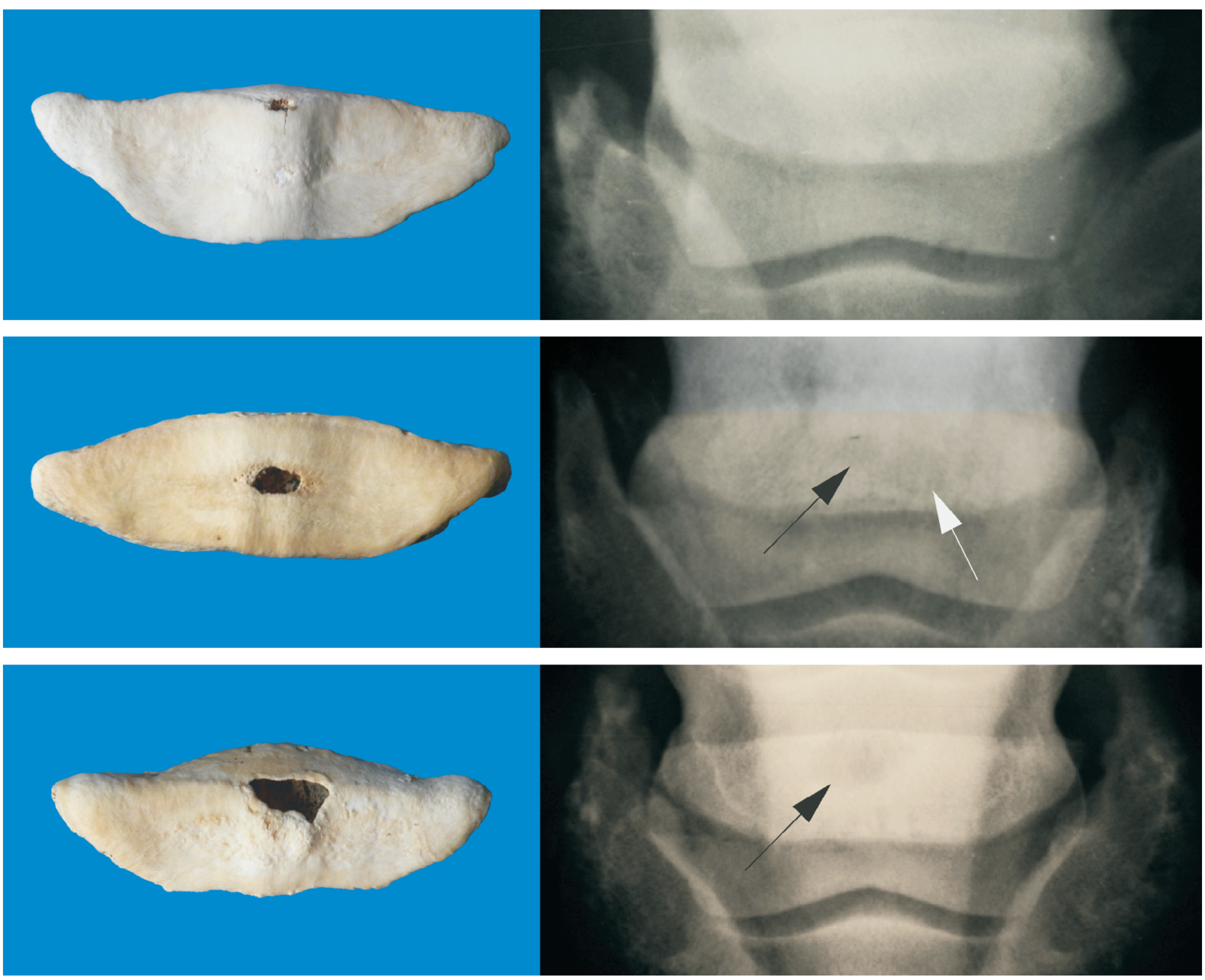

Fig. 4. **Top** – erosion located very high. **Middle** – comparison of the external bone loss area with the area of increased radiolucency. **Bottom** – very marked deep erosion.

