Blinded Comparison of Palmaroproximal-palmarodistal-oblique and Dorsoproximal-palmarodistal Oblique Radiographic Projections With Contrast Medium in the Navicular Bursa in Dissected Horse Front Feet With Native Radiographs and Gross Pathology

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Abstract

Background: Equine palmar foot syndrome is a common cause of chronic lameness. Radiographic and ultrasound imaging are sometimes insufficient to examine the podotrochlear apparatus. MRI and CT have great diagnostic value but are expensive and are not available for all patients. Bursography might become a highly available and inexpensive diagnostic tool for this purpose.

Material and Methods: To evaluate the technique, standard palmaroproximal-palmarodistal-oblique (PaPr-PaDiO) and dorsoproximal-palmarodistal oblique (DPr-PaDiO) radiographs were acquired both before and after injecting contrast medium in the navicular bursa (NB) and were subsequently compared with gross pathology as gold standard in 48 dissected front feet. For all results a scoring system with 4 groups was introduced.

Results: Compared with the gold standard, the fleiss kappa between groups were 0.349, 0.280, 0.358, and 0.455 for DPr-PaDiO, PaPr-PaDiO, DPr-PaDiO contrast enhanced (CE), and PaPr-PaDiO (CE), respectively ($P < 0.001$). The combined view of native images and the view of all pictures were correlated to the gold standard with a Spearman's rank correlation coefficient of 0.373 and 0.556, respectively ($P < 0.001$). The Kruskal-Wallis-Test did not reveal any significant difference between standard radiographs and gross pathology group 1, 2, and 3. Contrast enhanced (CE) radiographs showed significant differences between gross pathology group 1 versus 2 and 3. Group 4 feet (gross pathology score) were remarkably well evaluated by both radiographic imaging techniques. When more than two projections were graded with findings, the respective feet were found to be moderately to severely changed in gross pathology (specificity: 100 %, sensitivity: 41.4 %). 3/13 (23.1%) group 3 and 4/19 (21.1%) group 4 specimens showed altered CE radiographs and unremarkable native radiographs. 2/13 (15.4%) group 3 and 2/19 (10.5%) group 4 feet do not have any findings in radiographs.

Conclusion: In the present study, bursography with two additional CE images led to more information on the podotrochlear apparatus compared to native radiographs alone. Some cases with no changes in native radiographs will be detected in bursography, and in specimens with altered native radiographs, the diagnosis will be ensured. Therefore, bursography is a useful tool for diagnosing horses with suspected navicular disease when an MRI is not possible or the NB is injected anyway for therapeutic purposes.

Background:

Palmar foot pain is a common cause of chronic lameness in the front limb in horses (Waguespack and Hanson 2010; Dyson et al. 2011). Recent advances in diagnostic imaging, especially the MRI (Dyson and Murray 2007; Kottmeier et al. 2020; Gutierrez-Nibeyro et al. 2020), have led to the name equine palmar foot syndrome and allowed for a better understanding of the disease (Rijkenhuizen 2006), however, the terminus navicular disease (ND) is still in use (Dyson et al. 2011). Nevertheless, changes in the navicular bone, the collateral sesamoid ligament (CSL), the distal impar ligament (DIL), and the flexor cortex cartilage of the navicular bone, as well as synovitis of the NB, and changes in the deep digital flexor

tendon (DDFT) are common features in horses with ND. Further, changes in the distal interphalangeal joint and its collateral ligament have been reported in horses diagnosed with equine palmar foot syndrome (Blunden et al. 2006a, b). However, there are some limitations to MRI e.g. high costs and limited availability; thus, it is not possible for all patients to benefit from this technique.

