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Precision of ultrasonographic measurements of the suspensory apparatus of fetlock in the horse

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Für meine Eltern

I Contents

1 Introduction

The suspensory apparatus (SA) is part of the passive stay apparatus, which allows the horse to be in a standing position for long periods of time in a very energy efficient manner. Since most of the horses` weight rests on its tendons and ligaments, the requirement for muscular energy is minimal (Budras *et al*. 2003; Dyce *et al.* 2010). The most important function of the SA is to prevent the fetlock and pastern from overextension especially during the stance phase of the stride (Denoix 1994).

To the horses` SA belong the suspensory ligament (SL), the distal sesamoidean ligaments (DSL), the intersesamoidean ligament and the proximal sesamoidean bones (PSBs) (Barone 1989). The SL can be further divided into three areas: the origin, the body and the branches (Dyson and Genovese 2010). In the forelimb, the suspensory ligament has its origin in the proximal palmar aspect of the third metacarpal bone and the distal row of the carpal bones. In the hindlimb, it arises from the distal row of tarsal bones and from the proximal plantar aspect of the third metatarsal bone (Gibson and Steel 2002). Recently, an additional portion originating from the calcaneus has been reported (Schulze 2007, Schulze and Budras 2008). The body of the SL descends further between the splint bones and divides into a medial and lateral branch of the SL (Dyce *et al.* 2010). Each branch inserts on its corresponding proximal sesamoid bone and detaches a thin extensor branch to the common extensor tendon (Budras *et al*. 2003; Dyce *et al.* 2010). In the pastern the distal DSL are the functional continuation of the SL. The DSL are the short, cruciate, oblique (oDSL) and straight sesamoidean ligament (sDSL). They have their origin in the PSBs. The straight sesamoidean ligament inserts in the middle phalanx and the other three insert in the proximal phalanx (Budras *et al*. 2003).

Lameness originating from the proximal suspensory ligament (PSL) is common in horses (Dyson 1991; Dyson 2003). Lameness originating from the body and branches of the SL and the DSL has also been described (Dyson and Genovese 2010; Sampson *et al.* 2007; Smith *et al.* 2008 b; Carnicer *et al.* 2012). Diagnosis of pathological changes in the suspensory apparatus can be challenging. During the lameness examination flexion tests and diagnostic analgesia help to locate the site of pain. For further diagnosis different imaging methods are used.

Radiography is used to detect avulsion fractures at the origion of the SL as well as sclerotic changes in the bone that may be associated with proximal suspensory ligament desmitis (PSD). For example avulsion fractures occur in the origin or insertion of the ligaments of the suspensory apparatus. Moreover, in the ligaments of the SA dystrophic calcification is visible in radiographic images (Lischer *et al.* 2006). In some chronic cases of proximal suspensory ligament desmitis (PSD) areas of increased radiopacity are visible in the palmar/plantar aspect of the metacarpal/-tarsal (MC, MT) III. Most likely this is caused by entheseous new bone (Dyson and Murray 2012).

Nuclear scintigraphy images reveal an increased radiopharmaceutical uptake, which is associated with an increased bone turnover. Therefore, scintigraphy can be very helpful to detect bony pathologies like fractures, fissures, avulsion fractures and entheseous new bone. In the proximal MC III, MT III cases with an increased radiopharmaceutical uptake, but no ultrasonographic or radiographic abnormalities of the SL have been described (Dyson *et al.* 2007 a; Dyson 2007 b). It is not clear whether it is PSD or a primary bony pathology (Lischer *et al.* 2006). Therefore, scintigraphy is considered a not sensitive method of detecting PSD (Dyson *et al.* 2007 a; Dyson 2007 b).

Magnetic resonance imaging (MRI) is considered a very sensitive imaging method for detecting changes in the PSL (Dyson and Genovese 2010; Lischer *et al.* 2006; Dyson and Murry 2012; Labens *et al.* 2010) and in the DSL (Sampson *et al.* 2007; Smith *at al.* 2008 b). It gives information of osseous and soft tissue structures (Bischofberger *et al.* 2006). However, in the standing MRI examination the magic angle effect in the oDSLs can cause misinterpretation (Smith *et al.* 2008 a). At the moment the use of MRI is still limited to the low number of clinics offering this diagnostic modality.

Ultrasonography remains the most frequent used imaging modality for examination of the suspensory apparatus (Carnicer *et al.* 2012; Rheimer 2012). Though the interpretation of the PSLs image can be challenging since its diverse echogenicity. This is caused by artifacts and by the unique histology of the SL, which is also called third interosseus muscle (Budras *et al*. 2003). Artifacts equally affect the image of the body of the SL, while artifacts have no significant impact on the image of the branches of the SL. In the pastern the straight sesamoidean ligament is not as affected by artifacts as the oDSLs are (Whitcomb 2004). In the initial examination ultrasonography is used to detect a lesion. During the time of recovery the lesion is monitored and the rehabilitation program is adjusted according to the ultrasonographic appearance (Smith 2008). Defects of ligaments and tendons are assessed by the determination of the echo score (ES) and the fiber alignment score (FAS). Furthermore, by measuring the cross-sectional area (CSA) (Smith 2008; Edinger 2010). Taking the measurement of the CSA is considered the most objective method of measuring (Pickersgill 2001).

The aim of this study was to test the precision of ultrasonographic measurements in the SA. Since different methods and limb positions are described for the ultrasonographic examination of the PSL (Denoix 1992; Denoix 2008), the first part of the study was solely dedicated to the PSL. The second part of the study examined the precision of ultrasonographic measurements in the body and branches of the SL, the sDSL and the oDSLs.

2 Research publications in journals with peer-review

2.1 The proximal aspect of the suspensory ligament in the horse: How precise are ultrasonographic measurements?

Equine Veterinary Journal

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The proximal aspect of the suspensory ligament in the horse: How precise are ultrasonographic measurements?

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Summary

Reasons for performing study: To evaluate intra- and interobserver variability in ultrasonographic measurements of the proximal aspect of the suspensory ligament (PSL) in the horse.
Hypothesis: A minimum difference of ≥20% is required to differentiate reliably between physiological and pathological alterations related to dimensions.
Materials and methods: Two operators examined the PSL in all 4 limbs of 14 horses twice using different techniques and different probes with and without standoff pads. Measurements were taken from the longitudinal and transverse images. Inter- and intraoperator variability was evaluated using agreement indices (AI) and the 95% limits of agreement (LOA).
Results: On the longitudinal scan the mean inter- and intraoperator AIs for dorsopalmar/-plantar thickness were both ≥0.89 and the 95% LOA were within target values for almost all intra- and interoperator comparisons. Similar mean AIs and 95% LOA were calculated for the dorsopalmar/-plantar thickness on the transverse image. For lateromedial width, cross-sectional area and circumference on the transverse scan, the mean inter- and intraoperator AIs ranged between 0.81 and 0.95 and the 95% LOA were higher than target values regardless of the imaging technique used. In general, better values for AIs and 95% LOA were achieved in the fore- compared with the hindlimb.
Conclusion and clinical relevance: Acceptable precision was identified within and between operators only for the dorsopalmar/-plantar thickness in longitudinal and in transverse scanning directions. For the lateromedial width, cross-sectional area and circumference, a relatively large variability was identified. This aspect has to be considered if these parameters are to be used for objective measurement of the PSL from the transverse ultrasound image.

