Original Article

Radiological interpretation of the navicular bone

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Summary

Acquisition of a sufficient number of high quality radiographic views is an essential prerequisite to accurate radiological interpretation of the navicular bone. This requires appropriate preparation of the foot, careful attention to limb position and to both centring and direction of the x-ray beam, according to hoof capsule conformation. Artefacts are easily created. Potentially significant radiological abnormalities include: entheseiophytes at the proximomedial and proximolateral aspect of the bone; proximal or distal extension of the flexor border of the bone, distal border fragments, 8 or more large and variably shaped distal border radiolucent zones; discrete radiolucent areas in the spongiosa with or without detectable communication with the flexor cortex; new bone at the sagittal ridge; increased thickness of the flexor cortex; sclerosis of the spongiosa; and a bipartite bone.

Introduction

Radiography has long been the imaging modality of choice for the diagnosis of navicular disease. However, with the introduction of magnetic resonance imaging (MRI) into the diagnostic armamentarium, the limitations of radiography have been recognised (Dyson et al. 2006). It has also become apparent that there are probably a variety of different pathological processes that can affect the navicular bone, a structure which cannot be considered in isolation (Dyson et al. 2006; Dyson and Murray 2007). The navicular bone has a close relationship with both the other structures of the podotrochlear apparatus (the collateral sesamoidean ligaments [CSL] and the distal sesamoidean impar ligament [DSIL]), and with the navicular bursa and deep digital flexor tendon (DDFT). Comparison of magnetic resonance (MR) images and radiographs has improved our interpretation and understanding of radiographs. Moreover, the advent of computed and digital radiography has potentially enhanced our radiographic diagnostic capabilities, by improved image quality. As a result it should now be possible to identify more radiographic abnormalities of potential clinical significance than previously. Nonetheless it is important to recognise that the absence of significant radiological abnormalities of the navicular bone does not preclude the existence of significant navicular bone pathology. The purpose of this paper is to review radiological interpretation of the navicular bone, based on previous publications, and clinical comparison with MR images and/or post mortem specimens.

Fig. 1a and ai: Lateromedial (LM) radiographic view of a foot. This is not a true LM view, but an oblique projection of the navicular bone resulting in several superimposed lines representing the flexor cortex of the bone. This prohibits evaluation of the thickness of the flexor cortex and its demarcation from the spongiosa. The sagittal ridge cannot be assessed. An ossified cartilage of the foot is partially superimposed over the navicular bone. There is a small spur on the proximodorsal aspect of the navicular bone. There is also some radiopaque debris on the foot palmar to the navicular bone.
Is the radiograph of diagnostic quality?

Correct positioning during image acquisition is of crucial importance for image interpretation. A true lateromedial (LM) projection is required to assess the sagittal ridge of the flexor aspect of the navicular bone; the thickness of the flexor cortex from proximal to distal; the uniformity of opacity of the flexor cortex; the demarcation between the endosteal surface of the flexor cortex of the navicular bone and the trabecular bone of the spongiosa; the shape of the navicular bone to identify proximal or distal extension of the flexor aspect of the bone; to identify the presence of dorsoproximal periarticular osteophytes (Fig 1). It is important that the navicular bone is correctly positioned in dorsoproximal-palmarodistal oblique (DPr-PaDiO) views, so that the distal border of the bone is not superimposed over the distal interphalangeal (DIP) joint (Fig 2). Over or under flexion of the fetlock are the most common causes of superimposition of the distal border of the navicular bone over the DIP joint. Two views at slightly different angles may be required to evaluate the dorsal and palmar aspects of the proximal and distal borders of the bone.

Correct position of the limb and angulation of the x-ray beam are crucial to obtain a diagnostic palmarproximal-palmarodistal oblique (PaPr-PaDiO) view of the navicular bone (Fig 3). The foot must be positioned caudal to the contralateral foot with the fetlock joint extended, to avoid superimposition of the fetlock over the navicular bone. The x-ray beam should be tangential to the flexor aspect of the navicular bone. The precise angle depends on the conformation of the foot. With low collapsed heels a more shallow angle with the ground is appropriate, whereas with an upright foot the angle should be steeper. Inappropriate angulation results in artefactual increased opacity of the spongiosa and lack of definition between the trabecular and cortical bone (Fig 3b).

Which views are required?