After a complete lameness examination including a positive deep digital nerve block, radiographs are usually the first imaging modality. As standard, latero-medial (LM), dorsoproximal-palmarodistal oblique (DPr-PaDiO), and palmaroproximal-palmarodistal-oblique (PaPr-PaDiO) projections are acquired (Dyson 2008). An equine practitioner usually possesses a portable digital x-ray system, hence, radiographic examinations can be performed nearly everywhere. Alternatively, an ultrasound examination is possible, though limited to the anatomic features of the heels or the trans cuneal approach (MacDonald et al. 2018). With the bursography, a new diagnostic tool was presented, where an additional PaPr-PaDiO view with contrast medium in the NB was made to gather additional information (Turner 1998, 2013). This technique has already been used to show anatomic features (Jann et al. 1991) or for success control of NB injection (Verschooten et al. 1990). There is only one study where the PaPr-PaDiO CE view is compared with gross pathology (Wuerfel and Hertsch 2005). The ability to show pathologic changes, especially tendon tears, with CE radiographs is known from the digital flexor tendon sheath (Fiske-Jackson et al. 2013; Kent et al. 2020). To our knowledge, there is no study comparing DPr-PaDiO and PaPr-PaDiO CE with native radiographs and gross pathology. We hypothesize that, compared with native radiographs; the bursography will be in better accordance with gross pathological changes in the podotrochlear apparatus and thus facilitate their diagnosis. In a first step, all radiographic projections will be evaluated and then directly compared per each view with the gross pathology, to show if there is an advantage for diagnostics or if the findings could have been made with native radiographs anyway. In the next step, the summarized radiological interpretation of native views and all views will be compared with the gold standard. This will simulate the diagnostic trial, where all information are considered for a definite diagnose.

Materials And Methods:

The study was designed as a prospective and blinded in vitro study, where native radiographs and CE radiographs were compared with gross pathology as gold standard.

Forty-eight pairs of front feet were collected from an abattoir from October 2014 and February 2015. The feet were frozen at -18°C for a minimum of one week and a maximum of four weeks. All feet were thawed 24h before the beginning of the examination. For practical reasons, the examinations were performed in 4 separate sessions, including 10, 26, 22, and 38 feet, respectively. No anamnestic information on the horses was provided. Only feet that optically resembled those of warmblood horses were considered eligible for the study. All limbs were cleaned, the frogs trimmed, and the sulci packed with special wax (Moser®, Waiblingen, Germany). Subsequently, all limbs were individually labelled with a metal plate carrying a five-digit randomized (Microsoft Excel 2010, Microsoft, Redmont, USA) number.

First, the standard DPr-(65°)PaDiO (66kV and 3 mAs) and PaPr(50°)-PaDiO (66kV and 2,5 mAs) views were taken in a random order (Microsoft Excel 2010, Microsoft, Redmont, USA). Standard wooden blocks, skyline tunnel and bracket for the X-Ray tube were used (manufactures unknown) to obtain the pictures with distance of the examiner. Second, 3ml Iomeprol 300mg ID/ml (Imeron 300M© Bracco Imaging GmbH, Konstanz, Germany) were injected directly into the NB using a spinal needle (BD© Spinal Needle, 0,9 *90mm, Becton Dickinson GmbH, Karlsruhe, Germany) and a standard 5 ml syringe. The landmark for needle insertion was a point just proximal to the central sulcus of the frog, with the needle directed toward the apex of the frog and parallel to the ground surface of the hoof (Turner 2013). The success of injection was controlled with a latero-medial (LM) view. Afterwards, the additional DPr-PaDiO and PaPr-PaDiO views were obtained using the settings described above.

A standard portable x-ray tube (TR 90/30, Gierth®, Riesa, Germany) was used for all radiographic examinations, without using a grid. A Mark 3 (Sound-Eklin® Carlsbad, CA, USA) direct X-Ray detector obtained the pictures. The DICOM files were then sent to the clinics picture archiving and communication system (PACS, Synology© running open source PACS from dcm4che). The X-Rays were examined on an Apple Thunderbolt® Display A 1407 (Apple®, Cupertino, CA), USA) with 27" display running Osirix MD® version 6.5 (Apple®, Cupertino, CA); both parts were FDA approved.

