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Original Article

The angle contrast ultrasound technique in the flexed limb improves assessment of proximal suspensory ligament injuries in the equine pelvic limb

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Summary

Diagnosis of proximal suspensory ligament (PSL, third interosseous muscle) injuries in equine hindlimbs can be challenging because of the complex anatomy of the proximal metatarsal region. Ultrasonographic examination of the PSL using the angle contrast ultrasound technique in the flexed limb facilitates assessment of PSL desmopathies and enthesopathies, with subjectively improved sensitivity compared with the standard approach. The main limitation of ultrasonography is identification of deep osseous injuries, but combined with other imaging procedures, ultrasonography provides valuable diagnostic information of the injured structures. Ultrasonography also helps to specify the stage of a lesion. The repair process can be monitored, helping the clinician to adapt the rehabilitation programme and establish a prognosis for the horse to return to its previous level.

Introduction

Proximal suspensory ligament (PSL, third interosseous muscle) desmopathy/enthesopathy is one of the most frequent conditions inducing hindlimb lameness in horses (Denoix *et al*. 1991; Dyson 1991, 2003a,b; Dyson and Genovese 2003) and often has a serious negative impact on the horses' careers.

The clinical and imaging diagnosis of this condition has been widely debated in the literature including the use of diagnostic analgesic techniques and imaging modalities such as ultrasonography (Denoix *et al*. 1991; Denoix and Farres 1995; Dyson 1998), nuclear scintigraphy (Dyson *et al*. 1995, 2007; Martin *et al*. 1995; Dyson 2003a; Denoix and Audigié 2004), magnetic resonance imaging (MRI) (Dyson 2003a,b; Schneider *et al*. 2005; Brokken *et al*. 2007; Labens *et al*. 2010) and computed tomography (Werpy and Denoix 2012). The normal architecture of the PSL has been described using histology and MRI in comparison with ultrasound scans performed using a plantar or a slight plantaromedial approach (Bischofberger *et al*. 2006; Schramme *et al*. 2012).

A technique describing a plantaromedial approach of the proximal metatarsus to improve visualisation of the PSL in the pelvic limb has been described (Denoix and Farres 1995). More recently it was shown that examination of the PSL in the flexed thoracic limb with different probe angulations improves imaging of its architecture (Denoix *et al*. 2008; Werpy and Denoix 2012; Werpy *et al*. 2013).

The purpose of this paper is to demonstrate: 1) how to examine the proximal metatarsus in the weightbearing and in the flexed limb using an angle contrast ultrasound technique (ACUST); and 2) that the use of ACUST in the flexed limb enhances ultrasonographic evaluation of the ultrasound architecture of the PSL and improves the capacity of ultrasonography to detect and document PSL lesions.

Basic anatomy

The main proximal attachment of the suspensory ligament (SL) is located on the proximoplantar aspect of the third metatarsal bone (MtIII; **Fig 1**). The most plantar layer of the PSL is a continuation of the distal plantar ligament of the tarsus providing also the origin of the accessory ligament of the deep digital flexor tendon (DDFT) (Barone 1989; Denoix 1994a; Bischofberger *et al*. 2006). Through the distal plantar ligament of the tarsus, the SL inserts indirectly on the first tarsal bone and third tarsal bone. The most proximal fibres of the distal plantar ligament insert medially on the *sustentaculum tali* and are laterally in connection with the long plantar ligament (**Fig 2**). These fibres cross the tarsometatarsal joint and are in contact with the plantar recesses of the joint (Barone 1989; Denoix 1994a). Medially, adjacent to the PSL, runs the large medial plantar metatarsal vein which provides drainage to the SL while blood supply comes from the plantar metatarsal arteries (**Fig 3a**). The PSL is innervated by the deep ramus of the lateral plantar nerve originating from the tibial nerve (Barone 1989; Denoix 1994a).

The PSL, along with the plantar metatarsal vessels and nerves, are confined against the third and between the second and fourth metatarsal bones (MtII and MtIV) by the deep plantar metatarsal fascia (**Fig 3a**). This fascia could be responsible for compartmental syndrome in cases of PSL enlargement (Denoix 2009).

On transverse anatomical sections, the PSL first appears narrow and oblong at the level of the tarsometatarsal joint, before getting shaped like a right-angled triangle at its attachment to the plantar cortex of MtIII (the right sided angle being between MtIII and MtIV). Distally, at the most proximal part of the body, the SL then becomes oval (Barone 1989). The PSL is mainly made of dense collagenous connective tissue (tendon) including 2 separate bundles made of fat, and containing striated muscles fibres, vessels and nerves (Denoix 2009; Schramme *et al*. 2012; Shikh Alsook *et al*. 2013). These bundles divide the PSL into a major dorsal sagittal tendinous part and a peripheral tendinous part with medial, plantar and lateral parts (**Fig 3b**). This complex architecture explains the heterogenous echogenicity of the PSL on transverse ultrasound scans using standard weightbearing approaches

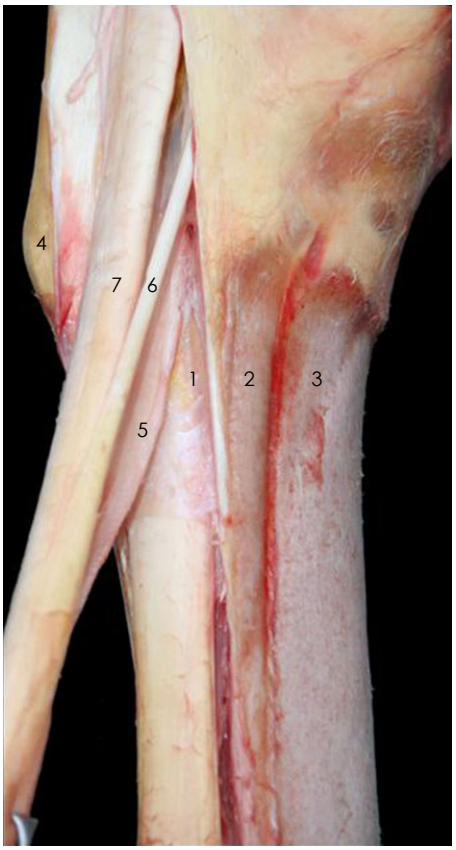

Fig 1: Dissected specimen showing the proximal suspensory ligament (PSL, third interosseus muscle); plantaromedial aspect. The main insertion takes place over the proximoplantar aspect of the third metatarsal bone. The most plantar layer of the proximal suspensory ligament PSL is a continuation of the distal plantar ligament of the tarsus providing also the origin of the accessory ligament of the deep digital flexor tendon. 1 = PSL; 2 = second metatarsal bone; 3 = third metatarsal bone; 4 = fourth metatarsal bone; 5 = accessory ligament of the deep digital flexor tendon; 6 = medial digital flexor tendon; 7 = lateral digital flexor tendon.