Keywords: horse; suspensory ligament; ultrasonography; measurement; precision

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2.2 Precision of ultrasonographic measurements of the equine suspensory apparatus

Pferdeheilkunde 29 (2013) 3 (Mai/Juni) 353-359

Precision of ultrasonographic measurements of the equine suspensory apparatus

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Summary

This study aimed to investigate the precision of ultrasonographic measurements of the body and branches of the suspensory ligament and straight and oblique distal sesamoidean ligaments in equine fore- and hindlimbs. Ultrasonographic measurements of the horses suspensory apparatus are used for diagnostic purposes but their precision has not been assessed yet. Fourteen sound horses underwent ultrasonographic examination of all four limbs by two operators, twice. Longitudinal and transverse ultrasonographic images were used to measure the depth, width, circumference and cross-sectional area at locations determined by anatomical features. Inter- and intraoperator comparisons were made and their variability was evaluated using agreement indices and 95% limits of agreement. This method showed that the depth of the suspensory ligament branches from longitudinal images and their circumference from transverse images, and circumference of the straight sesamoidean ligament in the distal pastern were the more reliable of the measurements. All measurements of the suspensory ligament body and the oblique sesamoidean ligaments had a low reliability. The reliability of measurements of the size of the suspensory apparatus should be considered when making clinical judgements from ultrasonographic images. Particular caution should be exercised with measurements of the suspensory ligament body and the oblique distal sesamoidean ligament.

Keywords: horse / suspensory apparatus / ultrasonography / measurement / precision / diagnostic imaging

Präzision ultrasonographischer Messungen am Fesseltrageapparat des Pferdes

Ziel der Studie war es, die Präzision ultrasonographischer Messungen des Fesselträgerkörpers, der Fesselträgerschenkel und des geraden und der schrägen Gleichbeinbänder an Vorder- und Hinterbeinen des Pferdes zu untersuchen. Ultrasonographische Messungen des Fesseltrageapparats des Pferdes werden zu diagnostischen Zwecken zwar genutzt, ihre Präzision wurde aber noch nicht untersucht. In der Studie wurden 14 gesunde Pferde ultrasonographisch untersucht; zweifach an allen vier Gliedmaßen von zwei Untersuchern. Longitudinale und transversale Sonogramme wurden benutzt, um die Tiefe, die Weite, den Umfang und die Fläche an durch die Anatomie definierten Stellen zu bestimmen. Die inter- Unterschiede zwischen und von den Untersuchern (inter- and intraoperator variability – bzw. Reproduzier- und Wiederholbarkeit) wurde mittels des mean agreement index (Übereinstimmung der Mittelwerte) und 95% limits of agreement (Übereinstimmungsgrenzen) bestimmt. Die Messung der Tiefe im longitudinalen Sonogramm in den Bereichen der Fesselträgerschenkel und die Messung des Umfangs im transversalen Sonogramm in den Bereichen der Fesselträgerschenkel und des geraden Gleichbeinbandes in der distalen Fesselbeuge gehörten zu den zuverlässigeren Messungen. Alle Messungen im Bereich des Fesselträgerkörpers und der schrägen Gleichbeinbänder haben eine geringe Zuverlässigkeit, was bei klinischen Entscheidungen berücksichtigt werden muss.

Schlüsselwörter: Pferd / Fesseltrageapparat / Ultrasonographie / Größenmessung / Präzision / bildgebende Diagnostik

3 Declaration of own portion of work in the research publications

3.1 The proximal aspect of the suspensory ligament in the horse: How precise are ultrasonographic measurements?

Authors: Zauscher, J.M., Estrada, R., Edinger, J., Lischer, C.J.

Year: 2013

Journal: Equine vet. J. 45, 164-169.

	J.M. Zauscher	R. Estrada	J. Edinger	C.J. Lischer
Study design	40 %	10 %	10 %	40 %
Data collection	70 %	30 %	-	-
Study execution	50 %	40 %	-	10 %
Data analysis and interpretation	60 %	10 %	10 %	20 %
Preparation of the manuscript	60 %	10 %	10 %	20 %

3.2 Precision of ultrasonographic measurements of the equine suspensory apparatus

Authors: Zauscher, J.M., Estrada, R., Voute, L.C., Edinger, J., Lischer, C.J.

Year: 2013

Journal: Pferdeheilkunde 3.13, 353-359.

	J.M. Zauscher	R. Estrada	J. Edinger	L.C. Voute	C.J. Lischer
Study design	40 %	10 %	10 %	-	40 %
Data collection	70 %	30 %	-	-	-
Study execution	50 %	40 %	-	-	10 %
Data analysis and interpretation	60 %	10 %	10 %	-	20 %
Preparation of the manuscript	60 %	10 %	-	20 %	10 %

4 Discussion

The purpose of this study was to test the precision of ultrasonographic measurements in the horses´ suspensory apparatus. Only if measurements are precise, they can be used for diagnostic purpose. In repeated measurements, results are considered very precise if they consistently are very similar (Lamb 2008; Steiner and Norman 2006).

The results of this study showed that in different parts of the suspensory apparatus different measurements are more precise than others. There were some measurements in the proximal suspensory ligament (PSL), the branches of the suspensory ligament (SL) and the straight distal sesamoidean ligaments (sDSL) that had acceptable precision for diagnostic purposes. In the body of the SL and in the oblique distal sesamoidean ligaments (oDSLs) no measurements were precise enough to be considered for diagnostic purpose.

The target values for the 95% limits of agreement (LOA) were set at approximately 20%, since previous studies reported a 20% - 23% difference between the superficial deep digital flexor tendon (SDFT) of the right and left limb in the normal range (Smith *et al.*1994, Avella *et al.* 2008). The results of this study reflect that the target values were set appropriately since a range of results were achieved. Some measurements showed excellent agreement indices (AI) and the calculated 95% LOAs were within target values. Some showed excellent AI but the 95% LOAs were not within the target values, other measurements had neither excellent target values nor were their 95% LOAs within target values. Subsequently this allowed an evaluation of the precision of the different measurements from the suspensory apparatus.