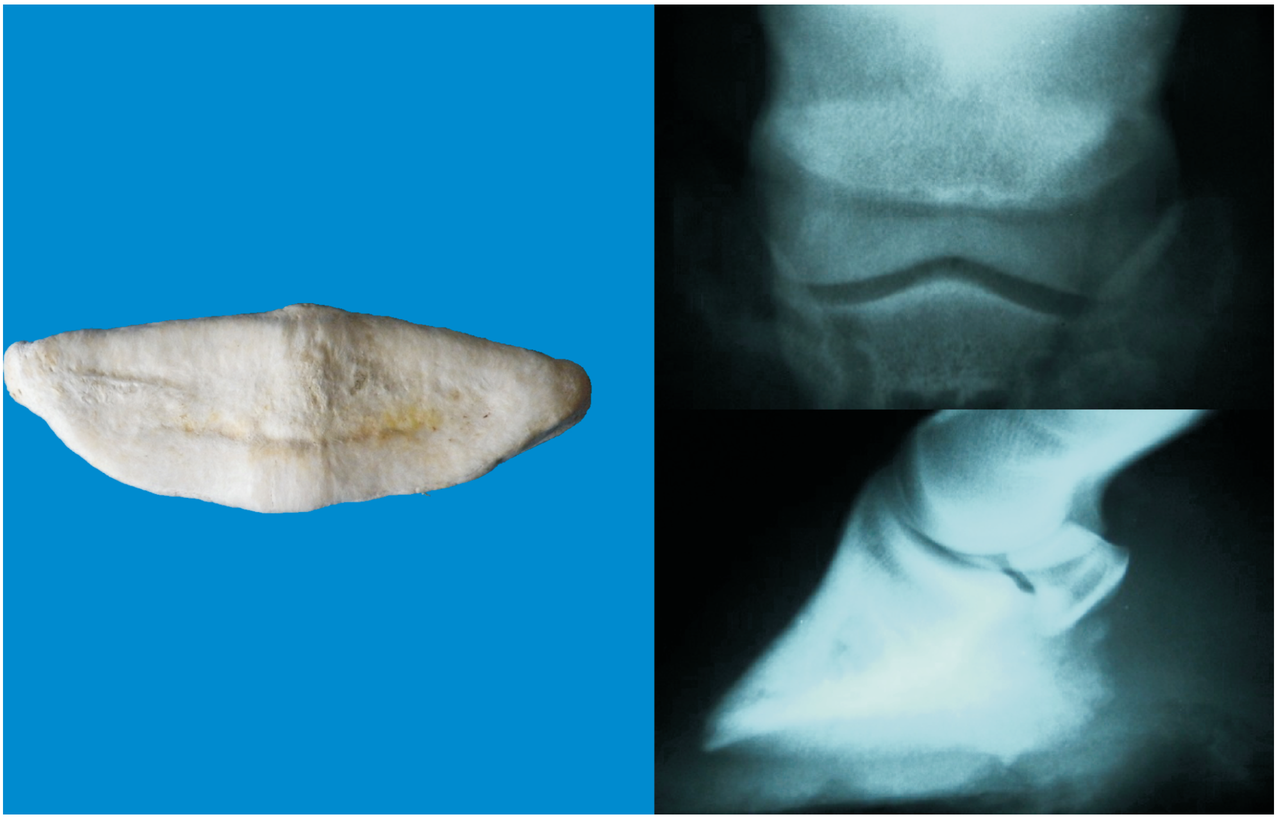

Fig. 5. Early lesions on the flexor surface in a two-year-old warmblood mare.

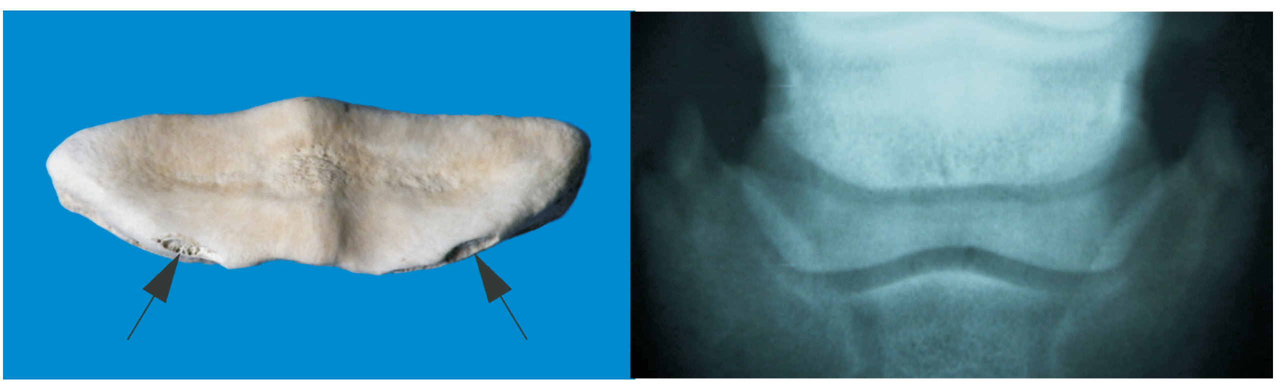

Fig. 6. DBF accompanying early lesions on the flexor service in a two-year-old warmblood stallion.

Another type of lesion, the frequency of which was statistically different between both types of the horses, were changes on the flexor surface. We found these lesions to be of different severity in both types of horses; however, they tended to dominate in warmbloods. Their end stage form was deep erosions in the area of the sagittal ridge. They were easily recognisable on radiographs because of their prominent radiolucency; however, in some cases their interpretation was difficult before dissection of the bone from the hoof. This was the case particularly in an individual with erosion very close to the proximal border (Fig. 4). In some cases, the radiolucent area was expanded over the edges of the bone loss area. This indicates more extensive internal regressive changes, namely loss of cancellous bone content.

While strong erosion of the flexor surface is evident in radiological diagnostics, the process of their formation is difficult to read and often quite elusive. Early lesions registered by us are visible on radiographs in A-P view as greater radiolucency in the central area of the navicular bone. The dissected navicular bone clearly shows a shallow transverse groove. In lateral view radiograph identification of this lesion is impossible (Fig. 5). Such an early lesion in the form of a transverse groove might be present