(Denoix and Farres 1995; Schramme *et al*. 2012) that hampers identification of lesions.

Equipment

Ultrasound scans of the hind PSL presented in this paper were acquired with 5–10 MHz linear and/or 3.5–7.5 MHz convex probes combined with a 5 mm stand-off pad for the weightbearing examination. To examine the PSL in the flexed limb, 5–10 MHz linear or curvilinear ('microconvex') probes were used. No stand-off pad was needed, the relaxed plantar soft tissues facilitating contact with the probe.

Technique and reference images

Horse preparation and positioning of the limb

The hair is clipped short from the chestnut to the middle of the metatarsus at the plantar and plantaromedial aspects of the limb. The skin is soaked with warm water and covered with acoustic gel. For the flexed examination, the limb is flexed and held with the foot placed forward on the operator's knees to be stabilised (**Fig 4**). In this position, the contralateral PSL could alternatively be imaged by crossing the limb under the

Fig 2: Dissected specimen showing the proximal suspensory ligament (PSL, third interosseus muscle); plantar aspect. The most plantar layer of the PSL is a continuation of the distal plantar ligament of the tarsus, which inserts on the* sustentaculum tali. *Laterally, it merges with the long plantar ligament. 1 = PSL; 2 = second metatarsal bone; 3 = third metatarsal bone; 4 = fourth metatarsal bone; 5 = accessory ligament of the deep digital flexor tendon (cut); 6 = distal plantar ligament; 7 = long plantar ligament; 8 = sustentaculum tali.

abdomen, moving neither the horse nor the machine. In order to increase sensitivity and specificity of the ultrasonographic diagnosis of PSL injuries, comparison to the contralateral limb should always be performed. These positions are well tolerated by most horses but care should be taken with difficult or dangerous horses.

Positioning of the probe

The PSL is examined on transverse sections using an oblique plantaromedial approach, from the distal row of the tarsus distally to the PSL body. Longitudinal sections are not considered in this paper that focuses on the ACUST technique.

Choice of the probe and of the limb position

In the weightbearing limb, a linear probe is used with an acoustic pad to improve contact with the skin, the profile of which appears concave on reference images. The ultrasound beam is nevertheless slightly oblique to the PSL and MtIII, and the axial border of MtII obscures partially the dorsomedial angle of the PSL. Convex probes can be used in the weightbearing limb with a more complete representation of the lateral and medial margins thanks to the trapezoidal shape of the ultrasound field. In addition, the beam is more perpendicular to MtIII, which appears more echogenic, facilitating detection of bone irregularities.

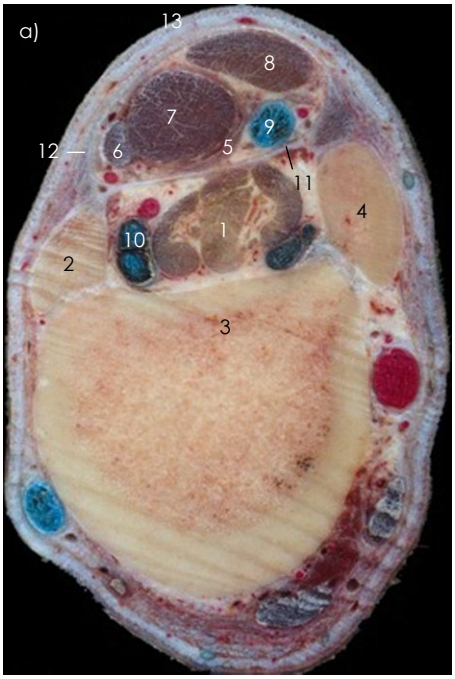

Fig 3: Transverse section of the proximal metatarsus (a) and transverse section highlighting the proximal suspensory ligament (b) confined against the third and between the second and fourth metatarsal bones by the deep plantar metatarsal fascia. The ligament consists of fibrous tissue, fat and striated muscle fibres (white stars). 1 = proximal suspensory ligament (third interosseous muscle): 1a = sagittal tendinous part; 1b = medial tendinous part; 1c = lateral tendinous part; 1d = plantar tendinous part; 2 = second metatarsal bone; 3 = third metatarsal bone; 4 = fourth metatarsal bone; 5 = accessory ligament of the deep digital flexor tendon; 6 = medial digital flexor tendon; 7 = lateral digital flexor tendon; 8 = superficial digital flexor tendon; 9 = lateral common digital vein; 10 = medial plantar metatarsal vein; 11 = deep plantar metatarsal fascia; 12 = plantar metatarsal fascia; 13 = skin.

A linear or microconvex probe can be used in the flexed limb. The short convex surface of the microconvex probe fits well the concave area imaged. It slides easily between MtII and the relaxed plantar soft tissues. In this way, the contact surface is extended and the ultrasound beam can be oriented more dorsally. Thus, examining the PSL in the flexed limb facilitates imaging of the entire ligament, the plantar aspect of MtIII and both intermetatarsal syndesmoses. In addition, flexion