After acquiring the x-rays the feet were dissected. The joint capsule and the collateral ligaments of the distal-interphalangeal-joint (DIP) were cut in order to exarticulate the joint. Then, the DIL and the DDFT were cut as distally as possible. This cut was continued around the DDFT. Afterwards, a bundle of navicular bone and DDFT was isolated, so that the flexor surface and the opposite part of the DDFT were visible. The DIL and the distal insertion of the DDFT on P3 were not evaluable. If there was an adhesion between the navicular bone and the DDFT, it was carefully removed. From all steps of preparation high resolution photographs were taken. The pathological assessment was directly performed and documented.

Evaluation of the x-rays and gross pathology:

The researcher (Resident ACSVSMR) and his supervisors (Dipl. ACSVSMR and a head of an equine university clinic in Germany) developed a scoring system for the evaluation of the x-Rays and the gross pathology to make the examination more objective and suitable for statistical analyses. All of the following findings were graded on a 0–3 scale (score 0 = good; score 1 = mild; score 2 = moderate; score 3 = severe changes) except of a round radiolucent opacity. The latter was graded on a 0–2 scale (score 0 = not existent; score 1 = existent, but without clear demarcation; score 2 = obvious, with clear demarcation). In order to weight the most important and unequivocal pathological findings, factors were introduced and multiplied with the respective score (Table 1).

Table 1
Test criteria's for the x-ray projections and the gross pathology

Name	criteria	from	to	factor
projection	DPr-PaDiO			
O1	contour	0	3	1
O2	bone density	0	3	1
O3	bone structure	0	3	1
O4	evaluation of vascular channels	0	3	1
O5	round radio lucent zone	0	2	4
projection	PaPr-PaDiO			
S1	border between cortex and medulla	0	3	1
S2	bone density	0	3	1
S3	bone structure	0	3	1
S4	round radio lucent zone	0	1	4
S5	flexor cortex of NB	0	3	2
projection	DPr-PaDiO CE			
K01	filling of navicular bursa	0	3	1
K02	pooling of contrast media (radio dense)	0	3	2
K03	lack of contrast media (radio lucent)	0	3	2
K04	structue of NB	0	3	1
projection	PaPr-PaDiO (CE)			
SK1	Borders from contrast medium	0	3	2
SK2	filling of navicular bursa	0	3	1
projection	gross pathology			
A10	navicular bone (flexor cortex) surface	0	3	1
A11	NB cartilage thickness	0	3	1
A12	NB cartilage color	0	3	1
A13	NB cartilage appaerance	0	3	1
A14	DDFT surface	0	3	1
A15	DDFT adhesion	0	3	1

Name	criteria	from	to	factor
A16	DDFT color	0	3	1
A17	DDFT metaplasia	0	3	1

In the DPr-PaDiO view the contour, density, structure, changes in the navicular channels, and the existence of a radiolucent zone (factor 4) were evaluated. In the PaPr-PaDiO view the border between the flexor cortex and medulla, density, structure, the flexor cortex (factor 2), and the existence of a radiolucent zone (factor 4) were noticed. These radiological findings were chosen for interpretation according to recommendations by Dyson 2008 and Butler et al. 2017. Some minor additional findings were documented but excluded from statistical analyses.

To date, there is no information on the DPr-PaDiO view with contrast medium in the NB. So far, only one picture showing the anatomic dimension of the NB has been published in literature (Jann et al. 1991). Figure 1 shows a bursogram without any pathological findings. Due to the lack of information about a DPr-PaDiO CE view, we hypothesized that a tendon tear would lead to a long, straight, and radio dense line (Figs. 2 and 3), a defect in the flexor cortex would manifest as a round, radio dense area (factor 2) (Fig. 4–6), and an adhesion would be represented by a radiolucent zone (factor 2) (Figs. 5 and 6). In addition, bursitis would lead to an irregular filling of the NB. The structure and border of the navicular bone were also graded. The dorsal border of the NB was also in aim, but only noticed as regular (grade 0) or irregular (grade 1), but not used for the statistical analysis.