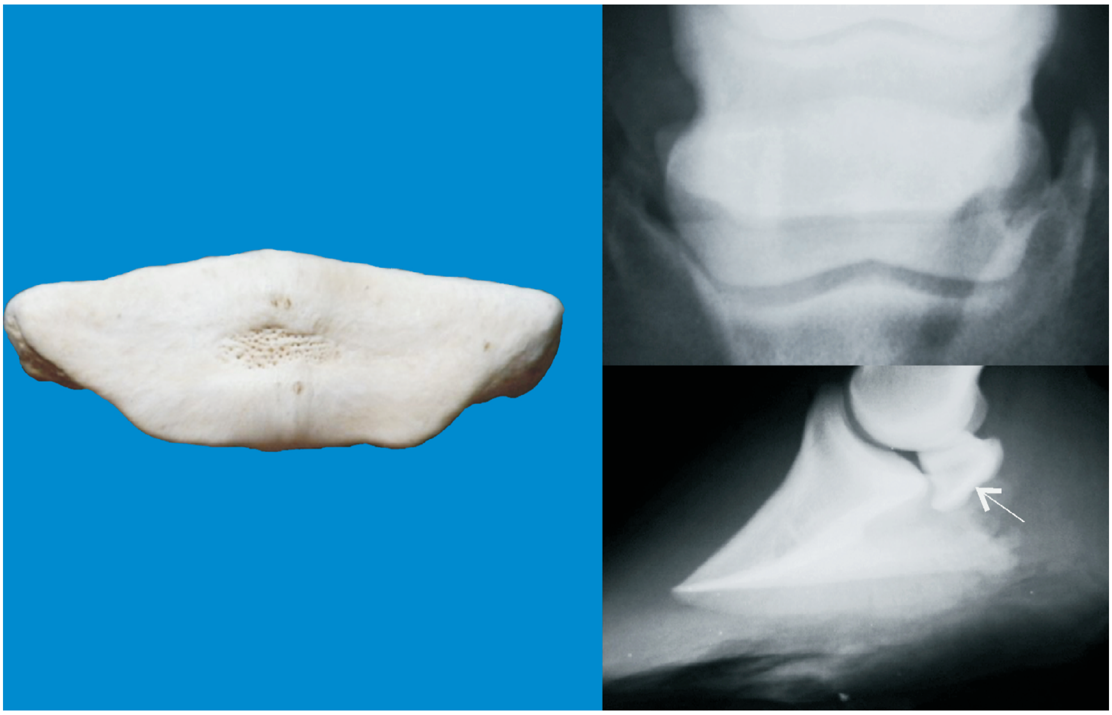

Fig. 7. Intermediate stage of development of a flexor surface lesion in a three-year-old warmblood mare. Please note the thick layer of subchondral bone and the recess in the centre, visible in the lateral view (arrow).

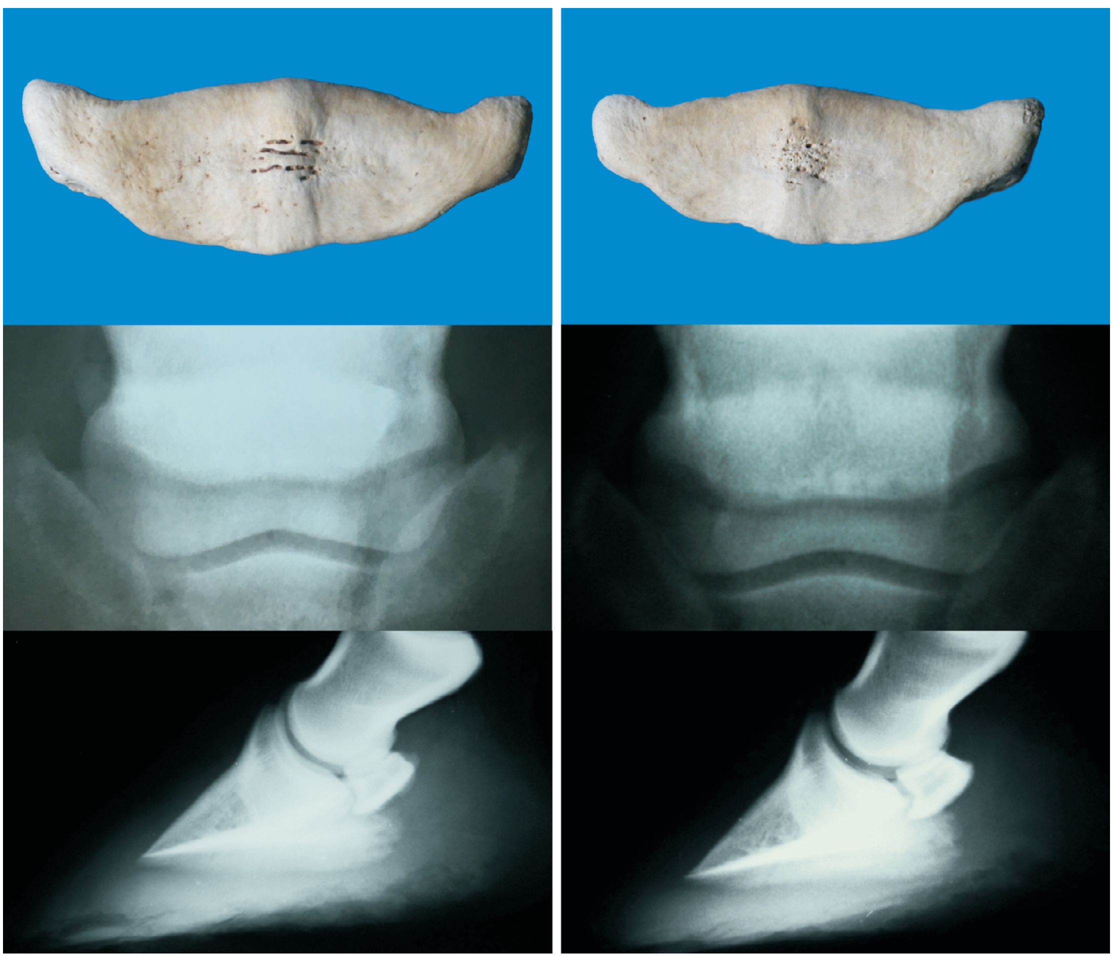

Fig. 8. Left and right limb of a 10-year-old warmblood mare with advanced stage of erosion development.

