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ORIGINAL INVESTIGATION

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Computed tomographic contrast tenography of the digital flexor tendon sheath of the equine hindlimb

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Abstract

Pre-surgical investigation of digital flexor tendon sheath pathology remains challenging with current standard imaging techniques. The aim of this prospective, anatomical, pilot study was to describe the anatomy of the equine hind limb digital flexor tendon sheath using a combination of computed tomography (CT) and computed tomographic contrast tenography in clinically normal cadaver limbs. Ten pairs of hind limbs with no external abnormalities were examined from the level of the tarsometatarsal joint distally. Limbs initially underwent non-contrast CT examination using 120 kVp, 300 mAs, and 1.5 mm slice thickness. Sixty millilitres of ioversol iodinated contrast media and saline (final concentration 100 mg/ml) were injected using a basilar sesamoidean approach. The computed tomographic contrast tenography examination was then repeated, before dissection of the specimens to compare gross and imaging findings. The combined CT and computed tomographic contrast tenography examinations provided excellent anatomical detail of intrathecal structures. The borders of the superficial and deep digital flexor tendons, and the manica flexoria were consistently identifiable in all limbs. Detailed anatomy including that of the mesotenons, two of which are previously undescribed, and the plantar annular ligament were also consistently identifiable. Dissection of all 10 pairs of limbs revealed there to be no pathology, in accordance with the imaging findings. In conclusion, the combination of CT and computed tomographic contrast tenography may be useful adjunctive diagnostic techniques to define digital flexor tendon sheath pathology prior to surgical exploration in horses.

KEYWORDS
CT, effusion, horse, lameness, tendon sheath

1 | INTRODUCTION

Pre-surgical evaluation of the digital flexor tendon sheath remains a diagnostic challenge. Current standard diagnostic imaging tests include ultrasonography and contrast radiography, with definitive diagnosis typically being confirmed tenoscopically.[1–3] Numerous causes of tenosynovitis have been described, with the most commonly reported lesion types being longitudinal tears of the deep flexor tendon,[1–3] and tears of the manica flexoria.[1,3] A clear anatomical distribution of lesions has been reported, with 79% of deep digital flexor tendon tears diagnosed in forelimbs; 75% of which occur in the lateral margin, and 85% of manica flexoria tears diagnosed in hind limbs.[1–4] Ultrasonography has been the most widely used diagnostic imaging modality,[5] with reported sensitivities for diagnosing deep digital flexor tendon tears from 36.4% to 71%[3,4,6] and a reported sensitivity of 38% for the diagnosis of manica flexoria tears.[3] Contrast radiography of the digital sheath has been demonstrated to predict manica flexoria tears with an overall sensitivity of 96% and specificity of 80%, and deep digital flexor tendon tears with an overall sensitivity of 57% and specificity of 84%.[7] Similarly, contrast enhanced ultrasonography has been reported to identify 90–100% of surgically created deep flexor tendon lacerations.[8]

Computed tomography (CT) offers a method of viewing anatomy in three dimensions, while enhancing visualisation of soft tissues.[11] Intra-arterial contrast enhanced CT has been used to improve lesion visualisation in the soft tissues of the equine distal extremity.[9–11] With respect to the digital flexor tendon sheath, contrast media can be injected intrathecally,[12] with anatomical soft tissue structures appearing as soft tissue attenuating structures outlined by hyperattenuating contrast medium, thus allowing detailed anatomical visualisation. A recent study has described the CT anatomy of the equine forelimb digital sheath,[12] however no hind limbs were included. Gaining three-dimensional images demonstrating clear anatomical detail could assist in identification of lesion laterality, resulting in more accurate surgical planning of approach and anaesthetic positioning for the horse. Although CT generally currently necessitates general anaesthesia, many of these cases currently undergo tenoscopic evaluation for diagnosis and treatment. Computed tomographic contrast tenography could be carried out within the same anaesthetic event, which in our hospital would be estimated to add 20 min of anaesthetic time.

Several synovial reflections (mesotenons/vinculae) within the digital flexor tendon sheath have been described. Examples include two short mesotenons located medially and laterally within the proximal recess, joining the borders of the deep digital flexor tendon to the adjacent synovial membrane.[13,14] Also documented are a midline mesotenon from the deep digital flexor tendon to the synovial wall at the level of the proximal inter-phalangeal joint,[15–18] and a broad attachment between the palmar/plantar border of the superficial tendon and the plantar annular ligament, sometimes termed the vinculum of the superficial digital flexor tendon.[16]

The aim of the present study was to describe the anatomy of the equine hind limb digital flexor tendon sheath using non-contrast CT and computed tomographic contrast tenography in clinically normal cadaver pelvic limbs.