Interestingly, a prior study showed a significant interoperator variability for the SDFTs CSA measurement (Pickersgill *et al.* 2001), which was not the case in this study. This probably can be explained since in the study by Pickersgill *et al.* (2001) the two operators had different experience in orthopedic ultrasound; one was relatively inexperienced and interpreted the outer boarder differently than the experienced operator. But not only experience, also different ultrasonographic equipment can influence measurement results (Whitcomb, 2004). However, Pickersgill *et al.* (2001) measured the SDFTs CSA with two different ultrasonographic machines and had consistent measuring results. The ultrasonographic equipment used for this study was the same for both operators. This can also give an explanation why there was no significant difference in the interoperator variability. Furthermore, measurement results are influenced by image quality, which can be influenced by transducer-frequency and machine settings. Recently it has been reported, that for the evaluation of the proximal suspensory ligament a linear transducer, set to a frequency of 10 or even 8 MHz, provides optimal image quality (Reimer, 2010). Though in this study a setting of 12 MHz was used, images had a high quality. Nevertheless, the results of this study greatly depended on the images quality. Measurements in general can only be reliable when images have optimal quality.

These two studies evaluated the different ultrasonographic measurements to assess the size of the structures of the suspensory apparatus in the horse. On one hand it is helpful to know, which of these parameters show an acceptable precision, but on the other hand we have to emphasize that the assessment of pathological changes in the sonographic structure is of equal importance.

5 Summary

Changes in the dimension of the suspensory apparatus are used to diagnose pathological changes and to evaluate the process of healing since pathological changes, in shape and structure, cannot always reliably be differentiated from normal findings. The individually very differing amount of muscle fibres in the origin and body of the suspensory ligament causes an ultrasonographic image with very variable echogenicity. Also, anastomoses, overlaying tendons and ligaments cause artifacts in all parts of the suspensory apparatus except in the oblique sesamoidean ligament.

The purpose of this study was to investigate the precision of ultrasonographic measurements of the origin, body and branches of the suspensory ligament and of the straight and oblique distal sesamoidean ligaments in equine fore- and hindlimbs. In addition, in the origin of the suspensory ligament different techniques for dimensional measurement were evaluated.

14 sound horses (six Standardbreds, six Arabian mix breeds, one Warmblood and one Quarter horse) in age between 5 - 28 years underwent ultrasonographic examination of all four limbs by two operators. Longitudinal and transverse ultrasonographic images, acquired with a linear probe (12 MHz), were used to measure depth, width, circumference and cross-sectional area at locations determined by anatomical features. In the origin of the suspensory ligament additionally a microconvex probe (8 MHz) was used. Also, in the origin of the suspensory ligament in the forelimbs with flexed limb position additional images were acquired using a linear and a microconvex probe. Two operators examined each animal sonographically twice with an interval of at least one day. The scans were saved and measured in the scanners archive. Inter- and intraoperator variability was evaluated using agreement indices and 95% limits of agreement (Bland und Altmann, 1986).

Measurements in the longitudinal image at the origin and the branches of the suspensory ligament were the more reliable of the measurements. In the transverse image the measurement of the circumference from the suspensory ligaments branches and the straight sesamoidean ligament in the distal pastern can also be considered reliable. All measurements of the suspensory ligament body and the oblique sesamoidean ligaments had low reliability.

The reliability of measurements of the size of the suspensory apparatus should be considered when making clinical judgements from ultrasonographic images.

6 Zusammenfassung

Die Präzision von ultrasonographischen Messungen am Fesseltrageapparat beim Pferd

Größenveränderungen des Fesseltrageapparats des Pferdes werden besonders im Bereich des Ursprungs bevorzugt zur Diagnose von Erkrankungen und zur Beurteilung des Heilungsverlaufes durchgeführt, da pathologische Form- und Strukturveränderungen gerade dort nicht immer sicher von normalen Befunden zu unterscheiden sind. Der individuell sehr unterschiedliche Gehalt an Muskelfasern führt im Bereich des Fesselträgerursprungs und des Fesselträgerkörpers zu einem Ultraschallbild mit variabler Echogenität. Auch verursachen Gefäßanastomosen und überlagernde Sehnen und Bänder Artefakte im Verlauf des gesamten Fesseltrageapparats mit Ausnahme der Fesselträgerschenkel.

Ziel der Studie war es, die Präzision von Messungen im Bereich des Ursprungs, des Körpers und der Schenkel des Fesselträgers sowie des geraden und der schrägen Gleichbeinbänder an Vorder- und Hinterbeinen des Pferdes zu untersuchen. Zusätzlich wurden im Bereich des Fesselträgerursprungs verschiedene sonographische Untersuchungstechniken zur Größenmessung evaluiert.

14 gesunde Pferde (sechs Traber, sechs Araber-Mix, ein Warmblut, ein Quarter Horse) im Alter von 5 - 28 Jahren wurden an allen vier Gliedmaßen sonographisch untersucht. Anhand von longitudinalen und transversalen Ultraschallbildern, die mit einer Linearsonde (12 MHz) erstellt wurden, wurde die Tiefe, die Breite, der Umfang und die Fläche an, durch die Anatomie definierten, Stellen gemessen. Im Bereich des Ursprungs wurde auch eine Microconvexsonde (8 MHz) eingesetzt. Ebenfalls im Ursprungsbereich der Vordergliedmaße wurde zusätzlich an der gebeugten Gliedmaße mit einer Linearsonde und einer Microconvexsonde ein Sonogramm erstellt.

Zwei Untersucher sonographierten die Tiere je zweimal im Abstand von mindestens einem Tag. Die Scans wurden im Archiv des Ultraschallgerätes gespeichert und dort ausgemessen. Die inter- und intraobserver Variabilität wurde mittels des mean agreement index und 95% limits of agreement (Bland und Altmann 1986) bestimmt.

Zu den zuverlässigeren Messungen gehörten im longitudinalen Sonogramm die Messung der Tiefe in den Bereichen des Fesselträgerursprungs und der Fesselträgerschenkel und im transversalen Sonogramm die Messung des Umfangs in den Bereichen der Fesselträgerschenkel und des geraden Gleichbeinbandes in der distalen Fesselbeuge. Alle Messungen im Bereich des Fesselträgerkörpers und der schrägen Gleichbeinbänder hatten eine geringe Reliabilität.

Die Zuverlässigkeit der Messungen der Größe im Bereich des Fesseltrageapparats sollten berücksichtigt werden, wenn diese verwendet werden um klinische Entscheidungen zu treffen.