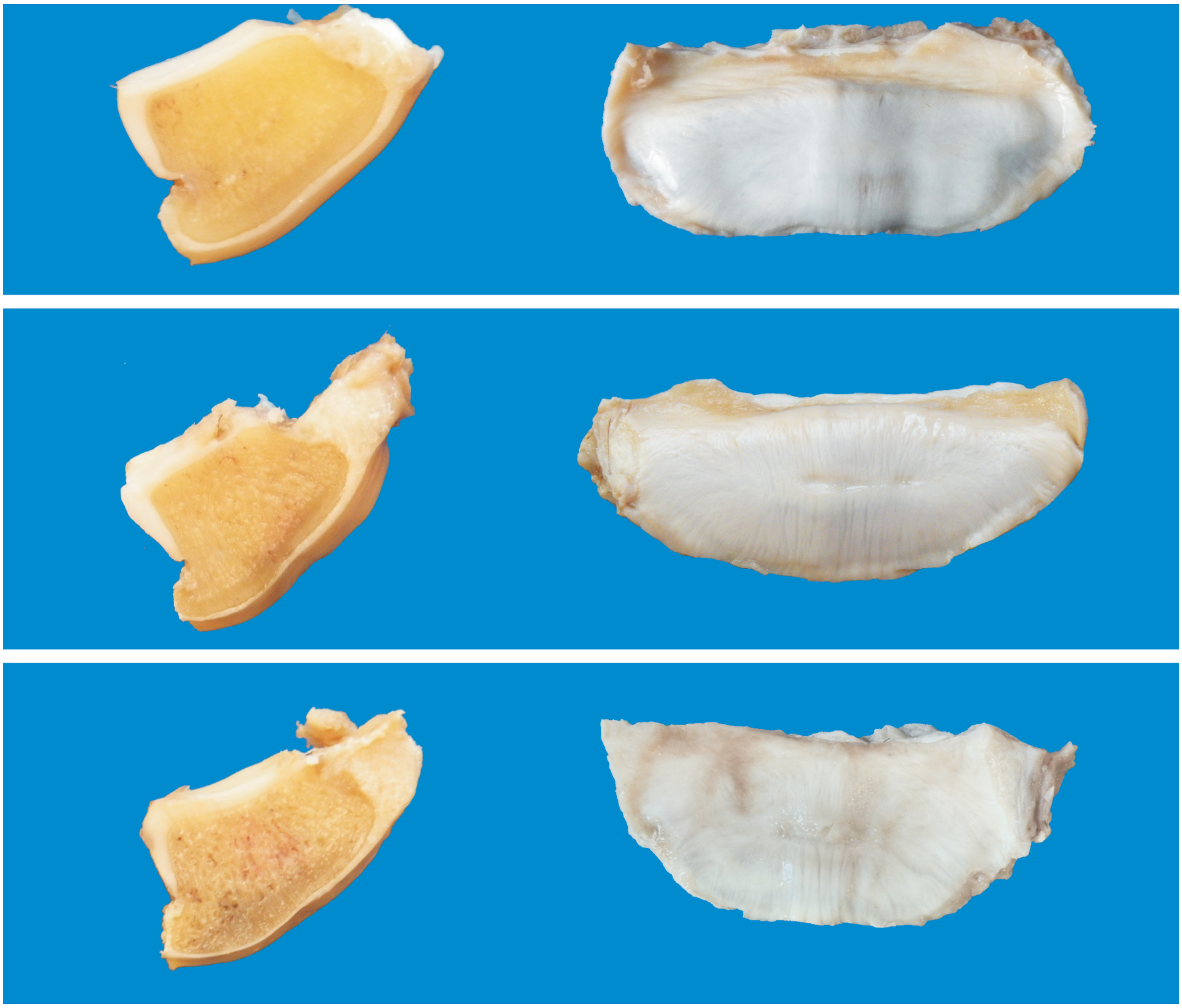

Fig. 9. Condition of fibrocartilage and transverse sections of navicular bones. **Top** – normal navicular bone. **Middle** – early lesions in fibrocartilage running transverse to sagittal ridge. **Bottom** – marked erosion of fibrocartilage running transverse to sagittal ridge.

even in very young horses, under four years of age. It might be accompanied by other lesions, such as DBF (Fig. 6). The next stage leading to the development of a deep erosion is multiple recesses on the sagittal ridge that continue to penetrate the subchondral bone in this area (Fig. 7). Interestingly, in the lateral view the subchondral bone is thick, which might suggest an increased adaptive remodelling process. Sometimes a recess in the central area in a lateral view radiograph (Fig. 8), or increased radiolucency in A-P view can be found, and this should alarm the practitioner.