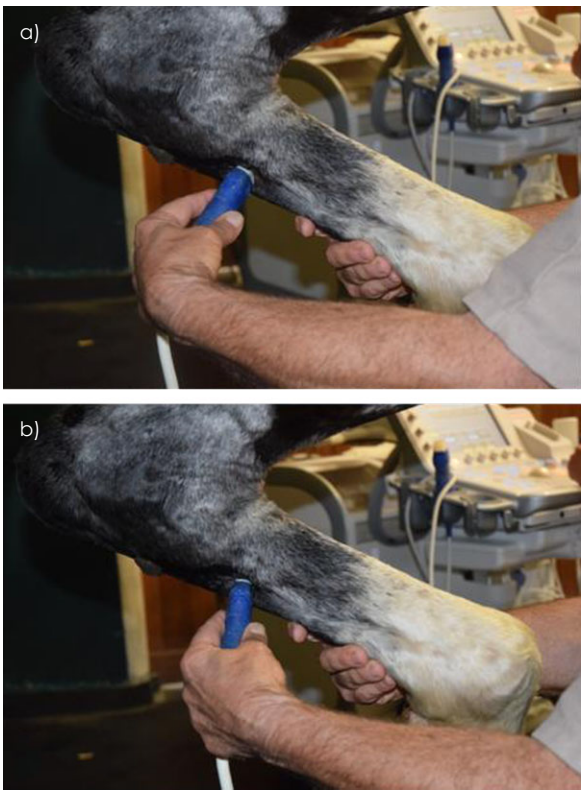

Fig 4: Position of the limb and the probe used for ultrasonographic examination of the proximal suspensory ligament in the equine pelvic limb using the angle contrast ultrasound technique in the flexed limb (left limb, medial aspect). The probe is placed on the plantaromedial aspect of the proximal metatarsal region. The angle contrast ultrasound technique is performed from the standard transverse section (a) perpendicular to the longitudinal axis of the proximal suspensory ligament by tilting the probe obliquely (b).

of the limb induces relaxation of the flexor tendons. Mild pressure to the probe then induces displacement of the flexor tendons, making the PSL much closer to the probe, which improves image resolution.

Angle contrast ultrasound technique – normal images

Angle contrast ultrasound techniques can be used whatever the probe, in either weightbearing or flexed limbs. This technique is performed from a standard transverse orientation, i.e. probe perpendicular to the longitudinal axis of the PSL ('positive image'; **Fig 4a**), by tilting the probe proximally or distally, i.e. probe oblique to the longitudinal axis of the PSL ('negative image'; **Fig 4b**) (Denoix *et al*. 2008; Denoix 2009, 2012; Werpy and Denoix 2012). Based on differences in isotropic properties of fat, tendon and peritendinous connective tissue, ACUST increases the ability to distinguish the shape of the PSL and its limits from the surrounding soft tissues (**Fig 5**). This technique also facilitates the imaging of the plantar aspect of MtIII together with the intermetatarsal syndesmosis, with either linear, convex or microconvex probes. By using ACUST, the outline of the PSL is clearer. The PSL distinctly appears triangular to oval on transverse ultrasound scans at the level of its enthesis on MtIII. It is slightly thicker laterally and medially adjacent to the large

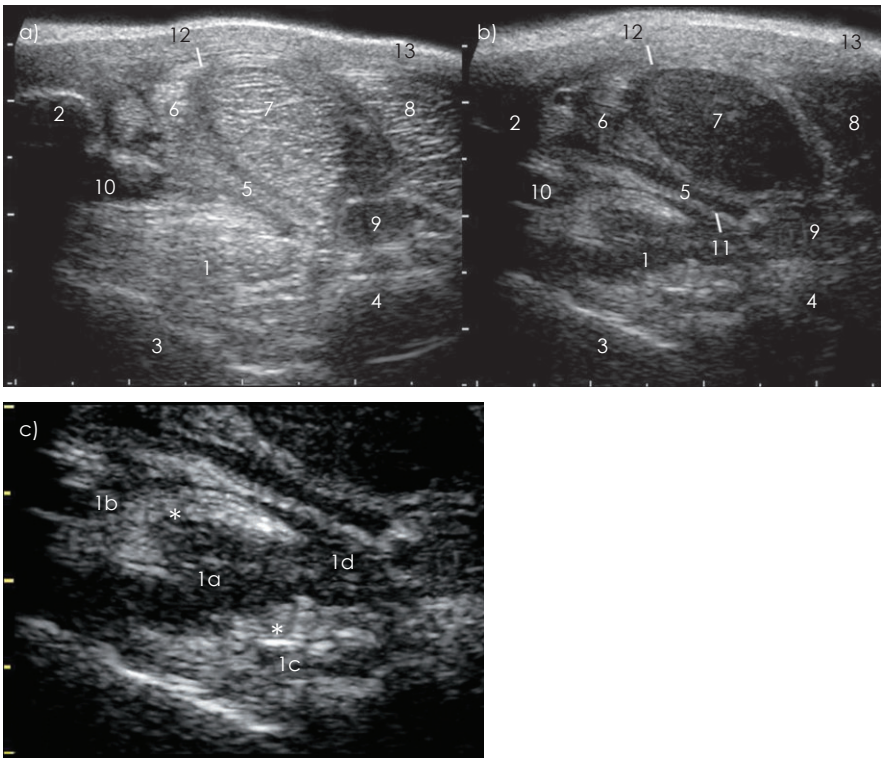

Fig 5: Transverse ultrasound scans of the proximal metatarsal region (medial is to the left) acquired with a linear probe in the weightbearing limb using perpendicular (a) and oblique (b) incidences, with (c) highlighting the proximal suspensory ligament. 1 = proximal suspensory ligament: white stars, fat bundles; 1a = sagittal tendinous part; 1b = medial tendinous part; 1c = lateral tendinous part; 1d = plantar tendinous part; 2 = second metatarsal bone; 3 = third metatarsal bone; 4 = fourth metatarsal bone; 5 = accessory ligament of the deep digital flexor tendon; 6 = medial digital flexor tendon; 7 = lateral digital flexor tendon; 8 = superficial digital flexor tendon; 9 = lateral common digital vein; 10 = medial plantar metatarsal vein; 11 = deep plantar metatarsal fascia; 12 = plantar metatarsal fascia; 13 = skin.