7 References

Avella, C.S., Ely, E.R., Verheyen, K.L.P., Price, J.S., Wood, J.L.N. and Smith, R.K.W. (2009) Ultrasonographic assessment of the superficial digital flexor tendons of National Hunt racehorses in training over two racing seasons. Equine vet. J. 41, 449-454.

Barone, R. (1989) Anatomie compare des mammifères domestiques. In: Barone R. (ed): Tome 2 Arthrologie Et Myologie, 3rd edn., Ed: R. Barone , Vigot, Paris. Paris: Vigot, pp 791-801.

Bischofberger, A.S., Konar, M., Ohlerth, S., Geyer, H., Lang, J., Uletschi, 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.

Bland, J.M. and Altman, D.G. (1986) Statistical methods for assessing agreement between two methods of clinical measurements. Lancet i, 307-310.

Bland, J.M. and Altman, D.G. (2003) Applying the right statistics: analyses of measurement studies. Ultrasound Obstet. Gynecol. 22, 85-93.

Boehart, S., Arndt, G., Gmachl M., Rindermann G. and Carstanjen, B. (2010 a) Assessment of ultrasonographic morphometric measurements of digital flexor tendons and ligaments of the palmar metacarpal region in Icelandic horses. Am. J. Vet. Res. 71, 1425-1431.

Boehart, S., Arndt, G. and Carstanjen, B. (2010 b) Ultrasonographic morphometric measurements of digital flexor tendons and ligaments of the palmar metacarpal region in Haflinger horses. Anat. Histol. Embryol. 39, 366-375.

Budras, K.-D., Sack, W.O. and Röck, S. (2003) Thoracic Limb. In: *Anatomy of the Horse,* 4th edn., Eds: K.-D. Budras, W.O. Sack and S. Röck, Schlütersche, Hannover. pp 2-13.

Carnicer, D., Coudry, V. and Denoix, J-M. (2012) Ultrasonographic examination of the palmar aspect of the pastern of the horse: sesamoidean ligaments. Equine vet. Educ. 25, 256-263.

Çelimli, N., Seyrek-Intas, D. and Kaya, M. (2004) Morphometric measurements of flexor tendons and ligaments in Arabian horses by ultrasonographic examination and comparison with other breeds. Equine vet. Educ. 16, 81-85.

Denoix, J.-M. (1992) Images echographiques des lésions du muscle interosseux III (ligament suspenseur du boulet). Pract. vét. Equine 23, 23-33.

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.,Coudry, V. and Jacquet, S. (2008) Ultrsonographic procedure for a complete examination of the proximal third interosseus muscle (proximal suspensory ligament) in the equine forelimbs. Equine vet. Educ. 3,148-153.

Dyce, K.M., Sack, W.O. and Wensing, C.J.G. (2010) The forelimb of the horse. In: Textbook of Veterinary Anatomy, 4th edn., Eds: K. M. Dyce, W.O. Sack and C.J.G.
Wensing, Elsevier, St Louise. pp 587-623.

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

Dyson, S.J., Arthur, R.M., Palmer S.E. and Richardson, D. (1995) Suspensory ligament desmitis. Vet. Clin. N. Am.: Equine Pract. 11, 177-215.

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

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

Dyson, S. (2007b) Diagnosis and management of common suspensory lesions in the forelimbs and hindlimbs of sport horses. Clin. Tech. Equine Pract 6, 179-188.

Dyson, S. and Genovese, R. (2010) The suspensory apparatus. In: Diagnosis and Management of Lameness in the Horse, 2nd edn., Eds: M. Ross and S. Dyson, Elsevier, St. Louis. pp 738-760.

Dyson, S. and Murray, R. (2012) Management of hindlimb proximal suspensory desmopathy by neurectomy of the deep branch of the lateral plantar nerve and plantar fasciotomy: 155 horses (2003-2008). Equine vet. J. 44, 361-367.

Edinger, J. (2010) Extremitäten. In: Atlas der Ultraschalluntersuchung beim Pferd. 1st edn. Eds: P.S. Glatzel, Schlütersche, Hannover, pp 18-77.

Filippi, M., Horsfield, M.A., Bressi, S., Martinelli, V., Baratti, C., Reganati, P., Campi, A., Miller, D.H. and Comi, G. (1995) Intra- and inter-observer agreement of brain MRI lesion volume measurements in multiple sclerosis. A comparison of techniques. Brain 118, 1593-1600.

Gibson, K.T. and Steel, C.M. (2002) Conditions of the suspensory ligament causing lameness in horses. Equine vet. Educ. 14, 39-50.

Kirchberger, R. (1995) Imaging artifacts in diagnostic ultrasound – a review. Vet. Radiol. Ultrasound 36, 297-306.

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.

Lamb, C.R. (2008) Statistical briefing: accuracy and precision. Vet. Radiol. Ultrasound 49, 600-601.

Lischer, C. J., Bischofberger, A. S., Fürst, A., Lang, J. and Uletschi, G. (2006) Erkrankungen im Bereich des Fesselträgerursprungs beim Pferd: Eine diagnostische Herausforderung. Schweiz. Arch. Tierheilk. 2, 86-97.

Pickersgill, C.H., Marr, M. and Reid, S.W. (2001) Repeatability of diagnostic ultrasonography in the assessment of the equine superficial digital flexor tendon. Equine Vet. J. 33, 33-37.

Ramzan, P.H.L., Palmer, L., Dallas, R.S. and Shepherd, M.C. (2012) Subclinical ultrasonographic abnormalities of the suspensory ligament branch of the athletic horse: A survey of 60 Thoroughbred racehorses. Equine vet. J. 45, 159-163.

Rantanen, N.W., Jorgensen, J. S. and Genovese, R.L. (2010) Ultrasonographic Evaluation of the Equine Limb: Technique. In: Diagnosis and Management of Lameness in the Horse. 2nd edn., Eds: M. Ross and S. Dyson, Elsevier, St. Louis. pp 182-205.

Reef, V.B. (1998) Musculoskeletal ultrasonography. In: Equine Diagnostic Ultrasound. 1st edn., Ed: V.B. Reef, Saunders, Philadelphia, PA. pp 39-61.

Redding, W.R. (1993) Evaluation of the equine digital flexor tendon sheath using diagnostic ultrasound and contrast radiography. Vet. Radiol. Ultrasound 34, 42-48.

Rheimer, J.M. (2010) How to maximise image quality for the sonographic evaluation of the hind proximal suspensory ligament. In: Proceedings, 56th annu meet am assoc equine pract 239-243.