Owing to the fact that the flexor surface is covered with fibrocartilage, we verified its condition in macro- and micro-anatomical analysis. In transverse section, normal navicular bones have fibrocartilage aligned exactly along the sagittal ridge. In the case of navicular bones with early or advanced lesions, the fibrocartilage was thinner. We also observed hyperaemia within the cancellous bone (Fig. 9). Histological preparations showed fraying of the fibrocartilage surface in these navicular bones (Fig. 10). Besides the areas of rubbing, in four cases we noticed the development of coarse bone growths on the flexor surface (Fig. 11). This could be the result of a defence mechanism of the navicular bone initiated as a reaction to the pressure exerted by the DDFT in horses with too much strain in this area.

During analysis of frequency of enthesophyte formation we found that early lesions were difficult to identify in radiography. Mild enthesophytes were only described on navicular bones dissected from the hoof. Anatomically, such lesions consist of gradual sharpening of the navicular bone borders. On the

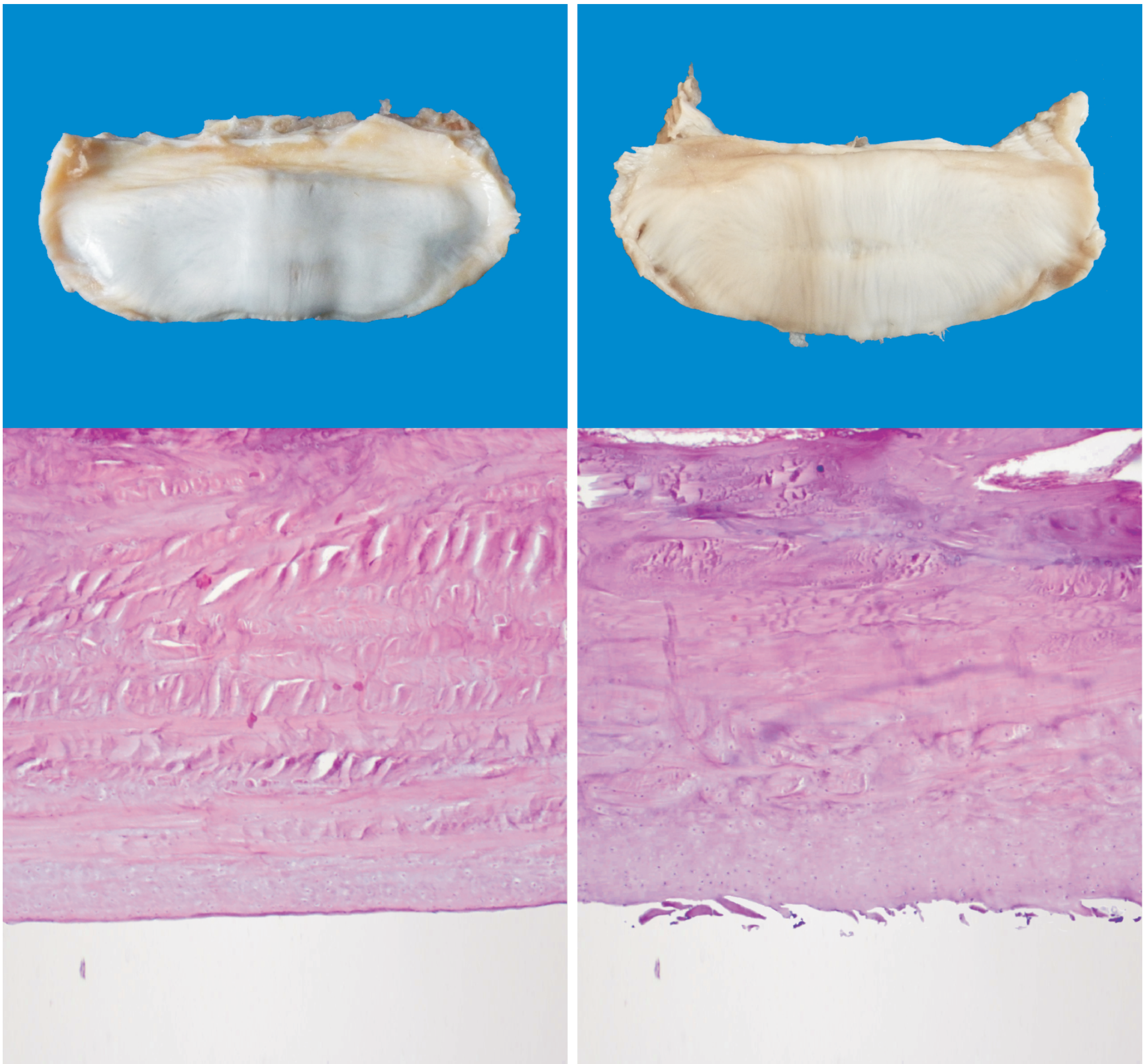

Fig. 10. Left: histological preparation of fibrocartilage taken from normal navicular bone; right: early lesions visible as frayed fragments.

proximal border, enthesophytes usually form initially in the central area. In more advanced cases, new bone formations are also found sideways and are characterised with thin, sharp edges (Fig. 12).

Synovial invaginations are quite frequently accompanied by DBF (Fig. 13). This situation is particularly common in the case of a markedly deepened synovial groove. The distal border of the navicular bone becomes strongly arched and prone to fractures during strain and pressure exerted by DDFT. Small DBFs might be impossible to find on radiographs.