2 | MATERIALS AND METHODS

The study was a prospective, anatomic, pilot design. Sample size was determined based on specimen availability and consistency of imaging findings.

2.1 | Specimens

A total of 20 (10 right and 10 left) clinically normal distal hind limbs were collected from animals euthanized for reasons other than hind limb lameness, sectioned at the level of the tarsometatarsal joint. Reasons for euthanasia included colic (six), forelimb lameness (three), and bolting behaviour (one). Limbs were examined within 12 h of euthanasia and were deemed to be free from visible or palpable digital flexor tendon sheath abnormalities by two authors, a diplomat of the European College of Veterinary Surgeons (B.F.) and a surgery resident (R.A.).

2.2 | Techniques for computed tomography and computed tomographic contrast tenography

Limbs initially underwent non-contrast CT examination using a sixteen slice multidetector CT scanner (GE Lightspeed 16, GE Healthcare, Buckinghamshire, UK), following a standard hospital protocol of 120 kVp, 300 mAs, and a 1.25 mm slice thickness. The field of view was manually set using a scout scan, which differed for each study, however was collimated to the structures of interest. An image matrix of 512×512 was applied and the images were reconstructed in a detail algorithm. For image acquisition, specimens were placed with the dorsal surface on the human patient table, with the dorsal cortices of the third metatarsal bone and phalanges aligned in a neutral position. The plantar aspect of the distal limb was clipped and contrast medium was injected with a 21-gauge 1.5-inch needle using a basilar sesamoidean approach[19] after synovial fluid aspiration was confirmed. The same operator (R.A., surgery resident) performed all injections. A total volume of 60 ml was injected into each digital sheath; consisting of 20 ml of the contrast agent ioversol 300 mg/ml (Mallinkrodt Pharmaceuticals, Surrey, UK), diluted with 0.9% saline solution (Dechra, Skipton, UK) to a final concentration of 100 mg/ml. The CT examination protocol was then repeated (computed tomographic contrast tenography).

2.3 | Image evaluation

All CT images were retrieved and reviewed using an image analysis workstation (Apple iMac Retina display, Cupertino, USA; OsiriX 8.5, Pixmeo, SARL, Switzerland). Transverse, sagittal, and dorsal planes were evaluated using multi-planar reformatting. Limbs were evaluated from proximal to distal by two readers, the same European College of Veterinary Surgeons diplomat (B.F.) and a diplomat of the European College of Veterinary Diagnostic Imaging (J.D.), using consensus interpretation. Characteristics of the following structures were described: superficial digital flexor tendon, deep digital flexor tendon, plantar annular ligament, manica flexoria, proximal digital annular ligament, distal digital annular ligament, distal digital manica, and eight mesotenons/vinculae. Grading for each structure was categorized as visible/present, or not clearly visible/present. Any structures partially visible were categorized as absent. Images were anonymized so that interpretation was performed blinded to the results of subsequent limb dissection.

2.4 | Gross examination techniques

Gross anatomic dissection of the specimens was then performed by two authors (R.A., surgery resident, and B.F, diplomat of European College of Veterinary Surgeons). The same structures were examined and recorded in the same way as for CT and computed tomographic contrast tenography examinations, as either clearly visible/present or not clearly visible/absent.

3 | RESULTS

3.1 | Computed tomography and computed tomographic contrast tenography

Labeled computed tomographic images are visible in Figures 1–4. Consensus interpretation was achieved in all limbs for all structures.

Table 1 demonstrates the frequency with which each intra-thecal structure was observed in all 20 limbs with CT, computed tomographic contrast tenography, and gross dissection, and with a combination of CT and computed tomographic contrast tenography. Superficial and deep digital flexor tendon borders were visualized in 85% of CTs and 100% of computed tomographic contrast tenographies. The manica flexoria was visible in 70% of CTs and 90% of computed tomographic contrast tenographies. Contrast CT was the only imaging modality enabling visualization of the vinculum of the superficial digital flexor tendon (100%) and other mesotenons, all of which were visible

FIGURE 1 Computed tomography images demonstrating the manica flexoria. A, Transverse non-contrast, B, transverse contrast images at the level of the manica flexoria. Dorsal is to the top. C, Sagittal contrast image. In all images, the black arrows demonstrate the manica flexoria. The red arrow highlights the deep digital flexor tendon. Purple arrow highlights the superficial digital flexor tendon. The proximal (blue arrow) and distal (yellow arrow) recesses of the digital flexor tendon sheath can be seen in the sagittal plane [Color figure can be viewed at wileyonlinelibrary.com]

during anatomic dissection. Non-contrast CT enabled visualization of 80% of plantar annular ligaments, compared with 20% on computed tomographic contrast tenography. The distal digital manica was most effectively observed using computed tomographic contrast tenography (95%), while the proximal digital annular ligament was more effectively visualized using CT (85% visible compared to 35% with computed tomographic contrast tenography). The distal digital annular ligament was visualized in 30% of CT images.