Sampson, S.N., Schneider, R.K., Russel, L.T., Gavin, P.R., Zudrod, C.J. and Ho, C.P. (2007) Magnetic resonance imaging features of oblique and straight distal sesamoidean desmitis in 27 horses. Vet. Radiol. Ultrasound 48, 303-311.

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.

Schulze, T. (2007) Magnetresonanztomographische, computertomographische und histologische Untersuchung zum M. interosseus medius der Beckengliedmaße des Pferdes. Vet. Med. Diss. Berlin.

Schulze, T. und Budras, K.-D. (2008) Zur klinisch-funktionellen Anatomie des M. interosseus medius der Hintergliedmaße im Hinblick auf die Insertionsdesmopathie des Pferdes – Kernspin-, computertomographische- und morphologische Untersuchungen. Pferdeheilkunde 3, 343-350.

Smith, S., Dyson, S.J. and Murray, R.C. (2008 a) Magnetic resonance imaging of the distal sesamoidean ligament injury. Vet. Radiol. Ultrasound 49, 516-528.

Smith, S., Dyson, S.J. and Murray, R.C. (2008) Is a magic angle effect observed in the collateral ligaments of the distal interphalangeal joint or the oblique sesamoidean ligaments during magnetic resonance imaging? Vet. Radiol. Ultrasound 49, 509-515.

Smith, R.K.W., Jones, R. and Webbon, P.M. (1994) The cross-sectional areas of normal equine digital flexor tendons determined ultrasonographically. Equine vet. J. 26, 460-465.

Smith, R.K.W. (2008 b) Tendon and ligament injury. In: Proceedings, 54th annu meet am assoc equine pract 475-501.

Smith R.K.W. (2010) Pathophysiology of Tendon Injury. In: Ross, M., Dyson, S. (Eds.) Diagnosis and Management of Lameness in the Horse, Elsevier, St. Louis, pp. 694-706.

Souza, M.V., van Weeren, P.R., van Schie, H.T. and van de Lest, C.H. (2010) Regional differences in biochemical, biomechanical, and histomorphological characteristics of the equine suspensory ligament. Equine Vet. J. 42, 611-620.

Steiner, D.L. and Norman, G.R. (2006) “Precision” and “Accuracy”: two terms that are neither. J. Clin. Epidemiol. 59, 327-330.

Tóth, F., Schumacher, J., Schramme, M., Holder, T., Adair, H.S. and Donnell, R.L. (2008) Compressive damage to the deep branch of the lateral plantar nerve associated with lameness caused by proximal suspensory desmitis. Vet. Surg. 37, 328-335.

van der Vlugt-Meijer, R.H., Meij, B.P. and Voorhout, G. (2006) Intraobserver and interobserver agreement, reproducibility, and accuracy of computed tomographic measurements of pituitary gland dimensions in healthy dogs. Am. J. vet. Res. 67, 1750-1755.

Whitcomb, M.B. (2004) Ultrasonographic Evaluation of the Metacarpus, Metatarsus, and Pastern. Clin. Tech. Equine Pract. 3, 238-255.

White, J.M., Mellor, D.J., Duz, M., Lischer, C.J. and Voute, L.C. (2008) Diagnostic accuracy of digital photography and image analysis for measurement of foot conformation in the horse. Equine vet. J. 40, 623-628.

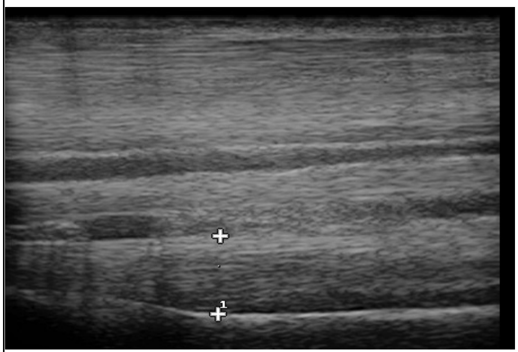
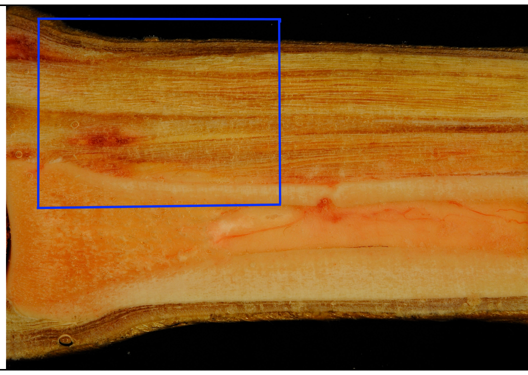
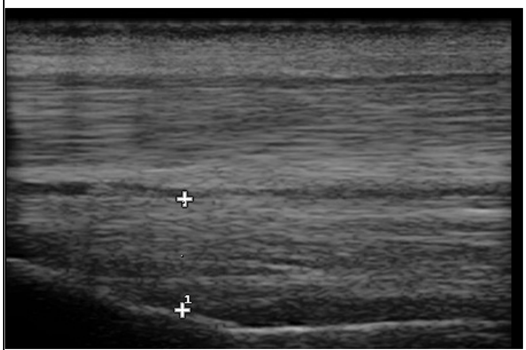
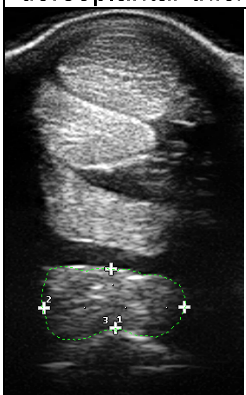
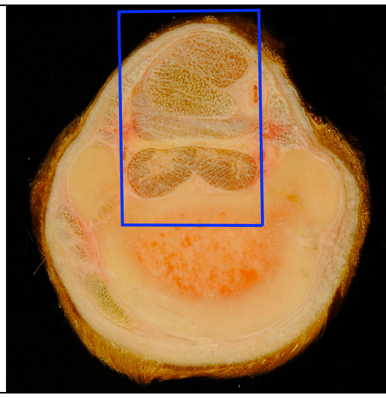
Zauscher, J.M., Estrada, R., Edinger, J. and Lischer, C.J. (2013) The proximal aspect of the suspensory ligament in the horse: How precise are ultrasonographic measurements? Equine vet. J. 45, 164-169.