Discussion

Obliteration of nutrient foramina on distal border

Among all pathological lesions of the navicular bone, the process of obliteration of nutrient foramina on the distal border caught our particular attention. Such lesions are very rarely mentioned in scientific papers on navicular diseases. One of the reasons could be that in conventional radiographs these lesions are practically not registered or found. Several researchers pay attention to the opposite process, namely the enlargement of nutrient

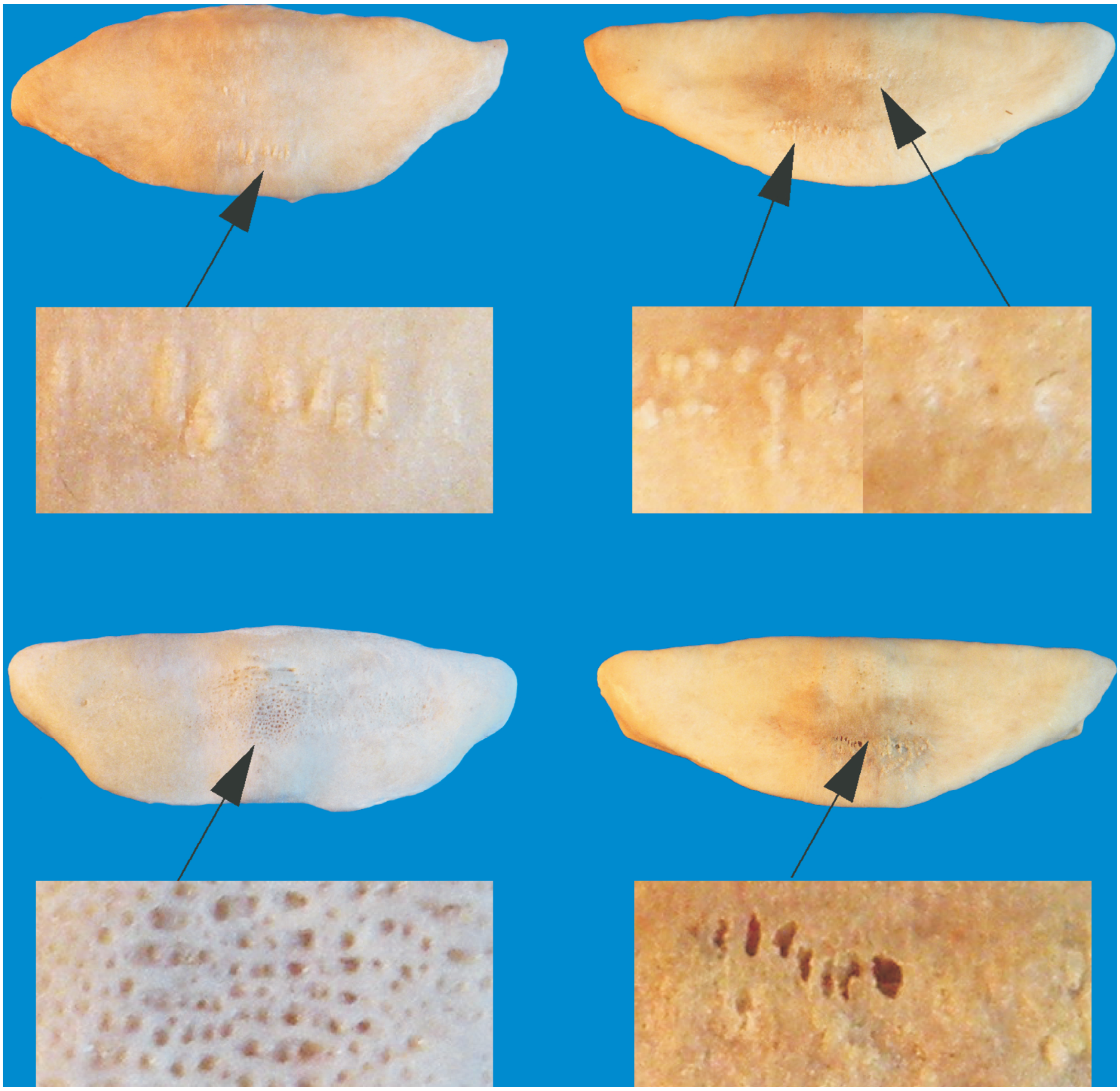

Fig. 11. Examples of coarse growths in the central area of navicular bone.

Fig. 12. Enthesophytes of proximal border; mild lesions “b”, moderate lesions “c” and severe lesions “d”.

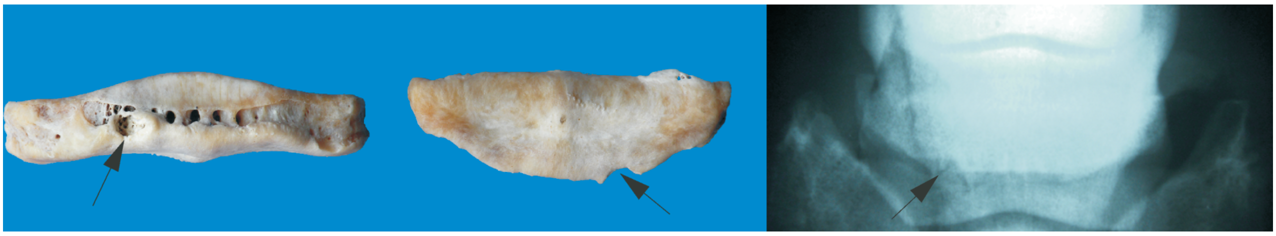

Fig. 13. Severe bone loss (DBF) identifiable in a radiograph as marked radiolucency.