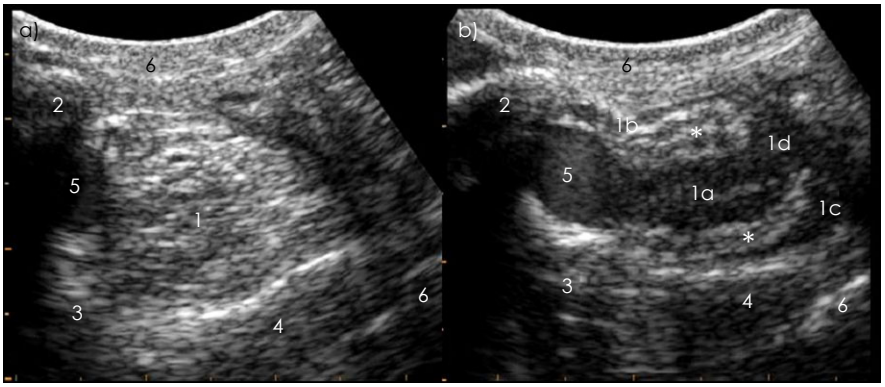

Fig 6: Transverse ultrasound scans of the proximal metatarsal region (medial is to the left) acquired with a microconvex probe in the flexed limb using perpendicular (a) and oblique (b) incidences. 1 = proximal suspensory ligament: white stars, fat bundles; 1a = sagittal tendinous part; 1b = medial tendinous part; 1c = lateral tendinous part; 1d = plantar tendinous part; 2 = second metatarsal bone; 3 = third metatarsal bone; 4 = fourth metatarsal bone; 5 = medial plantar metatarsal vein; 6 = skin.*

medial plantar metatarsal vein. It fits closely the lateral intermetatarsal syndesmosis without exceeding the plantar borders of MtII and MtIV on the most proximal images (**Fig 5**). Distally, where the PSL becomes detached from MtIII, the SL appears outlined on negative images with a clear oval shape (**Fig 6**), separated from the plantar cortex of MtIII by hypoechogenic connective tissue and vessels. The deep plantar metatarsal fascia adjacent to the plantar border of the PSL, and the accessory ligament of the DDFT, separated from the fascia by connective tissue are also highlighted on negative images (**Fig 5**).

Besides, ACUST improves imaging of the architecture of the PSL. It increases the ability to discriminate the various components of the PSL, the tendinous fibres becoming hypoechogenic and the fat content remaining echogenic. On reference negative images at the level of the enthesis on the proximal MtIII, the PSL shows 2 echogenic, lateral and medial, fat bundles with a characteristic crescent shape oriented in a dorsoplantar direction. These bundles divide the tendon tissue into one major central (sagittal) part and one thinner peripheral part. The peripheral part can further be divided in a medial part, a plantar part and a lateral part (**Fig 5c**). The size and shape of these different parts of the PSL present many individual variations.

Abnormal findings and lesions

Ultrasonographic findings compatible with PSL injuries include thickening, changes in echogenicity and architecture, and alteration of the enthesial bone surface. Nevertheless, assessment of these changes is challenging when a plantar approach is used. Enlargement of the SL can be suspected when the skin is convex or when the medial plantar metatarsal vein is collapsed (**Fig 7**). As there is much individual variation within breeds and sizes of horses, measurement of the cross-sectional area (CSA) of the PSL does not provide reliable information. As the different anatomical structures of the same