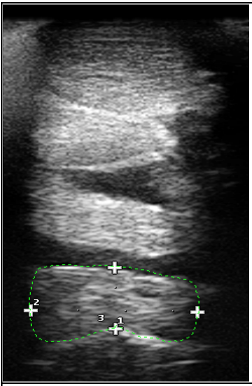
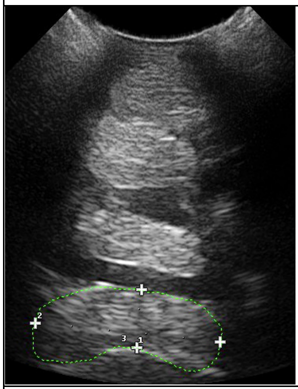
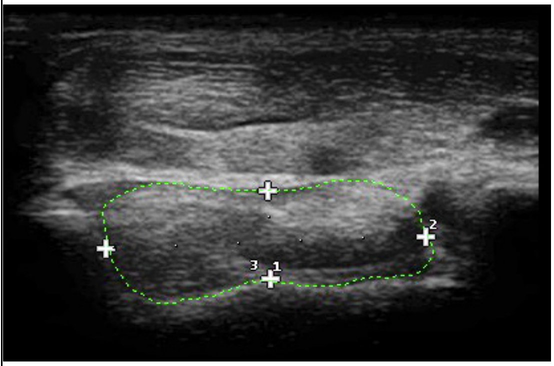
II List of abbreviations

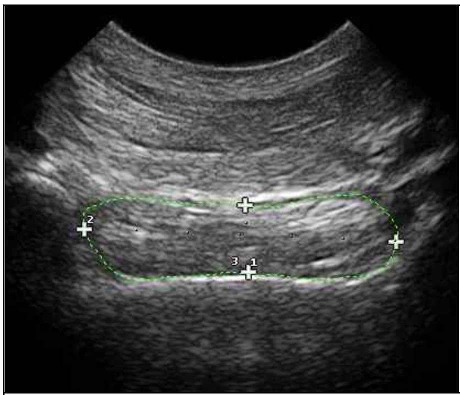
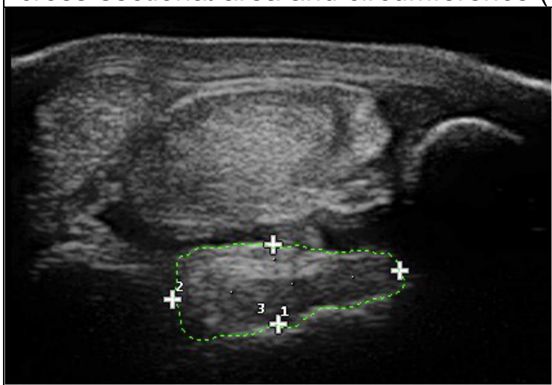
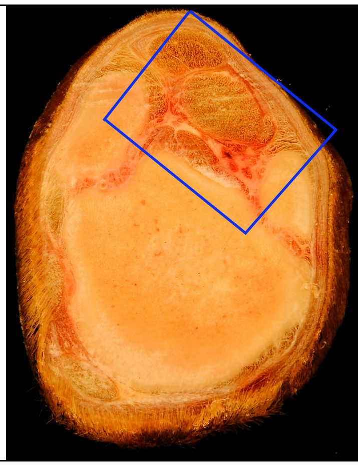
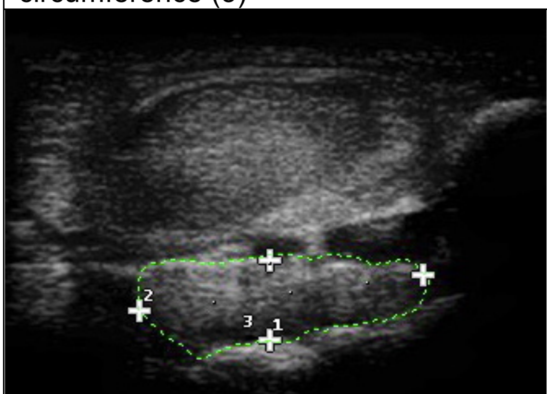
AI	**A**greement **I**ndex
ALDDFT	**A**ccessory **L**igament of the **D**eep **D**igital **F**lexor **T**endon
C	**C**ircumference
cm	**C**enti**m**etre
CSA	**C**ross-**S**ectional **A**rea
CT	**C**omputer **T**omography
DDFT	**D**eep **D**igital **F**lexor **T**endon
DP	**D**orso**p**almar
DSL	**D**istal **S**esamoidean **L**igament
ES	**E**cho **S**core
et al.	**et al**ii (latin for “and others”)
FAS	**F**iber **A**lignment **S**core
Fig	**Fig**ure
kg	**K**ilo**g**ram
LOA	**L**imits **of** **A**greement
LM	**L**atero**m**edial
MC III	**Third** **M**eta**c**arpal Bone
MC IV	**Fourth** **M**eta**c**arpal Bone
MHz	**M**ega**h**ert**z**
MRI	**M**agnetic **R**esonance **I**maging
MT II	**Second** **M**eta**t**arsal Bone
MT III	**Third** **M**eta**t**arsal Bone
MT IV	**Fourth** **M**eta**t**arsal Bone
O 1	**O**perator **1**
O 2	**O**perator **2**
oDSL	**O**blique **D**istal **S**esamoidean **L**igaments
PSB	**P**roximal **S**esamoidean **B**ones
PSD	**P**roximal **S**uspensory **L**igament
SDFT	**S**uperficial **D**igital **F**lexor **T**endon
s.d.	**S**tandard **D**eviation
sDSL	**S**traight **D**istal **S**esamoidean Ligaments
SL	**S**uspensory **L**igament