Overall visualization of the superficial and deep digital flexor tendons with a combination of CT and computed tomographic contrast tenography was 100%, and 95% for the manica flexoria, plantar annular ligament, and distal digital manica. The combination of CT and

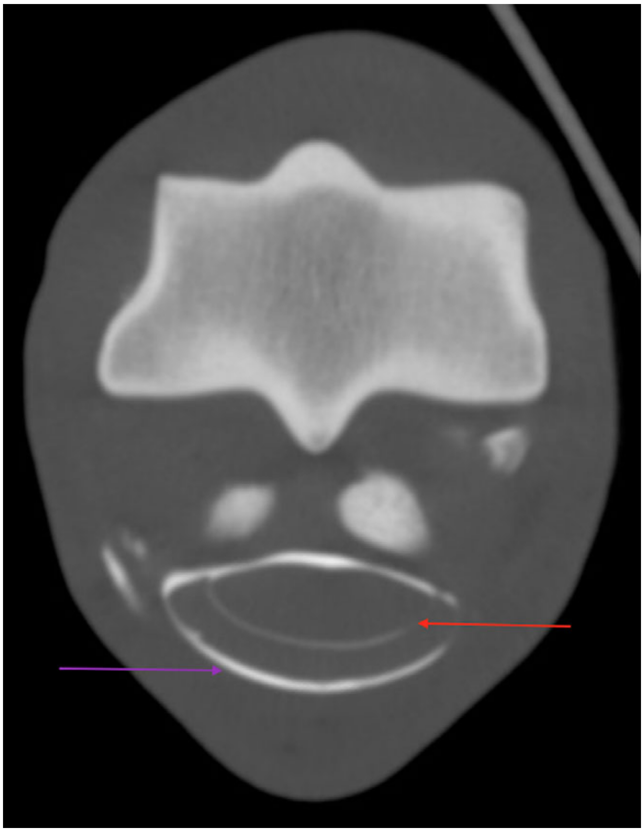

FIGURE 2 Transverse contrast CT image at the level of the distal third metatarsal bone. Dorsal is to the top. The borders of the deep digital flexor tendon (red arrow) and superficial digital flexor tendon (purple arrow) are well outlined [Color figure can be viewed at wileyonlinelibrary.com]

computed tomographic contrast tenography allowed visualization of 100% of the vinculum of the superficial flexor tendon, as well as 100% of the dorsal mesotenons of the deep flexor tendon. Proximolateral and medial deep digital flexor tendon mesotenons were visualized with 90% frequency, as was the proximal digital annular ligament. The distal digital annular ligament was visualized in 40% of limbs. The plantar mesotenon of the deep digital flexor tendon was visible in 20% of limbs.

3.2 | Gross examination (dissection)

In all limbs, there was no evidence of deep digital flexor tendon pathology, all limbs demonstrated an intact manica flexoria, and there was no notable damage to any other structures within the digital sheath. Figures 5 and 6 demonstrate the gross anatomy.

4 | DISCUSSION

The present preliminary study outlines the use of combined CT and computed tomographic contrast tenography for examination of the structures within the hind limb digital flexor tendon sheath in a sample of normal equine cadaver specimens. In these normal specimens, the manica flexoria and the deep digital flexor tendon borders could be reliably identified (95% and 100% respectively) and deemed to be without pathology. Limbs unaffected with sheath swelling or lameness were used in this study in order to first determine the normal appearance of the digital flexor tendon sheath and its associated structures, before further work could be undertaken investigating pathological specimens.