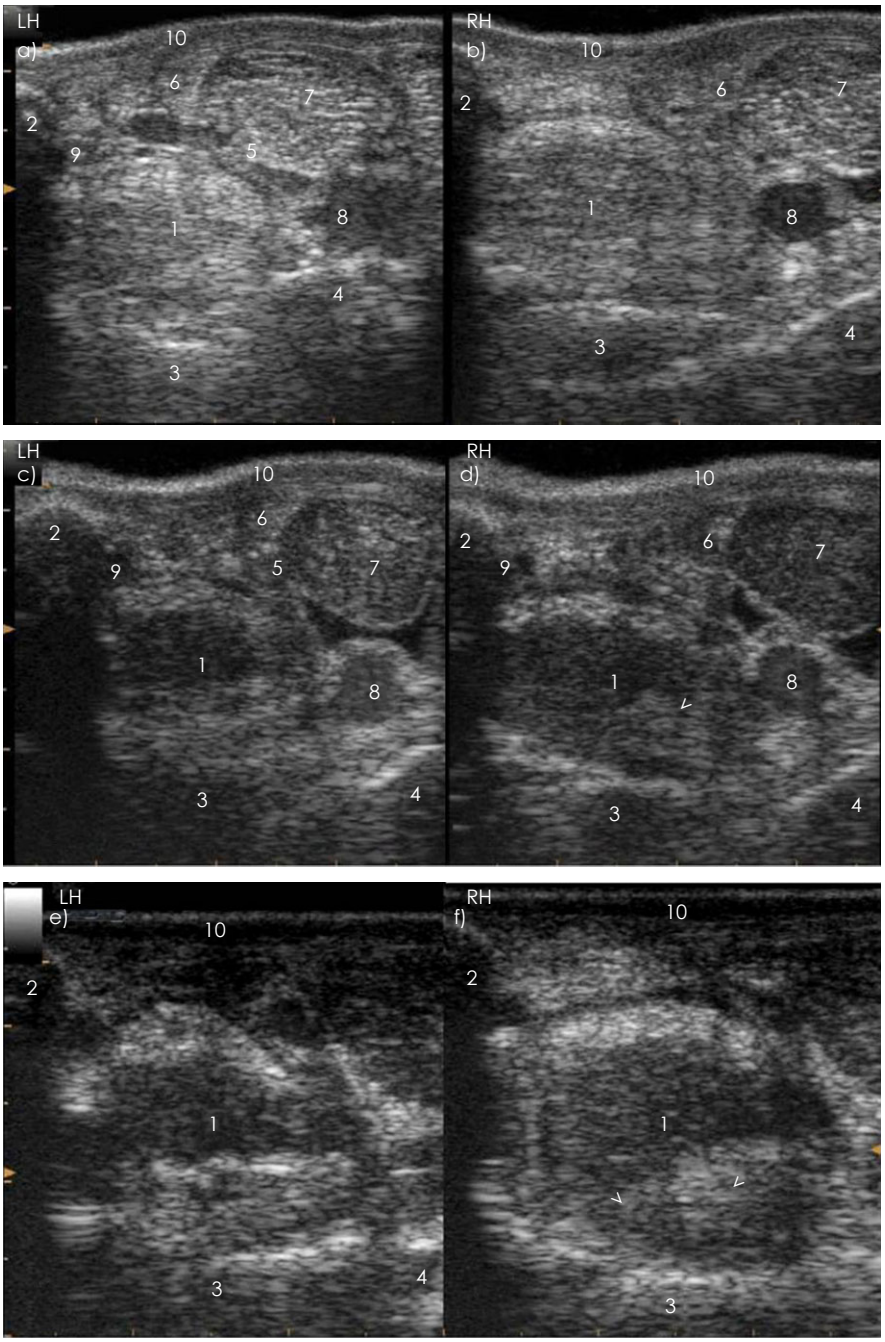

Fig 7: Comparative transverse ultrasound scans of the left (LH) and right (RH) proximal metatarsal region (medial is to the left) of the same mare presenting chronic hindlimb lameness. Images were acquired with a linear probe in weightbearing limbs, using perpendicular (a and b) and oblique (c–f) incidences, with (e and f) focused on the proximal suspensory ligament (PSL). The PSL is more enlarged on the RH than on the LH and the plantar metatarsal vein is collapsed on both LH and RH. The oblique incidences show that the sagittal tendinous part of the PSL is enlarged (more severe on the RH) with a collapse of the lateral fat bundle. There is an increased echogenicity (d–f) of the sagittal tendinous part (arrowheads) compared to normal tendon, consistent with fibrous tissue (scar). 1 = proximal suspensory ligament; 2 = second metatarsal bone; 3 = third metatarsal bone; 4 = fourth metatarsal bone; 5 = accessory ligament of the deep digital flexor tendon; 6 = medial digital flexor tendon; 7 = lateral digital flexor tendon; 8 = lateral common digital vein; 9 = medial plantar metatarsal vein; 10 = skin.

limb are supposed to be affected the same way by breed and size variations, the size of the PSL can be compared to the adjacent deep digital flexor structures (lateral and medial digital flexor tendons together with the accessory ligament of the DDFT). The normal PSL has approximately the same size as the whole deep digital flexor structures (**Fig 5**). When enlarged, the CSA of the PSL is clearly larger (**Fig 7**). Moreover, some asymmetry may be seen between left and right hind PSL in the same horse without ligamentous disease.

Detection of subtle abnormalities can, however, be challenging, especially as lesions are often bilateral, complicating comparison to the contralateral limb (**Fig 7**). Angle contrast ultrasound technique is a technique allowing a more accurate detection of subtle enlargements without clear global thickening of the PSL, nor collapse of the medial plantar metatarsal vein (**Fig 8**). In proximal enthesopathies and desmopathies, ACUST demonstrates clearly that the main sagittal tendinous part of the PSL is enlarged and induces collapse of the medial and/or lateral fat bundles (**Fig 8**). In addition, for dorsal lesions, the medial and lateral edges of this sagittal part are no longer parallel (**Fig 6**) but divergent dorsally (**Fig 8c** and **d**); for axial lesions, the distance between the 2 fat bundles increases. Detection of these changes is even easier in the flexed limb, the probe being oriented more dorsally (**Fig 8c** and **d**). Lesions of the plantarolateral tendinous part are also more easily identified using ACUST in the flexed limb

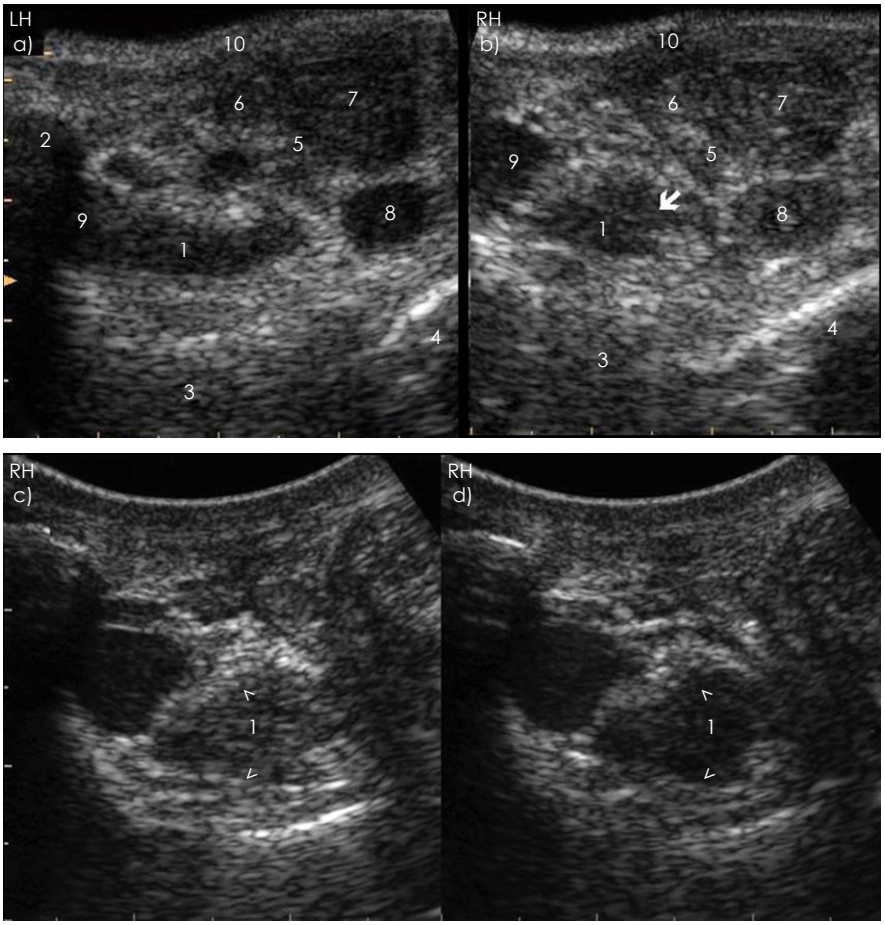

Fig 8: Comparative transverse ultrasound scans of the left (LH) and right (RH) proximal metatarsal region (medial is to the left) of the same sound horse. Images were acquired with a linear probe on weightbearing limbs (a and b) and with a microconvex probe in the RH flexed limb (c and d), using perpendicular (c) and oblique (a, b and d) incidences. Images show subclinical changes of the proximal suspensory ligament (PSL). The sagittal tendinous part of the RH PSL appears enlarged (arrow) without clear global enlargement of the PSL nor collapse of the plantar metatarsal vein. Fat bundles are collapsed and divergent (arrowheads). 1 = proximal suspensory ligament; 2 = second metatarsal bone; 3 = third metatarsal bone; 4 = fourth metatarsal bone; 5 = accessory ligament of the deep digital flexor tendon; 6 = medial digital flexor tendon; 7 = lateral digital flexor tendon; 8 = lateral common digital vein; 9 = medial plantar metatarsal vein; 10 = skin.