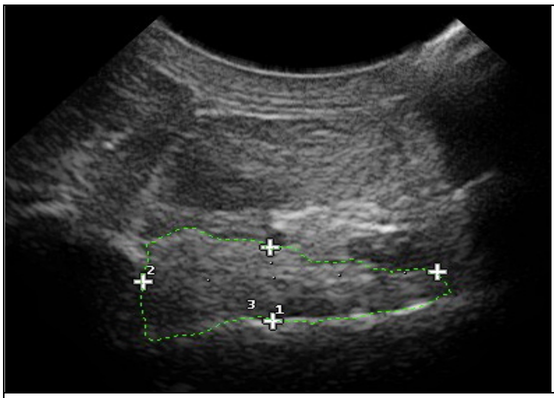
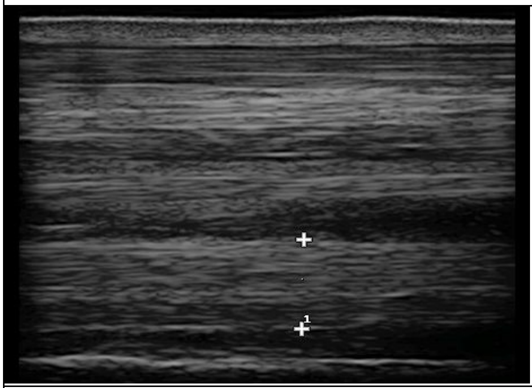
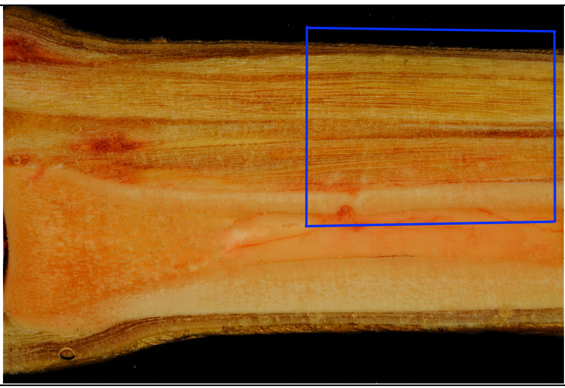
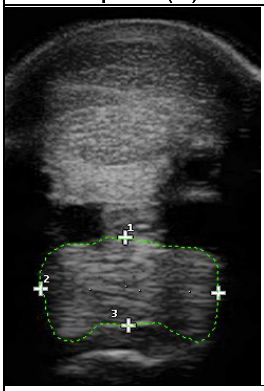
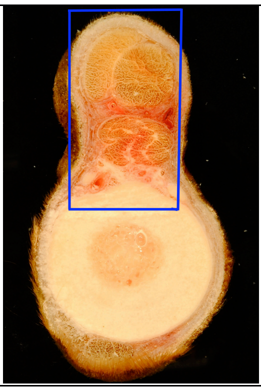
TV **T**arget **V**alues

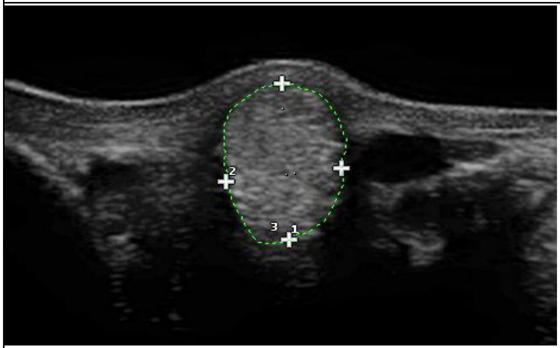
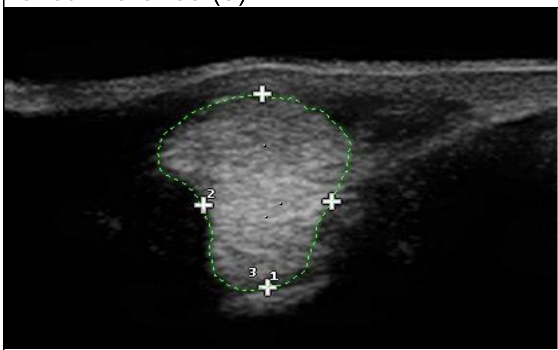
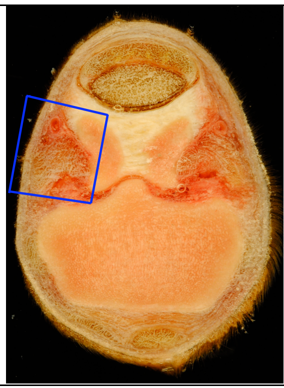
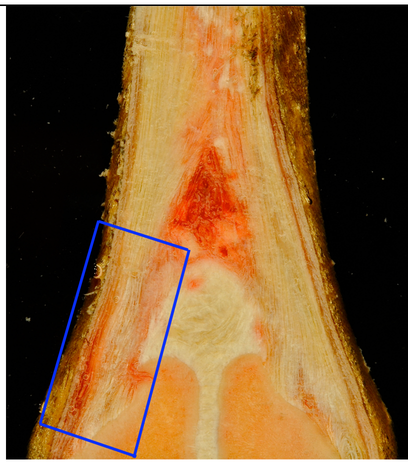
III Appendix

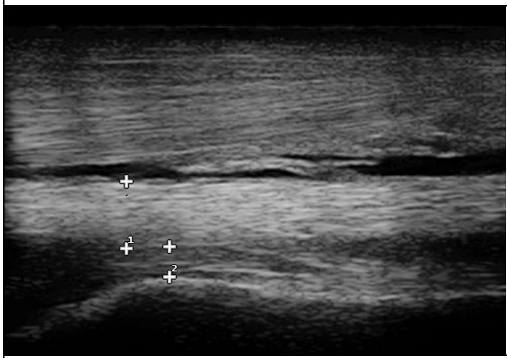
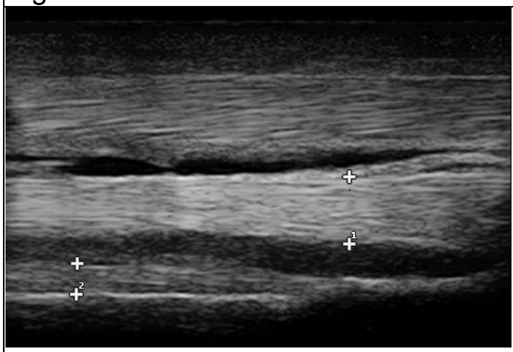
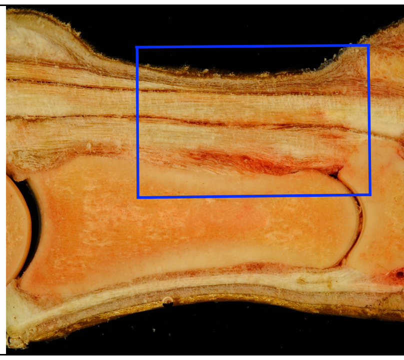
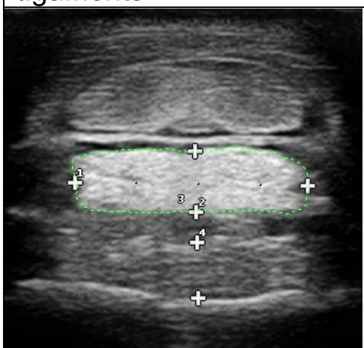
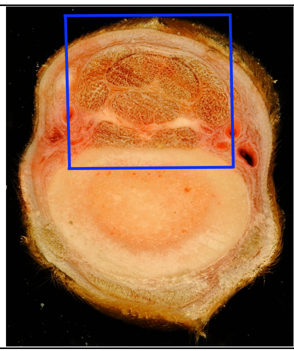
Ultrasonographic Images	**Gross Pathological Images**
Proximal suspensory ligament	
	
location 1: forelimb, measurement of the dorsopalmar thickness (1)	
	
location 1: hindlimb, measurement of the dorsoplantar thickness (1)	
	
location 2: forelimb, with a linear probe and a standoff pad with measurements of the dorsopalmar thickness (1), lateromedial width (2) and cross-sectional area and circumference (3)	