A comprehensive radiographic evaluation of the navicular bone requires LM, DPr-PaDiO and PaPr-PaDiO views. A recent publication suggested that PaPr-PaDiO views were not essential, because abnormalities were always detectable on conventional views (De Clerq et al. 2000). However, this study
focused on bones with advanced pathological change. There are many examples of either lucent zones in the flexor cortex of the navicular bone, or less commonly new bone on the flexor cortex that are only detectable in PaPr-PaDiO views (Fig 4). A weightbearing dorsopalmar view is occasionally useful to confirm the presence of a parasagittal fracture or a bipartite navicular bone. It may be the view that is most sensitive for detection of enthesophytes on the proximomedial and lateral aspects of the navicular bone (Fig 5). Appropriate preparation of the foot is crucial for diagnostic images. The shoe should be removed to enable proper trimming of the foot and to avoid superimposition of the shoe over the medial and lateral aspects of the navicular bone. The frog clefts should be packed with appropriate material to eliminate radiolucent lines superimposed over the navicular bone (Fig 2).

**Development and shape of the navicular bone**

The shape of the navicular bone is considered to be heritable in Dutch Warmblood horses. The proximal articular border may be convex, horizontal or undulating or concave as seen in a DPr-PaDiO view (Fig 6). In Dutch Warmblood horses it has been suggested that horses with a convex or horizontal proximal articular border are at less risk of navicular disease compared with those with an undulating or concave articular margin (Dik and van den Broek 1995; Dik et al. 2001a,b). Similar studies have not been performed in other breeds to verify these observations.

A smoothly outlined depression in the sagittal ridge of the navicular bone is a normal variant seen in a LM view (Fig 7). The fossa along the distal border of the navicular bone varies in its depth in a LM view (Figs 1b, 7, 19b and 20c).

**Radiolucent zones along the distal border of the navicular bone**

The interpretation of distal border radiolucent zones, which represent synovial invaginations from the DIP joint (Poulos 1983,
abnormal stress at the origin of the DSIL. Comparison between DPr-PaDiO and PaPr-PaDiO views helps to determine the dorsopalmar extent of the radiolucent zones (Fig 9).

Large radiolucent zones close to, but apparently discrete from the distal border of the navicular bone may occur alone, or in association with distal border synovial invaginations (Fig 10). Such radiolucent zones usually extend from the palmar to dorsal cortices when assessed in a PaPr-PaDiO view and are not normally seen in clinically sound horses.

Figs 5a and ai: Dorsopalmar radiographic view of a foot. Medial is to the left. There is a rather irregularly outlined enthesophyte on the proximomedial aspect of the navicular bone superimposed over the middle phalanx (arrow). There is mild ossification of the lateral cartilage of the foot and moderate ossification of the medial cartilage of the foot.

Fig 5b: Dorsopalmar radiographic view of a foot. Medial is to the left. There is a large enthesophyte on the proximolateral aspect of the navicular bone (arrow) projecting beyond the middle phalanx.

1988), has long been subject to controversy. It is generally accepted that the larger the number of radiolucent zones (>7), of variable size and shape, the more likely they are to be of clinical significance (Fig 8) (Table 1). Such lucent zones may be seen in association with localised sclerosis. Radiolucent zones positioned on the medial and lateral sloping borders of the bone are considered more likely to be of clinical significance (Fig 8d). Clusters of axially positioned lucent zones, combined with distal elongation of the flexor border of the navicular bone may reflect...
Osseous fragments on the distal border of the navicular bone usually occur at the distal medial and lateral angles of the navicular bone (Figs 6c, 11b and c), although less commonly involve the medial or lateral sloping border (Fig 11a). Several studies have shown that such fragments occur more commonly in lame horses with other abnormalities of the navicular bone than in clinically normal horses (Wright 1993; Wright et al. 1998; Schramme et al. 2005; Blunden et al. 2006). Prevalence was low in a group of clinically normal horses undergoing a prepurchase examination (Kaser-Hotz and Ueltschi 1992). Such fragments may reflect ectopic mineralisation in the DSIL, a fracture of the distal border of the navicular bone or a fracture of an entheseophyte at the origin of the DSIL. The presence of a radiolucent area at the medial border fragments

TABLE 1: Radiographic findings of the navicular bone in normal and diseased horses