(**Fig 9**). In addition, using ACUST, true enlargement of the PSL can be differentiated from perilagamentous fibrosis and deep plantar metatarsal fascia enlargement seen in chronic lesions. Further, ACUST is a key technique to assess the evolution stage of a lesion. A diffuse loss of echogenicity of the PSL is generally observed on positive images whatever the stage of the lesion (**Fig 7a** and **b**). Old or chronic lesions remain hypoechogenic for months or even years. On negative images, acute and subacute lesions become less echogenic than normal tendon while old or chronic lesions may be more echogenic because of the presence of scar tissue (**Figs 7d–f** and **10a**). Reduction of the PSL CSA and improvement in architecture and echogenicity with even reduction of enthesophytes can also be seen when monitoring the repair of the ligament. Irregularities of the plantar aspect of MtIII consistent with PSL enthesopathies as well as hyperechogenic material casting an acoustic shadow (avulsion fracture or dystrophic mineralisation) are also highlighted on negative images, even more in the flexed limb, as the probe is more perpendicular to the plantar aspect of MtIII (**Fig 10b**).

Discussion

Technique

Improvements in ultrasound technique and equipment, as well as the advancing knowledge of anatomy, architecture and histology, have increased the diagnostic value of ultrasonography. A plantar approach of the limb was used in the first papers describing PSL injuries (Denoix *et al*. 1991; Dyson 1991). A plantaromedial approach of the proximal metatarsus was shown to improve and complete imaging of the PSL in the weightbearing limb (Denoix and Farres 1995). Then, using this approach, the ACUST was demonstrated to improve imaging of the architecture of the PSL (Denoix 2009). Having been performed for more than 5 years, we consider that the ACUST in the flexed limb is the safest and most reliable ultrasound technique for assessment of PSL enthesopathies and desmopathies. In order to detect subtle changes, detailed evaluation of the size, shape, margins and echogenicity of the different architectural components (sagittal and peripheral tendinous parts as well as lateral and medial fat bundles) of the ligament should be undertaken.

Ultrasonographic examination of the PSL in the flexed limb improves image resolution resulting in a higher definition of the PSL architecture and margins. By displacing the plantar soft tissues and vasculature, flexion also reduces edge artefacts which could mislead the operator on true lesions. It further extends the representation of PSL and facilitates evaluation of its relationships with MtIII and intermetatarsal syndesmoses. In addition, the flexed technique is well tolerated by the horse, comfortable for the operator and safer, as the operator is placed at the dorsal aspect of the limb, towards the front.

Combined/comparative imaging

Achieving accurate lameness diagnosis is the key to adapt a horse's management, choose the appropriate corrective

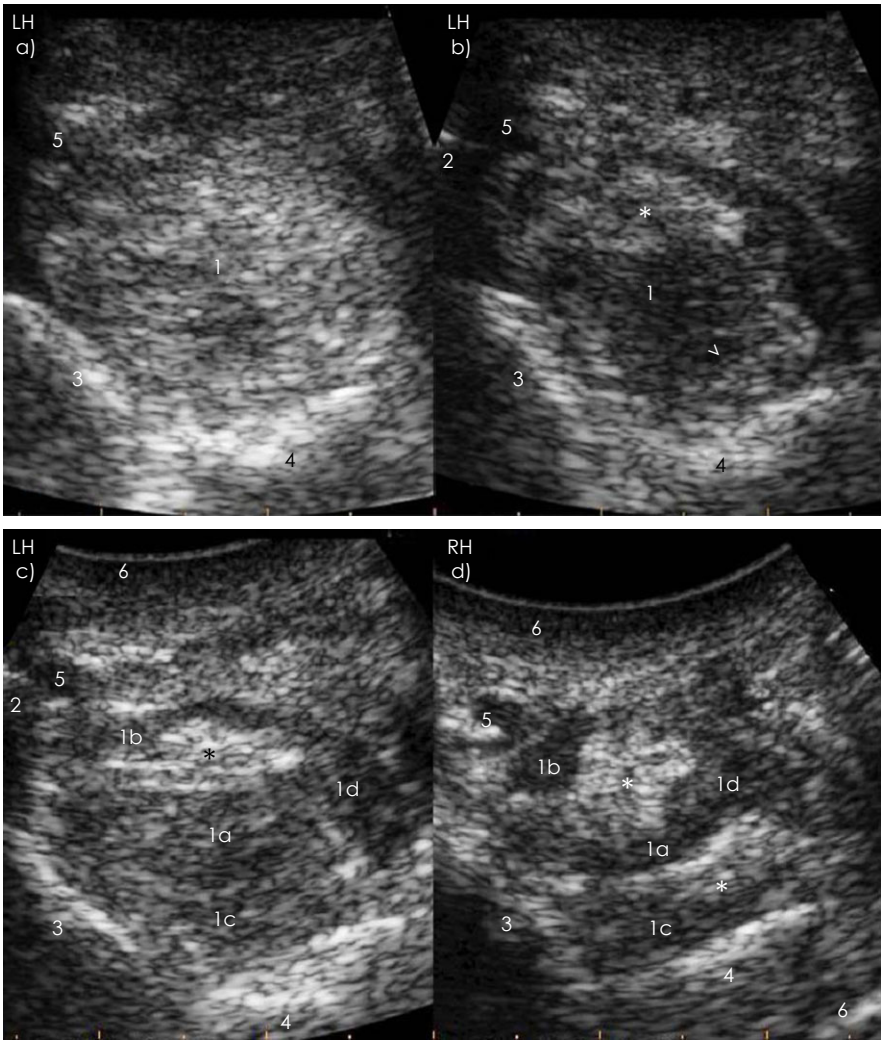

Fig 9: Comparative transverse ultrasound scans of the left (LH) and right (RH) proximal metatarsal region (medial is to the left) of the same horse presenting chronic hindlimb lameness. Images were acquired with a microconvex probe in the flexed limb, using perpendicular (a) and oblique (b–d) incidences. On oblique images (b and c), the plantarolateral tendinous part of the LH proximal suspensory ligament appears enlarged with a collapse of the lateral fat bundle (arrowheads). 1 = proximal suspensory ligament: white stars, fat bundles; 1a = sagittal tendinous part; 1b = medial tendinous part; 1c = lateral tendinous part; 1d = plantar tendinous part; 2 = second metatarsal bone; 3 = third metatarsal bone; 4 = fourth metatarsal bone; 5 = medial plantar metatarsal vein; 6 = skin.