There is, however, some information about the PaPr-PaDiO CE view (Wuerfel and Hertsch 2005; Turner 2013). Accordingly, the regular filling of the NB and the border to the DDFT, as evidence of dorsal tears or fibrillation (Figs. 2 and 3), or radiodense zones within the navicular bone, as evidence for lesions in the flexor surface, were graded (Factor2). The reported three lines, providing detailed information about the flexor cortex, were only seen in 43 feet. Therefore, they were noticed but excluded from statistical analyses.

In gross pathology the appearance, color, thickness, and the presence of lesions of the flexor surface was graded. Furthermore, the dorsal part of the DDFT was examined including surface, color, adhesions, and changes in appearance (Blunden et al. 2006a, Blunden et al. 2006b). The surface of the cartilage of the DIP joint was also evaluated but excluded from statistical analyses.

Statistic

The obtained scores from x-ray examination and gross pathology were transferred to one table (Microsoft Excel 2010, Microsoft, Redmont, USA). The scores were then summed up and arranged in four groups (group 1 = no findings, group 2 = mild, group 3 = moderate, and group 4 = severe findings). This evaluation was done for each radiographic view and the gross pathology, respectively. The group definition and frequencies are provided in Table 2. Subsequently, results were exported to SPSS (Version 23, IBM, Armonk, USA). Fleiss' kappa was calculated to compare the agreement from x-ray findings and gross

pathology groups. Spearman's rho (ρ) was used to assess the association between the sum of scoring of every x-ray projection and gross pathology. Spearman's rho (ρ) and a Kruskal-Wallis-Test were performed for the sum of classes of native and all pictures compared to the gross pathology groups. Finally, sensitivity and specificity were determined. Therefore, group 1 and 2 were considered negative for changes related to ND and group 3 and 4 positive for each x-ray view and the gross pathology.

Table 2
Group definition and frequencies for all x-ray projections and gross pathology

	DPr-PaDiO	PaPr-PaDiO	DPr-PaDiO CE	PaPr-PaDiO CE	gross pathology
Group1	29 (30.2%)	42 (43.7%)	45 (46.9%)	42 (44.2%)	39 (40.6%)
from	0	0	0	0	0
to	2	3	2	1	3
Group2	54 (56.3%)	35 (36.5%)	28 (29.2%)	19(20.0%	28 (29.2%)
from	3	4	3	2	4
to	5	7	6	3	10
Group3	7 (7.3%)	9 (9.4%	10 (10.4%)	16 (16.9%)	11 (11.46%)
from	6	8	7	4	11
to	9	12	10	5	15
Group4	13 (13.5%)	10 (10.4%)	13 (13.5%)	18 (18.9%)	18 (18.75%)
from	10	13	13	6	16
N Sum	96	96	96	95	96

Results:

In all 96 feet, puncture and contrast medium injection into the NB using the above mentioned technique was successful. There was one (1.1%) foot with a communication of the bursa to the DIP joint. On average 0.92 redirections of the needle were needed, however, there was a great difference between the sets. In the first set the mean number of needle reinsertions and redirections counted 1.4. In the last 38 specimens it was only 0.74 per successful injection.

Table 3 summarizes the Fleiss' kappa values for the different x-ray groups compared with the gross pathology groups. Except for the DPr-PaDiO CE view with, showing a moderate agreement ($\rho = 0.455$; $p = < 0.001$), all other views only showed a fair agreement with gross pathology in the chosen scale. Contrast enhanced views showed a higher agreement between x-ray evaluation and gross pathology compared with native views. Spearman's rho (ρ) between the sum of native radiographs and total gross

pathological evaluation was 0.373 (N = 96, $p < 0.001$), and was 33.9% better combining native and CE radiographs with $p = 0.565$ (N = 95, $p < 0.001$).