<table>
<thead>
<tr>
<th>Grade</th>
<th>Condition</th>
<th>Radiographic findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Excellent</td>
<td>Good corticomedullary demarcation; fine trabecular pattern. Flexor cortex of uniform thickness and opacity. No lucent zones along the distal border.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right and left navicular bones symmetrical in shape.</td>
</tr>
<tr>
<td>1</td>
<td>Good</td>
<td>As above, but lucent zones on the distal border of the navicular bone more variable in shape.</td>
</tr>
<tr>
<td>2</td>
<td>Fair</td>
<td>Slightly poor definition between the palmar cortex and the medulla due to subcortical sclerosis. Crescent-shaped lucent zone in the central eminence.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Several (&lt;8) lucent zones of variable shape along the horizontal distal border of the navicular bone.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mild entheseophyte formation on the proximal border of the navicular bone.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Navicular bones asymmetrical in shape.</td>
</tr>
<tr>
<td>3</td>
<td>Poor</td>
<td>Poor corticomedullary definition due to medullary sclerosis. Thickening of the dorsal and flexor cortices. Poorest defined lucent areas in the flexor cortex.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Many (&gt;7) radiolucent zones along the distal horizontal or sloping borders of the navicular bone.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lucent zones along the proximal border of the bone.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large entheseophyte formation on the proximal border of the bone. Discrete mineralisation within a collateral ligament of the navicular bone.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Radiopaque fragment on the distal border of the navicular bone.</td>
</tr>
<tr>
<td>4</td>
<td>Bad</td>
<td>Large cyst-like lesion within the medulla of the navicular bone. Lucent region in the flexor cortex of the navicular bone. New bone on the flexor cortex.</td>
</tr>
</tbody>
</table>

Figs 8a–f: Dorsoproximal-palmarodistal oblique views of 6 navicular bones showing various patterns of radiolucent zones (synovial invaginations) along the distal border of the bone. Figures 8a and b are considered within the normal range, but Figures 8c–f are abnormal.
or lateral angle of the distal border of the navicular bone is suggestive of the presence of a fragment, which can be present uniaxially or biaxially. Fragments can be seen as an incidental abnormality, especially if the opacity of the adjacent navicular bone is normal (Fig 11b), but if seen in association with a radiolucent area are more likely to be associated with lameness (Fig 11c). Such fragments have been associated with marked reactions in the adjacent navicular bone seen in MR images, presumably the result of chronic movement, or associated with adhesions to the DDFT and/or associated lesions of the DSIL. Fragments are most easily detected in a DPr-PaDiO view, but the ease with which they can be seen is somewhat position dependent. In some horse the presence of a fragment can be verified in a PaPr-PaDiO view (Fig 11b) in which an opacity representing the fragment is usually seen superimposed over the spongiosa of the navicular bone.

Radiolucent zones in the proximal aspect of the navicular bone

Proximal border radiolucent zones are occasionally seen and are not normal. They have been seen in association with lesions of the CSL.
A crescent-shaped lucent zone in the flexor cortex of the navicular bone in the sagittal ridge seen in a PaPr-PaDiO view is considered to be a normal variant, representing a reinforcement line (Berry et al. 1992) (Figs 12, 18a). The crescent-shaped lucent zone in the sagittal ridge of the navicular bone is rarely seen in very young horses. It represents early navicular bone modelling, in response to stress. A relatively sclerotic reinforcement line develops in the subchondral bone parallel with the flexor cortex in the region.
only detectable radiographic abnormality. Such lesions usually occur at the sagittal ridge or abaxial to it (Figs 4 and 15). The lesion usually reflects erosion of the overlying fibrocartilage and adhesions of the DDFT. There may be associated sclerosis of the trabecular bone dorsal to the lesion.

**New bone formation on the flexor cortex of the navicular bone**

New bone formation on the flexor border of the navicular bone is usually only detectable in a PaPr-PaDiO view and is of the sagittal ridge. The intervening bone is relatively radiolucent and is projected in the palmaroproximal-palmarodistal oblique view as the crescent shaped lucent zone in the sagittal ridge. If the bone between the reinforcement line and the flexor cortex becomes compacted, then the lucent zone becomes less clear and may be obliterated.

An ill-defined loss of opacity at the most palmar aspect of the sagittal ridge has been seen as an incidental finding (Fig 13), with no other pathological change, but may be a precursor to the development of significant degeneration (see ‘Lucent zones in the flexor cortex’).

**Central or acentric lucent zones**

Central or acentric radiolucent zones, cyst-like lesions, in the spongiosa of the navicular bone seen in DPr-PaDiO views are almost invariably of clinical significance (Fig 14). They usually involve the middle third of the bone from proximal to distal, but not invariably so. In some horses such lesions can be seen to involve the flexor cortex of the bone in PaPr-PaDiO views. However, not all such lesions involve the flexor cortex. Moreover some lesions do penetrate the flexor cortex, but this cannot be verified radiographically. This depends on which part of the flexor cortex is tangential to the x-ray beam, the location of the lesion and its size.