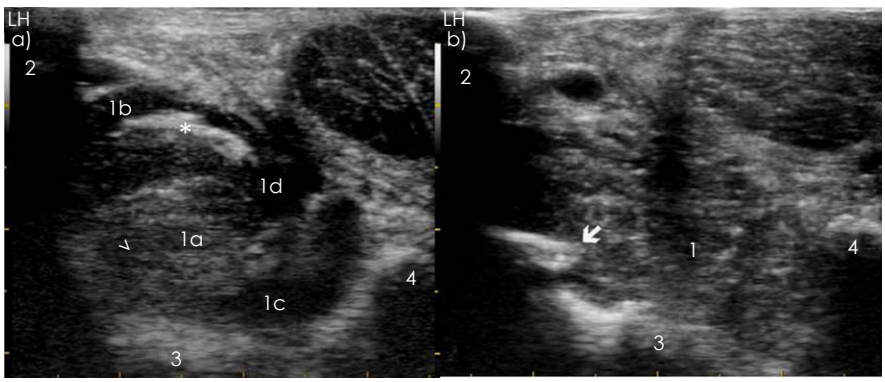

Fig 10: Transverse ultrasound scans of the left (LH) proximal metatarsal region (medial is to the left) acquired with a linear probe in the flexed limb with an oblique incidence, on a horse presenting a chronic left hind lameness. There is clear increased echogenicity of the sagittal tendinous part (arrowhead) compared to normal tendon, consistent with fibrous tissue (scar), and the lateral fat bundle is collapsed (a). There are irregularities of the plantar aspect of the third metatarsal bone with an enthesophyte (arrow) (b). 1, = proximal suspensory ligament: white stars = fat bundles; 1a = sagittal tendinous part; 1b = medial tendinous part; 1c = lateral tendinous part; 1d = plantar tendinous part; 2 = second metatarsal bone; 3 = third metatarsal bone; 4 = fourth metatarsal bone.

shoeing and establish a prognosis. Diagnostic of PSL injuries remains, however, challenging in clinical practice. Physical and dynamic examinations are sometimes unrewarding and false positive and false negative responses to diagnostic analgesic techniques are not unusual (Dyson 2003a,b). Radiography and nuclear scintigraphy have been proven helpful in detecting bone changes such as avulsion fractures or enthesopathies, bringing complementary information to soft

tissue lesions (Denoix and Audigié 2004). However their sensitivity and specificity is low and some reports have shown their limited value in the diagnosis of PSL injuries (Dyson 2003a,b; Brokken *et al*. 2007). Ultrasonography has been proven particularly helpful in the diagnosis of soft tissue injuries (Genovese *et al*. 1986; Denoix 1994b, 1998). This technique is widely available, noninvasive and can be performed in the field with portable machines, which is particularly useful to monitor repair and adapt the rehabilitation programme. However, the complex anatomy of the proximal metatarsal region creates various artefacts and limits visualisation of the PSL using a standard approach. Interpretation of images was reported to be confounding in many papers, with low specificity and sensitivity of the standard technique. (Dyson 2003a,b; Bischofberger *et al*. 2006; Labens *et al*. 2010; Schramme *et al*. 2012). As previously demonstrated in forelimbs (Denoix *et al*. 2008; Werpy *et al*. 2013), this paper indicates that ACUST and examination of the PSL in the flexed limb enhance standard ultrasonographic examinations of the PSL, thereby improving the accuracy of the technique. On the basis of this technique the contrast between the different intraligamentous components and between the PSL and the surrounding tissues is highlighted, facilitating the detection of scar tissue. A better correlation between MRI and ultrasonographic findings can thus be obtained (Werpy *et al*. 2013).

Magnetic resonance imaging is considered as the gold standard imaging technique to identify PSL lesions (Dyson 2003a; Bischofberger *et al*. 2006; Brokken *et al*. 2007; Labens *et al*. 2010; Schramme *et al*. 2012). It combines excellent soft tissue contrast and the ability to detect bone lesions. This 3D modality combining various contrasts brings additional data on the extent, nature and stage of the lesion. Magnetic resonance imaging is the only method allowing detection of bone-marrow oedema-like lesions. Such lesions affecting the SL proximal enthesis can cause clinical signs despite no ultrasonographic or radiographic abnormality (Werpy and Denoix 2012). Imaging of the proximal plantar metatarsal region has nevertheless only been described using high field magnets, with general anaesthesia, cost and low availability as constraints, limiting its use in current equine practice. Similar concerns affect computed tomography, which can be used to detect PSL injuries with a highly detailed cross-sectional representation of bone, but soft tissue contrast is lower than with MRI and bone marrow oedema-like lesions cannot be detected. Standing MRI can alternatively be performed on clinical cases to avoid those constraints, but the procedure is challenging and depends on the horse's behaviour and stability. Resolution of images is inferior and many artefacts can limit image interpretation.

Conclusion

ACUST improves ultrasound evaluation of the architecture of the PSL and its limits from surrounding soft tissue. This technique is likely to increase the sensitivity of ultrasonography to detect and document PSL lesions. ACUST can further easily be used to follow-up healing of PSL lesions. This follow-up is essential to adapt the rehabilitation programme and establish the prognosis for the horse to return to its previous performance level.

Authors' declaration of interests

No conflicts of interest have been declared.

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References

Barone, R. (1989) *Anatomie comparée des mammifères domestiques*, Tome second Arthrologie et Myologie, Ed: R. Barone, Editions Vigot, Paris.