Table 3
Fleiss' kappa between each radiographic projection group and the gross pathology group

view	weighting	Fleiss' kappa	Asymptomatic standard error	Z	p value	Lower 95% Asymptotic CI Bound	Upper 95% Asymptotic CI Bound
DPr-PaDiO	linear	0.349	0.080	4.829	$p < .001$ ***	0.191	0.506
PaPr-PaDiO	linear	0.280	0.081	3.963	$p < .001$ ***	0.122	0.438
DPr-PaDiO CE	linear	0.358	0.079	4.891	$p < .001$ ***	0.204	0.512
PaPr-PaDiO CE	linear	0.455	0.071	5.947	$p < .001$ ***	0.315	0.595

The Kruskal-Wallis-Test (Fig. 7) reveals the association between radiological interpretations of native pictures and native plus CE views, respectively, and each gross pathology group. Feet showing severe changes in gross pathology (group 4) have been rated with a significant higher score in both CE and native images. The native pictures have no significant differences between gross pathology group 1, 2, and 3, and there was an overlapping among group 4 and the others. All 4 views combined, a significant difference between group 1 versus group 2 and 3 was found, and there was nearly no overlapping among group 4 and the others. No specimen in group 1 had been rated with a score ≥ 9 .

Table 4 summarizes the test criteria for all radiographs alone and in addition to each other. The sensitivity of all views alone was around 50%, whereas the PaPr-PaDiO CE view reached 72.4%. Then again, this view only has specificity around 80% compared to 90% in the other views. Feet with more than two findings in radiographic examination is definitely a gross pathology group 3 or 4.

Table 4
test values for each view and for all views

view	Sensitivity	specificity	total	Positive predictive value	Negative predictive value	total
DPr-PaDiO	51.7	92.5	147.2	75.0	81.6	156.6
PaPr-PaDiO	44.8	91.0	135.8	68.4	79.2	147.6
DPr-PaDiO CE	55.2	89.6	144.8	70.0	82.2	152.2
PaPr-PaDiO CE	72.4	80.3	152.7	61.8	86.9	148.7
1 finding	86.2	60.6	146.8	49.0	90.9	139.9
2 findings	62.1	93.9	156.0	81.8	84.9	166.7
3 findings	41.4	100	141.4	100	79.5	179.5
4 findings	34.5	100	134.5	100	77.6	177.6

7 out of 10 tears of the DDFT diagnosed in gross pathology were seen in the DPr-PaDiO-CE view, whereas 9/10 were found in the PaPr-PaDiO-CE view. 7 out of 8 extensive adhesion formations were noticed evaluating both projections. A full thickness cartilage lesion in the flexor surface was detected in 10/10 cases in the PaPr-PaDiO-CE view and in 7/10 cases in the DPr-PaDiO-CE view. There were 3 minor adhesions between the navicular bone and the DDFT. All 3 were seen in the PaPr-PaDiO-CE view, whilst 2/3 were detected in the DPr-PaDiO-CE view. Dorsal superficial fibrillation of the DDFT was seen in 52.9% of cases (9/17) in the DPr-PaDiO-CE view and only in 37.5% of cases (6/16) in the PaPr-PaDiO-CE view radiographs. There were 3/13 (23.1%) group 3 and 4/19 (21.1%) group 4 specimens that only had changes in the CE radiographs. From these feet 6/7 showed moderate fibrillation on the dorsal aspect of the DDFT. Two group 3 feet showed one changed native radiograph (one PaPr-PaDiO and the other DPr-PaDiO) but no findings in the CE views. Finally, 2/13 (15.4%) group 3 and 2/19 (10.5%) group 4 feet were not diagnosed with any findings based on radiographs.