**Lucent zones in the flexor cortex**

A large radiolucent area in the flexor cortex of the navicular bone is invariably clinically significant, and in some horses is the
usually centred around the sagittal ridge (Fig 16). It has only been seen in association with lameness, and has not necessarily been seen in conjunction with other abnormalities of the navicular bone.

**Proximal border fragments**

Fragments displaced from the proximal border of the navicular bone are rare and in the author’s experience have been associated with lameness and presumably reflect an avulsion at the insertion of the CSL (Fig 17).

**Thickness of the cortices**

The thickness of the cortices of the navicular bone varies within and between horses. The thickness of the flexor cortex is easiest to evaluate in a well positioned LM view. Like any bone, shape is influenced by Wolff’s law. In a sound horse with one foot that is much more upright than the other, the flexor cortex of the more upright foot is often thinner than the contralateral foot (Fig 18a).

In one form of navicular disease there is progressive thickening of the cortices of the bone and the trabeculae of the spongiosa (Wright et al. 1998). Abnormal thickness of the flexor cortex of the navicular bone probably reflects pathological change (Figs 18b and c).

**Sclerosis of the spongiosa**

A normal navicular bone has a regular trabecular architecture that is clearly defined from the dorsal and palmar cortices in both LM and PaPr-PaDiO views. In one form of navicular disease there is generalised sclerosis of the spongiosa,
involving particularly the middle third of the bone from laterally to medially. This can also develop as a sequel to acute trauma to the bone (Fig 19a). However, a thick overlying frog can create increased opacity in this region and this should be differentiated from genuine sclerosis. Alternatively sclerosis may be localised towards the palmar aspect of the bone, affecting the endosteal aspect of the flexor cortex (Fig 19b). This can be seen in association with abnormal thickness of the cortices of the bone, and may be associated with a defect in the flexor cortex not detectable radiographically.

Corticotrabeular demarcation

Demarcation between the spongiosa and the flexor cortex of the navicular bone must be assessed from both LM and PaPr-PaDiO views. However, it must be borne in mind that

Fig 19a: Palmaroproximal-palmarodistal oblique radiographic view of a navicular bone. There is increased opacity of the middle third of the spongiosa of the bone. This was associated with focal intense increased radiopharmaceutical uptake. There had been acute onset severe lameness 8 weeks previously. No radiographic abnormality was present 4 days after the onset of lameness. This sclerotic reaction is thought to reflect the response to focal trauma to the bone. Care should be taken not to confuse increased radiopacity associated with the overlying frog with genuine sclerosis.

Fig 19b: Lateromedial radiographic view of a foot with a pathologically thick flexor cortex of the navicular bone. There is poor demarcation between the flexor cortex and the trabecular bone of the spongiosa. Note the distal extension of the flexor cortex of the bone and the large fossa on the distal aspect of the bone.

Fig 19bi: Palmaroproximal-palmarodistal oblique radiographic view of the same foot as Figure 19b, with a pathologically thick flexor cortex of the navicular bone and marked endosteal sclerosis. There was a partial thickness flexor cortex defect that was not detectable radiographically.

Fig 20a: Lateromedial radiographic view of a navicular bone with a large proximal entheseophyte (arrow).

Fig 20b: Lateromedial radiographic view of a navicular bone with a small proximal entheseophyte (arrow).

Fig 20c: Lateromedial radiographic view of a navicular bone with proximal and distal extension of the flexor cortex of the navicular bone. Note the large fossa in the distal aspect of the bone.
positioning of the foot during image acquisition may influence the appearance of the navicular bone in the skyline projection, and give a false impression of trabecular sclerosis. The 2 views should be compared carefully (Figs 3 and 19).

**Distal or proximal extension of flexor border**

The shape of the navicular bone should be assessed carefully in a LM view (Verschooten et al. 1989). Distal extension of the flexor border of the navicular bone may reflect chronic stress at the origin of the DSIL (Figs 20a, c and d). Proximal extension of the flexor border of the navicular bone may reflect chronic stress at the insertion of the CSLs (Figs 20b, c and d).

**Enthoseophytes**

Enthoseophytes at the proximal medial and lateral aspects of the navicular bone are best identified in DPr-PaDiO or DPa views. Small lateral enthesophytes are a common incidental abnormality and presumably reflect asymmetric stress at the insertion of the lateral and medial CSLs. However, the presence of a large lateral enthesophyte, or a medial enthesophyte, is more likely to reflect abnormal stress on the podotrochlear apparatus, and potentially to be associated with lameness (Figs 5, 21a and b).