Bischofberger, A.S., Konar, M., Ohlerth, S., Geyer, H., Lang, J., Ueltschi, G. and Lischer, C.J. (2006) Magnetic resonance imaging, ultrasonography and histology of the suspensory ligament origin: a comparative study of normal anatomy of Warmblood horses. *Equine Vet. J.* **38**, 508-516.

Brokken, M.T., Schneider, R.K., Sampson, S.N., Tucker, R.L., Gavin, P.R. and Ho, C.P. (2007) Magnetic resonance imaging features of proximal metacarpal and metatarsal injuries in the horse. *Vet. Radiol. Ultrasound* **48**, 507-517.

Denoix, J.-M. (1994a) Functional anatomy of tendons and ligaments in the distal limbs (manus and pes). *Vet. Clin. North Am.: Equine Pract.* **10**, 273-322.

Denoix, J.-M. (1994b) Diagnostic techniques for identification and documentation of tendon and ligament injuries. *Vet. Clin. North Am.: Equine Pract.* **10**, 365-407.

Denoix, J.-M. (1998) Joints and miscellaneous tendons. In: *Equine Diagnostic Ultrasonography*, Eds: N. Rantanen and A. McKinnon, Williams and Wilkins, Baltimore. p 475.

Denoix, J.-M. (2009) Ultrasonographic examination – Metatarsus. In: *Proceedings of the sixth ISELP module: The equine distal hind limb (metatarsus and digit)*, Fairefield Equine, Connecticut.

Denoix, J.-M. (2012) Angle contrast ultrasound technique (ACUST) improves diagnosis and prognosis of tendon and ligaments injuries. In: *Proceedings of the Havemeyer Symposium 2012, Estes Park, Colorado*, pp 35-36.

Denoix, J.-M. and Audigié, F. (2004) Imaging of the musculoskeletal system in horses. In: *Equine Sports Medicine and Surgery: Basic and Clinical Science of Equine Athlete*, Eds: K.W. Hinchcliff, A.J. Kaneps and R.J. Geor, Saunders, Elsevier Ltd, Philadelphia. pp 161-187.

Denoix, J.-M., Coudry, V. and Jacquet, S. (2008) Ultrasonographic procedure for a complete examination of the proximal third interosseous muscle in the equine forelimbs. *Equine Vet. Educ.* **20**, 148-153.

Denoix, J.-M. and Farres, D. (1995) Ultrasonographic imaging of the proximal third interosseous muscle in the pelvic limb using a plantaromedial approach. *J. Equine Vet. Sci.* **15**, 346-350.

Denoix, J.-M., Perrot, P. and Bousseau, B. (1991) Images échographiques des lésions du muscle interosseux III (ligament suspenseur du boulet). *Prat. Vét. Équine* **23**, 23-33.

Dyson, S.J. (1991) Proximal suspensory desmitis: clinical, ultrasonographic and radiographic features. *Equine Vet. J.* **23**, 25-31.

Dyson, S.J. (1998) The suspensory apparatus. In: *Equine Diagnostic Ultrasonography*, Eds: N. Rantanen and A. McKinnon, Williams and Wilkins, Baltimore. p 447.

Dyson, S.J. (2003a) Proximal metacarpal and metatarsal pain: a diagnostic challenge. *Equine Vet. Educ.* **15**, 134-138.

Dyson, S.J. (2003b) The metacarpal region. In: *Diagnosis and Management of Lameness in the Horse*, Eds: M.W. Ross and S.J. Dyson, W.B. Saunders, Philadelphia. pp 362-376.

Dyson, S.J., Arthrur, R., Palmer, S. and Richardson, D. (1995) Suspensory ligament desmitis. *Vet. Clin. North Am.: Equine Pract.* **11**, 117-215.

Dyson, S.J. and Genovese, R. (2003) The suspensory apparatus. In: *Diagnosis and Management of Lameness in the Horse*, Eds: M.W. Ross and S.J. Dyson, W.B. Saunders, Philadelphia. pp 654-672.

Dyson, S.J., Weekes, J.S. and Murray, R.C. (2007) Scintigraphic evaluation of the proximal metacarpal and metatarsal regions of horses with proximal suspensory desmitis. *Vet. Radiol. Ultrasound* **48**, 78-85.

Genovese, R.L., Rantanen, N.W., Hauser, M.L. and Simpson, B.S. (1986) Diagnostic ultrasonography of equine limbs. *Vet. Clin. North Am.: Equine Pract.* **2**, 145-226.

Labens, R., Schramme, M.C., Robertson, I.D., Thrall, D.E. and Redding, W.R. (2010) Clinical, magnetic resonance, and sonographic imaging findings in horses with proximal plantar metatarsal pain. *Vet. Radiol. Ultrasound* **51**, 11-18.

Martin, F., Herthel, D.-J. and Snow, V. (1995) Scintigraphie osseuse et diagnostic des desmites proximales du muscle interosseux III chez le cheval: à propos de 28 cas (1990-1992). *Point Vet.* **26**, 1061-1067.

Schneider, R.K., Sampson, S.S. and Gavin, P.R. (2005) Magnetic resonance imaging evaluation of horses with lameness problems. *Proc. Am. Ass. Equine Practnrs.* **51**, 21-34.

Schramme, M., Josson, A. and Linder, K. (2012) Characterization of the origin and body of the normal equine rear suspensory ligament using ultrasonography, magnetic resonance imaging, and histology. *Vet. Radiol. Ultrasound* **53**, 318-328.

Shikh Alsook, M.K., Antoine, N., Piret, J., Moula, N., Busoni, V., Denoix, J.M. and Gabriel, A. (2013) Morphometric analyses of the body and the branches of the normal third interosseous muscle (suspensory ligament) in Standardbreds. *Anat. Histol. Embryol.* **42**, 461-470.

Werpy, N.M., Denoix, J.M., McIlwraith, C.W. and Frisbie, D.D. (2013) Comparison between standard ultrasonography, angle contrast ultrasonography, and magnetic resonance imaging characteristics of the normal equine proximal suspensory ligament. *Vet. Radiol. Ultrasound* **54**, 536-547.

Werpy, N.M. and Denoix, J.-M. (2012) Imaging of the equine proximal suspensory ligament. *Vet. Clin. North Am.: Equine Pract.* **28**, 507-525.