Discussion:

The injection technique described above (Turner 2013) represents a successful approach to injecting the NB. This has been reported before (Schramme et al. 2000). Nevertheless, there are some risks. First of all, septic inflammation is likely to be caused by puncture of a synovial structure (Steel et al. 2013), however, these authors reported no case of septic complication in 541 injections. Secondly, the DDFT is pierced during puncture, presumably multiple times due to needle redirections (Labens and Redding 2012). In fact, there is a reported case from DDFT tendinopathy after injection of the NB (Froydenlund et al. 2017). This problem could be avoided by choosing other ways of contrast medium administration (Nottrott et al.

2017), such as an ultrasound guided injection technique (Spriet et al. 2004; Daniel et al. 2016). An additional advantage of the latter is the lower exposure to radiation for the examiner.

The injection of the NB is a crucial part in treating ND (Gutierrez-Nibeyro et al. 2010). Horses with bursitis and DDFT tendonitis usually respond well, whereas horses with adhesions between the DDFT and the navicular bone or with multiple lesions are less likely recover subsequent to intrabursal corticosteroid or hyaluronic acid injection (Marsh et al. 2012). There is some evidence that the normally occurring diffusion of medication from the DIP into the NB (Boyce et al. 2010) is decreased in pathologically changed limbs (Manfredi et al. 2012). Therefore, it is a delicate decision whether to inject the NB or not (Labens and Redding 2012). Here, the standing MRI represents a noninvasive diagnostic tool to facilitate this decision (Murray et al. 2009). The risk of developing colic after MRI under general anesthesia has been reported as 1.5% out of 211 cases (Andersen et al. 2006). The mortality after general anesthesia (excluding colic surgery, no MRI) within five days post-surgery is 0.1% (932 cases) (Laurenza et al. 2020). Hence, MRI under general anesthesia comprises risks around 0.5–1% (Dugdale and Taylor 2016). Moreover, the costs for an MRI in Germany are currently roughly € 1200 to € 1500 compared to € 250 for a bursography.

The first bursographies were performed in order to check if injection was successful (Verschooten et al. 1990) or for anatomical studies (Jann et al. 1991). As reported above, there are many ways to inject the NB. The ultrasound guided injection led to 100% success in 20 horses (Spriet et al. 2004). In a larger survey, difficulties were revealed: in 58/62 specimens (94%) contrast agent was found in the NB alone, as intended, in 2/62 limbs (3%), however, contrast medium was identified in the DIP joint alone, and in 2/62 limbs (3%), contrast medium was found in the soft tissues lateral and proximal to the navicular bone (Nottrott et al. 2017). Other authors reported a success rate of approximately 68% (Perrin et al. 2016). X-ray controlled injection led to a success rate of 82.4% (14/17) (Piccot-Crézollet et al. 2005). Taking these facts into consideration, it is recommended to check a successful injection of the NB with contrast agent medium and a lateral view anyway. In this case, the two more additional radiographs are not a big effort, but will bring an additional radiation exposure. If the contrast agent is mixed with medication the bursograms will look different. The mixture of mepivacaine and sodium meglumine diatrizoate in the digital flexor tendon sheath seems to be harmless in living horses (Fiske-Jackson et al. 2013). Another point to consider is the maximum amount of injection volume.

The results of the present study shows that contrast enhanced radiographic imaging significantly improve the diagnostic evaluation of the navicular apparatus in horses with advanced pathologies. In horses with moderately to severely changed native x-rays, bursography serves as verification for the suspected diagnosis. This is very important, because if a full thickness flexor cartilage defect or adhesions between the navicular bone and the DDFT are found, affected horses will have a poor prognosis with medical treatment (Gutierrez-Nibeyro et al. 2020). In these cases, there is no need for an MRI. But our results also show that there are small but significant differences between group 1 and group 2/3 if the contrast views are considered. Therefore, it is reasonable to conduct a bursography in lame horses whenever an MRI is not possible. In this study, some fibrillations or tears in the dorsal aspect of

the DDFT were partially seen in bursography, but not in native radiographs. These are common findings in the MRI (Dyson and Murray 2007; Gutierrez-Nibeyro et al. 2020). 10.5% of severely and 15.4% of moderately changed specimens did not show any findings in the radiological interpretation scheme used in this study.