**Periarticular osteophytes**

The navicular bone is part of the distal interphalangeal (DIP) joint. An osteophyte on the dorsoproximal aspect of the navicular bone may be identified as an osteophyte on the distolateral aspect of the distal phalanx (Figs 23).

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*Fig 20d: Lateromedial radiographic view of a navicular bone with proximal and distal extension of the flexor cortex of the navicular bone. There were also biaxial distal border fragments seen in a dorsoproximal-palmarodistal oblique view.*

*Fig 21a: Dorsopalmar radiographic view of a foot. Medial is to the left. There is a moderately sized enthesophyte on the proximomedial aspect of the navicular bone. Medial enthesophytes are not a normal finding. There is also moderate symmetrical ossification of the cartilages of the foot.*

*Fig 21b: Dorsoproximal-palmarodistal oblique radiographic view of a navicular bone with a large enthesophyte proximolaterally. This is not normal. There are also several variably shaped and sized lucent zones along the distal border of the bone.*

*Fig 22: Lateromedial radiographic view of a foot. There is a large osteophyte on the proximodorsal aspect of the navicular bone (arrow), in association with periarticular modelling of the distal dorsal aspect of the middle phalanx and the proximodorsal aspect of the distal phalanx (arrowheads).*

*Fig 23: Lateromedial radiographic view of a right front foot of a 5-year-old Warmblood with severe bilateral forelimb lameness. The distal aspect of the navicular bone is unusually close to the distal phalanx. There is distal extension of the flexor cortex of the navicular bone, which is also thickened. There is a small periarticular osteophyte on the dorsoproximal aspect of the navicular bone. There is modelling of the extensor process of the distal phalanx. A large lateral enthesophyte, biaxial distal border fragments and sclerosis of the spongiosa of the navicular bone were seen in other radiographic views. There was also modelling of the distal dorsal lateral aspect of the middle phalanx and narrowing of the DIP joint space laterally, consistent with osteoarthritis of the DIP joint.*
navicular bone seen in a LM view is likely to reflect disease of the DIP joint, which can occur alone or in association with navicular disease (Fig 22).

**Position of the navicular bone**

The position of the navicular bone in a LM radiograph relative to the middle and distal phalanges is partly influenced by the position of the limb during image acquisition. However, occasionally the bone is abnormally close to the distal phalanx. This has been seen in young horses with lameness recognised soon after the introduction of work and has generally been associated with advanced pathological changes of the navicular bone and the DIP joint (Fig 23). This may reflect a congenital abnormality.

**Fracture of the navicular bone**

Fractures of the navicular bone are usually parasagittal and are seen in the acute phase as one or 2 radiolucent lines traversing the bone obliquely from proximal to distal (Fig 24a). In more chronic fractures radiolucent zones develop along the fracture line, which may be quite broad (Fig 24b). Less commonly other configurations of fracture occur.

**Bipartite navicular bone**

Rarely the navicular bone develops as 2 separate centres of ossification that never unite by osseous union. This may occur unilaterally or bilaterally. There is a broad, well-defined lucent line between the 2 pieces. If unstable, secondary lucent areas may develop along the borders of the lucent line. A bipartite navicular bone may be identified in a clinically normal horse, but such horses may experience episodic lameness if in full athletic function (Fig 25). However, in contrast to a fracture, there is not a history of acute onset severe lameness.

**Proximal displacement of the navicular bone secondary to rupture of the DSIL**

A rare injury, to date recorded only in steeplechase horses, is proximal displacement of the navicular bone, secondary to rupture of the DSIL (Heitzmann and Denoix 2007). This occurs predominantly in hindlimbs.

**Hindlimb navicular bone lesions**

Navicular disease is not exclusive to forelimbs and is occasionally seen in hindlimbs either unilaterally or bilaterally. Rarely this has been seen in association with unusual proximity between the navicular bone and the distal phalanx, suggestive of a congenital abnormality.

**Conclusion**

There are a variety of radiographic abnormalities of the navicular bone that are potentially detectable, provided that...
the radiographs are of high quality and are appropriately positioned. There is some degree of variation of the architecture of the navicular bone in clinically normal horses, but some abnormalities, even when subtle, can reflect severe pathology. The absence of significant radiological changes does not mean that the navicular bone is structurally normal, or preclude the bone as a potential source of pain causing lameness.

References