Although manica flexoria tears have recently been reportedly diagnosed with 96% sensitivity,[7] pre-operative diagnosis of deep digital flexor tendon tears remains a diagnostic challenge, with reported sensitivities of 36.4–71%.[3,4,6] Longitudinal tears of the deep digital flexor tendon were first reported by Wright and McMahon, they occur most commonly in the forelimbs (65–94%)[1,2] and are associated with a poorer prognosis compared with other lesions; with 38–42% of horses reported to return to pre-injury exercise levels.[1,2] By contrast, 79% of horses demonstrating manica flexoria tears treated by tenoscopic resection of the manica are reported to return to previous ridden exercise level.[20] Being able to provide owners with an accurate diagnosis prior to exploratory tenoscopy would enable them to make more informed decisions regarding choice of treatment.

A large proportion (up to 85%[2]) of deep digital flexor tendon tears are reported to occur at the lateral border. The majority of equine surgeons perform tenoscopy with the horse in lateral recumbency, with the affected limb uppermost. If, for example, the horse was found at surgery to have a medial border deep digital flexor tendon tear, this would be difficult to debride with the limb uppermost. With computed tomographic contrast tenography and the ability to determine lesion laterality, the horse could be positioned appropriately to facilitate the best surgical access and hence improve outcome. Future study should be directed at investigating this technique for the evaluation of pathologic specimens.

The anatomy of the digital flexor tendon sheath was clearly visible with excellent anatomic detail using CT and computed tomographic contrast tenography. The medial and lateral mesotenons connecting the deep digital flexor tendon to the sheath wall within the proximal recess were consistently identifiable in their expected locations.[13,14] There were two additional mesotenons identified consistently within the proximal recess, running from the medial and lateral edges of the superficial digital flexor tendon to the sheath wall (Figure 5C). These two mesotenons are previously undescribed to the authors' knowledge. The vinculum of the superficial digital flexor tendon was clearly visible in all limbs using computed tomographic contrast tenography, as a broad attachment between the plantar border of the superficial digital flexor tendon to the plantar annular ligament (Figure 2), consistent with the findings of other authors.[13,14,16] The mesotenon running from the deep digital flexor tendon to the sheath wall located distal to the distal digital manica, appeared in all limbs to originate from the plantar wall of the deep digital flexor tendon and be located medially, coursing in a plantaromedial direction. This structure was identified in all dissections, however was only visible in 20% of computed tomographic contrast tenographies and not in any CTs. Proximal to this, the attachment between the superficial digital flexor tendon and the straight sesamoidean ligament at the level of the distal digital manica was consistently located laterally, coursing in a dorsolateral direction. This anatomy has not yet been described in such detail.