Limitations

Because our study design suggested gross pathology as gold standard for diagnosing navicular disease in horses, histological changes were not taken into consideration (Blunden et al. 2006a, b; Komosa et al. 2014). This would particularly be a problem in early stages of the disease. Because no anamnestic information about the horses was available, especially regarding the presence of lameness, our findings rated in gross pathology were based on findings from other authors (Blunden et al. 2006a, b; Komosa et al. 2014) and are not necessarily associated with clinical lameness. Due to the preparation and gross pathological examinations of the surfaces exclusively, pathological changes in the DSIL, CSL, core defects in the DDFT, subchondral changes in the navicular bone and others were excluded from the examination.

All pictures were evaluated by a resident (ACVSMR) under guidance of a Diplomate (ACVSMR). The results could be different if a radiologist, specialized in equine medicine, would have performed the examination. For flexor cortex lysis, a difference between 4th year students, radiology residents, veterinarians with more than five years working experience and radiologists (DACVR) in evaluating the PaPr-PaDiO view has been reported. However, in this examination, the gold standard was a consensus of the radiologists (Johnson et al. 2018). Hence, additional studies need to be done to assess the interrater reliability and the situation in living horses with weight-bearing feet. Additionally, the true LM image of the navicular bone is also an important standard view (Dyson 2008) and was not considered in this study.

As already mentioned above, the visibility of the flexor cortex in the PaPr-PaDiO contrast enhanced view mentioned by Turner (2013) was observed in 43 horses only, and was not further integrated into analyses. From our point of view, there is a simple explanation why this finding was only seen in half of the feet. From the lateral perspective, the filled NB looks round-shaped. As a consequence, if the angle of the PaPr-PaDiO view is flattened, the distal border will be projected on the x-ray film. Applying a medium angle, the middle part, and using a raised angle, the proximal part of the border of the dye column will be found on the x-ray film (Fig. 8). Following this idea, only the x-ray beam parallel to the flexor cortex will project its shadow on the film. This is a known problem in measuring the thickness of the flexor cortex in the PaPr-PaDiO view. In our study, all feet were x-rayed applying the same angle, regardless of individual heel conformation, leading to some variance in the angle hitting the navicular bone.

From our point of view, this is the first study assessing DPr-PaDiO views with contrast medium in the NB with cadaver feet. There may be some more findings we have not noticed yet. Retrospectively, the conformation of both the dorsal and distal border of the NB seems to be an interesting finding in this view, because adhesions in this area are a common feature in ND seen in MRI in lame horses (163/550,

29.4%) (Gutierrez-Nibeyro et al. 2020). Turner (2013) additionally described a leakage from the NB to the DIP joint or other surrounding structures / tissues, respectively, as a pathognomonic feature. This might be better visible in the DPr-PaDiO view and might be a finding possibly even not recognizable in MRI.

Conclusion:

Navicular bursography is an additional, inexpensive, and highly available technique to examine equids with equine palmar soreness. In cases with no or only mild radiological findings, when an MRI is not possible or a therapeutic injection of the NB is intended, the use of contrast medium and specific radiographic projections, as presented in this manuscript, can lead to more information and function as a success control for intrabursal injection. In horses with radiographic findings, bursography can confirm a suspected ND without an expensive MRI. This is very important, because neurectomy, retirement or euthanasia is quite common decisions in these cases.

Abbreviations

PaPr-PaDiO palmaroproximal-palmarodistal-oblique

DPr-PaDiO dorsoproximal-palmarodistal oblique

DDFT deep digital flexor tendon

MRI magnet resonance imaging

CE contrast enhanced

ND navicular disease

NB navicular bursa

DIP distal interphalangeal (joint)

CSL collateral sesamoid ligament

DIL distal impar ligament

Declarations

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Authors' contributions:

CS designed the study, carried out the study, performed statistical analysis, wrote the original draft, and edited and revised the manuscript. CS and JK evaluated the samples. JK and HG performed the study design and concept, and assisted in manuscript review. All authors read and approved the final manuscript.