foramina, resulting in synovial invaginations (SI) (Lejeune et al. 2006, Claerhoudt et al. 2011, Claerhoudt et al. 2012). In our post mortem studies, we found cases of complete obliteration of all foramina on the distal border. We also frequently saw navicular bones with deep synovial invaginations in one area, and complete closure thereof with osseous tissue in other areas of the same bone. Moreover, radiographs of such dissected navicular bones have shown canaliculi internally closed by cancellous osseous tissue. This might be a secondary process to the occurrence of invaginations. Navicular bones changed in such a way lose their groove on the distal border and seem to be increasing their articular surface contacting the distal phalanx. Many navicular bones dissected from the hoof capsule have an atypical shape: they are thicker and slightly cylindrical, resembling the shape of a cigar. This can indicate a very intense process of adaptive remodelling. This process was statistically more frequently found in coldblood horses. Unfortunately, we do not know the history of these horses, therefore there are few possible hypotheses explaining the process. Comparative analysis of the navicular bone shape in the context of these observations seems to be worth separate analysis in the future.

In the first hypothesis, the obliteration of nutrient foramina can be related to longer periods of rest after intensive work. Coldblood horses are usually used seasonally in harness, with a longer resting period in winter, while warmbloods are frequently used all year round. Not all riders give their horse a break that would last longer than one month. Such a short break may be insufficient for regeneration. Moreover, there is the question if this method of repairing synovial invaginations is safe for the navicular bone, as it blocks the blood supply. The closure of foramina through which blood vessels enter the bone might make the bone more prone to fractures. It is true that the arterial blood is also supplied to the navicular bone by nutrient foramina on its proximal border, as well as lateral and medial sides; however, the distal supply covers the largest part of the navicular bone (Rijkenhuizen et al. 1989a, b, Colles and Hickman 1997).

The other possible hypothesis is that the greater frequency of obliterated nutrient foramina in coldblood horses is a result of the different conformation of the hoof, alignment of the digit, and the tension of the distal sesamoidean impar ligament (DSIL). This theory is confirmed by the research of Dzierzęcka et al. (2016). Coldblood horses have a more upright position, and moreover they work on hard surfaces, with long calks attached to horseshoes that additionally raise the rear part of the hoof. Such a conformation makes the horse land toe first. As a result, the DSIL is stretched more than in case of a heel first landing. Moreover, in cold blood horses the vertical axis of the digit (hoof-pastern axis) is frequently broken. As a result, the distal interphalangeal joint is more open on the palmar side than in the case of the unbroken vertical axis. This also increases the tension of the DSIL. This ligament is attached just under the groove with nutrient foramina and it is within the ligament that arteries run into the foramina. Thus, DSIL traumas might result in injuries to arteries entering nutrient foramina on the distal border. Comparing our research to the studies of other authors, we would like to mention the work of Bowker (2003) who proved that changes reflecting “abnormal stress” at the insertion of the DSIL and DDFT have been demonstrated in horses with poor foot conformation. Likewise, Gabriel et al. (1998) compared different types of horses and found that the mineralised part of the DSIL was larger for heavy horses. The DSIL firmly anchors the navicular bone to the distal phalanx. The importance of its mineralised part could be related to the size of the ligament, its bone attachment zone and the strain to which it is submitted.

It is worth adding that the upright feet and greater body mass of cold blood horses are frequently associated with ossification of the collateral hoof cartilages (Lejeune et al. 2006, Dzierzęcka et al. 2016). This factor deteriorates the mechanics of the hoof and can be related to blood flow problems. Moreover, it is probable that osseous tissue in coldblood horses has a different metabolism, including different dynamics of adaptive remodelling. This, with other accompanying factors, might facilitate the development of such lesions. However, verification of this hypothesis requires detailed physiological and histologic research.

Presence of enthesophytes

Our research showed that the presence of enthesophytes on the distal border only is statistically related to the type of horse and occurs more frequently in coldbloods. New bone formation in this area is a result of increased tension of DSIL, as explained above. However, age also has a strong and statistically significant impact on the development of enthesophytes on the distal border. No statistically significant relationship with the type of horse has been found in the case of enthesophytes on the proximal border; age, however, proved to be a relevant factor for this area too. Therefore, irrespective of the area where enthesophytes are present, a clear trend of increase in the number or size of enthesophytes with animal age has been shown. According to Dyson et al. (2011), the presence of entheseous new bone on the proximal border indicates previous insertional desmopathy of the collateral sesamoid ligaments (CSL). Its clinical significance remains uncertain, although more extensive new bone in this location tends to be associated with other signs of navicular disease.

Small enthesophytes often go unnoticed on radiographs. Only cadaver study made it possible to count the structures more precisely. The first stage of enthesophyte formation is usually the development of sharp edges in areas where the CSL enters the periosteum of the navicular bone. The conclusion is that formation of enthesophytes is a process that might take a considerable amount of time.