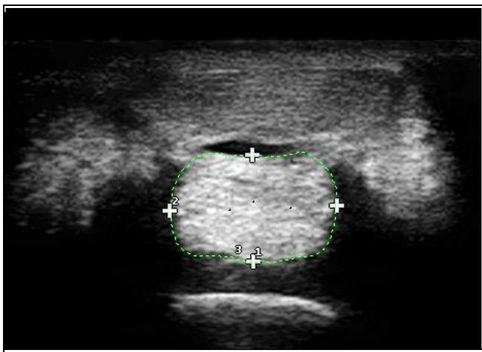
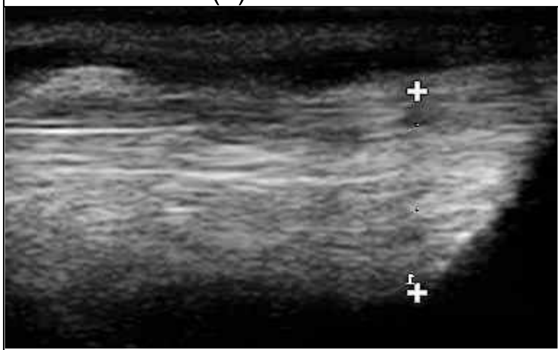
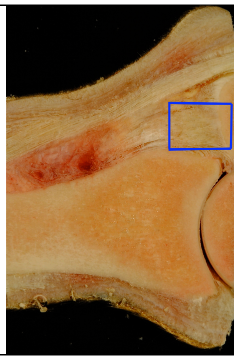
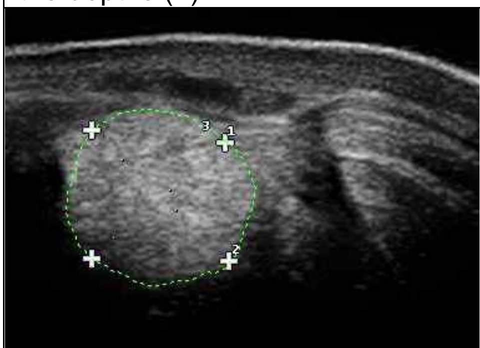
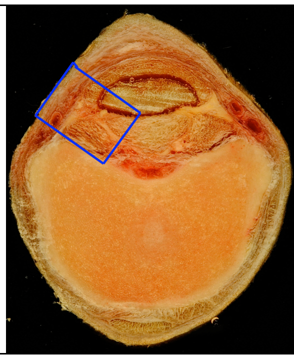
	
location 2: forelimb, with a linear probe with measurements of the dorsopalmar thickness (1), lateromedial width (2) and cross-sectional area and circumference (3)	
	
location 2: forelimb, microconvexprobe with measurements of the dorsopalmar thickness (1), lateromedial width (2) and cross-sectional area and circumference (3)	
	
location 2: forelimb, in flexed limb position acquired with a linear probe with measurements of the dorsopalmar thickness (1), lateromedial width (2) and cross-sectional area and circumference (3)	

	
location 2: forelimb, in flexed limb position acquired with a microconvex probe with measurements of the dorsopalmar thickness (1), lateromedial width (2) and cross-sectional area and circumference (3)	
	
location 2: hindlimb, with a linear probe and a standoff pad with measurements of the dorsoplantar thickness (1), lateromedial width (2) and cross-sectional area and circumference (3)	
	
location 2: hindlimb, with a linear probe with measurements of the dorsoplantar thickness (1), lateromedial width (2) and cross-sectional area and circumference (3)	

	
location 2: hindlimb, acquired with a microconvex probe with measurements of the dorsoplantar thickness (1), lateromedial width (2) and cross-sectional area and circumference (3)	
Body of the suspensory ligament	
	
location 3: body of the SL; measurement of the depths (1)	
	
location 4: body of the SL; measurement of the depths (1), width (2) and cross-sectional area and circumference (3)	

Branches of the suspensory ligament	
	
Location 5 & 6: proximal image of the medial and lateral branch of the SL; measurement of the depths (1), width (2) and cross-sectional area and circumference (3)	
	
Location 7 & 8: distal image of the medial and lateral branch of the SL; measurement of the depths (1), width (2) and cross-sectional area and circumference (3)	
	
Location 9 & 10: longitudinal image of the medial and lateral branch of the SL; measurement of the depths (1)	

Pastern	
	
Location 11: longitudinal image; proximal thickness measurement of the straight (1) and oblique (2) distal sesamoidean ligaments	
	
Location 12: longitudinal image; distal thickness measurement of the straight (1) and oblique (2) distal sesamoidean ligaments	
	
Location 13: proximal transverse image; measurements of the proximal straight distal sesamoidean ligament: depths (1), width (2) and cross-sectional area and circumference (3), Measurement of the oblique distal sesamoidean ligaments (4)	

	
Location 14: distal transverse image; measurements of the proximal straight distal sesamoidean ligament: depths (1), width (2) and cross-sectional area and circumference (3)	
	
Location 15 & 16: longitudinal image of the medial and lateral oblique distal sesamoidean ligament; measurement of the depths (1)	
	
Location 17 & 18: image of the medial and lateral oblique distal sesamoidean ligament; measurement of the depths (1), width (2) and cross-sectional area and circumference (3)	

IV Oral presentation

Zauscher J. M., Estrada R., Edinger J., Lischer C. J. Reproduzierbarkeit von Messungen im Bereich des Fesselträgerursprungs. 22. Arbeitstagung der DVG-Fachgruppe Pferdekrankheiten, Hannover (16. - 17.03.2012)

IV List of publications

Zauscher, J.M., Estrada, R., Edinger, J. and Lischer, C.J. (2013) The proximal aspect of the suspensory ligament in the horse: How precise are ultrasonographic measurements? Equine vet. J. 45, 164-169.

Zauscher, J.M., Estrada, R., Voute, L.C., Edinger, J., Lischer, C.J. (2013) Precision of ultrasonographic measurements of the equine suspensory apparatus. Pferdeheilkunde 3.13, 353-359.

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VI Selbstständigkeitserklärung

Hiermit bestätige ich, dass ich die vorliegende Arbeit selbstständig angefertigt habe. Ich versichere, dass ich ausschließlich die angegebenen Quellen und Hilfen in Anspruch genommen habe.

Berlin, den 4. Mai 2013 Johanna Zauscher