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Not applicable.

Competing interests:

The authors declare that they have no competing interests.

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Figures

Figure 1

Bursography of group 1 horses. a) and b): palmaroproximal-palmarodistal-oblique and c) dorsoproximal-palmarodistal oblique projection. a) the contrast column has a smooth border to the DDFT and the navicular bone, there is a consistent radiolucent line reflecting the flexor cartilage, b) presumably taken with a slightly different angle, so no radiolucent line palmar of the navicular bone was seen, both border

and filling of the NB are regular, c) the dorsal and distal border of the dye column is even, the filling of contrast medium above the navicular bone is regular

Figure 2

Bursography of one horse. a) palmaroproximal-palmarodistal-oblique, b) dorsoproximal-palmarodistal oblique projection and c) gross pathology (bundle of navicular bone (below) and back-flipped DDFT (above). a) on the left side of the image there is a huge, on the right side a small filling defect in the border to the DDFT, b) the bursa is unevenly filled with contrast medium, there are two distinct lines above the navicular bone, the dorsal border of the navicular bursa is not visible, c) two large splits in the dorsal surface of the DDFT were found in the same location as already supposed in a) and b), and an adhesion between the CSL and the DDFT

Figure 3

Bursography of one horse. a) palmaroproximal-palmarodistal-oblique, b) dorsoproximal-palmarodistal oblique projection and c) gross pathology (as in Fig2), a) on the left side, a pooling of contrast medium in the DDFT is visible, the right pouch of the navicular bursa is not as evenly filled as the left pouch, b) the same findings as in a), c) there is a tendon split as predicted in a) and b) and an adhesion on the right side between the CSL and the DDFT

Figure 4

Diagnostic procedure in one horse. a) dorsoproximal-palmarodistal oblique, b) dorsoproximal-palmarodistal oblique projection with contrast medium and c) gross pathology (as in Fig2), a) there is a round radiolucent zone with surrounding sclerosis (cyst-like-lesion) b) there is a radiodense filling in the suspected radiolucent zone (suspected full thickness lesion), the borders of the navicular bursa seem irregular, c) there is a full thickness cortex lesion as suspected in a) and b)

Figure 5

Bursography of one horse. a) palmaroproximal-palmarodistal-oblique, b) dorsoproximal-palmarodistal oblique projection and c) gross pathology (as in Fig2), a) the filling of the NB is irregular, there is a leakage in the dye column to the DDFT and the navicular bone, there is contrast medium in the visible radiolucent line reflecting an adhesion, flexor cortex lesion and DDFT tears, b) central is a distinct radiolucent area next to an accumulation of contrast medium suggesting an adhesion next to a flexor lesion, c) the predicted pathologies in a) and b) are seen

Figure 6

Bursography of one horse. a) palmaroproximal-palmarodistal-oblique, b) dorsoproximal-palmarodistal oblique projection and c) gross pathology (as in Fig2), a) the filling of the NB is irregular, there is a leakage in the dye column and filling defects to the DDFT and the navicular bone, there is contrast medium in the visible radiolucent line reflecting an adhesion, flexor cortex lesion and DDFT tears, b) there are complex accumulations and leakages of contrast medium suggesting some severe adhesions next to flexor lesions and tendon splits c) the predicted pathologies in a) and b) are seen

Figure 7

Kruskal-Wallis-Test, left side: summation of all radiographs, right side: summation of native pictures only

Figure 8

LM-view of contrast medium application and filling of the NB with marked exaggerated angles of beams for the palmaroproximal-palmarodistal-oblique projection. The flattened angle (1) will hit the distal part of the dye column perpendicularly. The raised angle (2) will be perpendicular to the flexor cortex of the navicular bone so the borders will represent the dorsal layers of these structures. The highest angle (3) will highlight the dorsal layer of the DDFT proximal to the navicular bone.