Lesions on flexor surface

Early lesions on the flexor surface were difficult to diagnose with radiographs, both in lateral and A-P views. Only an anatomical analysis of navicular bones dissected from the hoof capsule gave conclusive about the condition of the external cortical bone and subchondral bone. Lesions that are graded as "b" are radiopaque, while lesions qualified as "c" are radiolucent to some extent only. Sherlock et al. (2008) also found that erosions of the flexor surface are more easily diagnosed by low field MR imaging than conventional radiography. What makes correct diagnosis even more difficult is the fact that lateral radiographs showed a very thick subchondral bone in horses with the flexor surface in the early stages of rubbing by DDFT. This fact may be misleading, as the process of formation of cyst-like lesions is usually associated with gradual thinning of the cortical bone leading to development of erosions on the flexor surface. However, such erosions usually develop only in the central part of the navicular bone on the sagittal ridge, which is not always visible in a lateral view. Moreover, before such severe lesions develop, the navicular bone shows increased positive adaptive remodelling thanks to which it adapts to the pressure exerted by DDFT. This explains why not every horse with a thicker subchondral bone is a potential suspect of pathological lesions, as it might be an individual adaptation to strain coming from its work. However, Biggi and Dyson (2012) found that the palmar cortex was thicker in lame compared with sound horses. Other studies (Wright et al. 1998, Sandler et al. 2000) also suggest that, indeed, in the early stage of workload, the navicular bone thickens its subchondral bone. The later stage usually includes thinning of fibrocartilage, podotrochlear bursa and the chondral layer of DDFT (Blunden et al. 2006a,b, Komosa et al. 2014). Only after this stage does the subchondral bone on sagittal ridge continue to become thinner until erosions, or cyst-like lesions, finally develop. These erosions are usually located in the central part of the sagittal ridge or close to the proximal border, which might be related to the positioning of the navicular bone, which depends on the height of the heels. The location of erosion suggests the location of the strongest action of DDFT.

Our analysis showed that lesions on the flexor surface develop statistically more frequently in warmblood horses. These results are consistent with the observations of Gabriel et al. (1998) who found that draft horses possess a thicker cortical bone and, therefore, a stronger flexor surface. According to these authors, this finding could partly explain their lower susceptibility to navicular disease. It should be stressed, however, that cyst-like lesions are sometimes also found in coldblood horses, which means that the thickness of the cortical bone is not the only factor determining the development of these pathologies. Interestingly, early anatomical lesions (grade "b" and "c") can be found already in very young horses, especially warmbloods. Initially, such lesions look like a long groove along the long axis of the palmar aspect of the navicular bone. The next stage includes some thinning, mostly on the sagittal ridge, accompanied by thinning of fibrocartilage. Other lesions can also be present, particularly synovial invaginations and DBFs. Perhaps the main reason for these lesions is making young horses work hard without a proper preparation period. The situation is more frequent in saddle horses which from the beginning of their career, are subject to the high demands of sport.

Synovial invaginations and distal border fragments

Other type of negative changes to the navicular bone, such as development of synovial invaginations and DBFs, were not related to horse type. It is worth noting that development of DBFs is strongly related to the horse's age. However according to many authors, these two processes are interrelated (Wright 1993, Biggi and Dyson 2011, Komosa et al. 2013). The presence of deep synovial invaginations deepens synovial grooves as a result. Subsequently, the distal edge of the flexor side surface becomes sharp and strongly differentiated. Pressure exerted by DDFT can lead to fractures and moving fragments.

Based on our study we can say that several of the lesions described above are frequently coexistent. Likewise, Dyson and Murray (2007) learned from clinical experience using MRI, that frequently several structures of the navicular apparatus are affected concurrently. We believe that inflammatory and degenerative processes close to the navicular bone lead to increased blood flow in peripheral blood vessels in the area, to the release of mediators of inflammation by the surrounding tissues, and in consequence – to the vasodilation of capillaries and their greater permeability for plasma proteins and phagocytes. The inflammatory process is aggravated by pathological tensions, particularly in the area of the DSIL, damaging the local blood vessels, creating clots and occluding them (Fricker et al. 1982). These factors increase the pressure within the hoof capsule and inhibit its supply (Sampson et al. 2009). Moreover, histological changes in the navicular bone can be typical for osteoarthritis (Van Hamel et al. 2014). Pathological biomechanical strain on this area leads to an increase in the number of trabeculae in the medullary cavity of the navicular bone, its swelling and degeneration (Sampson et al. 2009). With time, the trabeculae are destroyed and sclerotized, which may lead to development of synovial invaginations. It is possible that, once the horse is provided with a longer rest period, the earlier loss of the bone would fill up with new osseous tissue thanks to regenerative processes. On the other hand, according to the findings presented above, the reaction of the navicular bone to stress might to a large extent depend on a variety of factors and their interactions.

Conclusions

In our research a greater tendency for the obliteration of nutrient foramina on the distal border was observed in coldblood horses than in warmbloods. This fact can be explained as a regenerative process related to increased remodelling, covering the phenomenon of closure of synovial invaginations and canaliculi within the navicular bone. As a result, the synovial groove disappears and blood vessels cannot enter the distal border.

New bone formation on the distal border is more frequently observed in coldblood horses. The development of enthesophytes both on the distal and proximal borders depends to a large extent on the age of horses of both types.

Warmblood horses are more prone to have the lesions located on the flexor surface, leading as a consequence, to deep erosions. They might be found even in very young horses in the form of grooves crossing the sagittal ridge. They are frequently accompanied by other lesions on the navicular bone.

Post-mortem analysis of navicular bones helped interpret radiographs in a more precise manner. This was true particularly in cases where the obliteration of nutrient foramina was found, in early lesions on the flexor surface, small enthesophytes and small distal border fragments. All these lesions may develop concurrently.

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