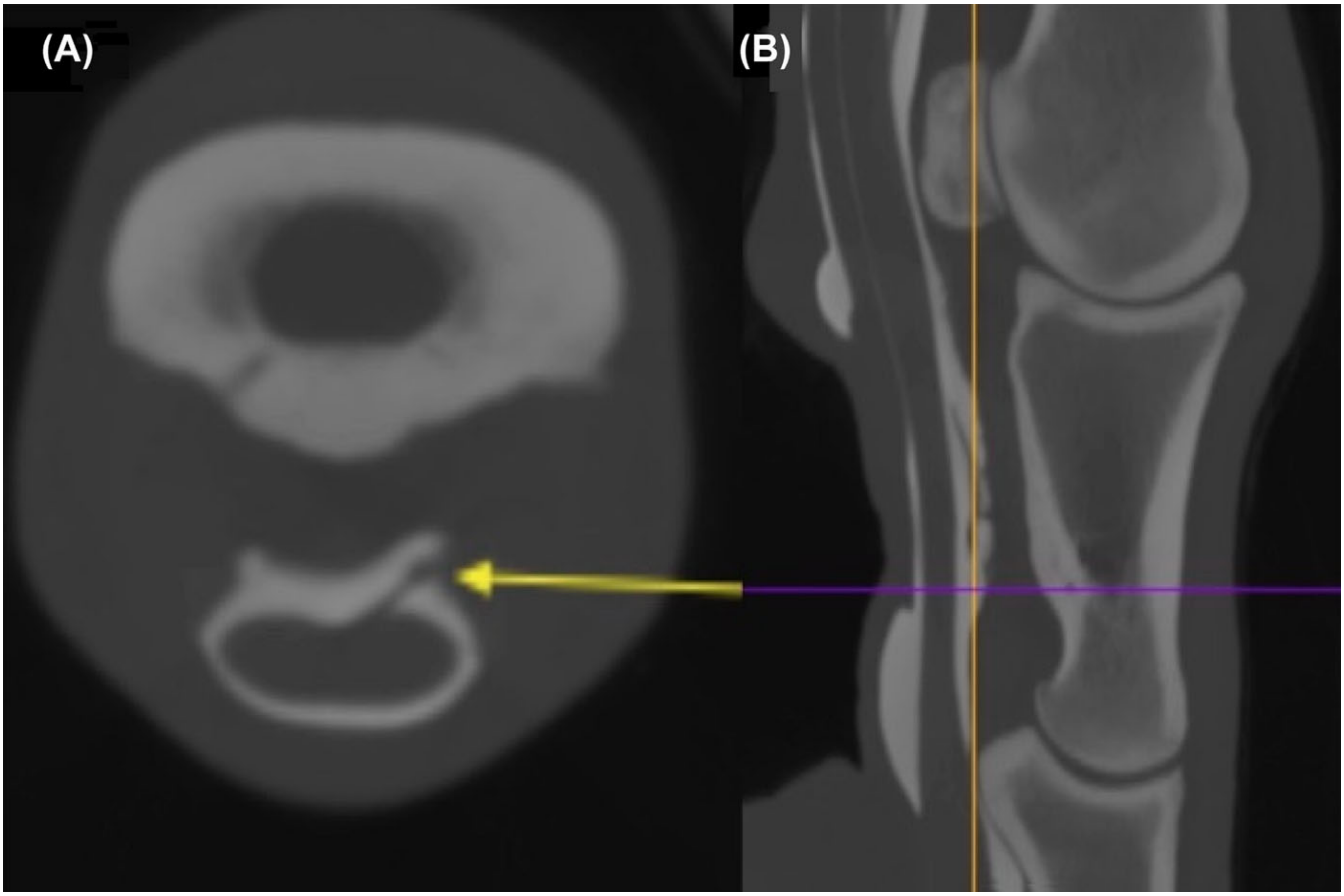

FIGURE 3 A, Transverse contrast CT image, dorsal is to the top. The horizontal purple line in (B) denotes the location of the transverse image, (A). The dorsal mesotenon of the deep digital flexor tendon is indicated by the yellow arrow [Color figure can be viewed at wileyonlinelibrary.com]

The plantar annular ligament was most consistently visible using non-contrast CT, being visualized in 16 out of 20 limbs. Four out of 20 plantar annular ligaments were visible using computed tomographic contrast tenography. This may have been because of the marked hyperattenuation of the contrast agent, such that a blooming artefact obscured the plantar annular ligament. To avoid this problem, the ioversol contrast agent could be further diluted in an attempt to reduce these artefacts, however this has not been investigated.

The digital flexor tendon sheath were distended with a 60 ml total volume in order to assist with visualization of intra-thecal structures. In a small number of limbs, there was slight visible subcutaneous, extra-thecal contrast media accumulation, exiting through the needle tract following its removal. This did not seem to have a negative effect on the quality of images; the only apparent difference was that extra-thecal contrast enabled visualization of the plantar border of the plantar annular ligament on computed tomographic contrast tenographies, actually improving anatomic structure visualization. This problem could be avoided by distending with a lesser volume, or attempting to apply significant pressure with a tight wrap following removal of the needle. While the extra-thecal contrast did not pose a problem in this anatomic study, it is unknown whether this would cause a potential problem in clinical cases with regards to subsequent surgery.

The distal digital annular ligament was difficult to appreciate on either CT or computed tomographic contrast tenography, only being visualized in 40% of limbs using both techniques combined in this study. Magnetic resonance imaging (MRI) has been used to diagnose primary distal digital annular ligament desmitis in a report of seven horses,[21] suggesting that MRI may offer superior visualization of this structure compared with CT. Low field MRI of the standing horse offers an alternative modality with the advantage of negating the requirement for GA. Images of the distal limbs have been shown to allow visualization of soft tissue anatomical detail.[22] Imaging of structures within the digital flexor tendon sheath in a weight bearing horse are likely to be of poorer diagnostic quality due to the strain placed on the plantar soft tissues, particularly the deep digital flexor tendon in this position. High field MRI under GA is a potential alternative, although computed tomographic contrast tenography offers the advantage of increased image acquisition speed over MRI. Direct comparison of imaging of the digital flexor tendon sheath with MRI and CT offers an interesting avenue of future exploration.

Intra-arterial contrast enhanced CT has also been used to evaluate the soft tissues within the equine distal extremity, and although the digital flexor tendon sheath itself has not specifically been explored, there is some evidence to suggest its merits for evaluation of the deep digital flexor tendon and other soft tissues within the foot.[9–11] The use of intra-arterial contrast for evaluation of the structures within the digital flexor tendon sheath also warrants further investigation.

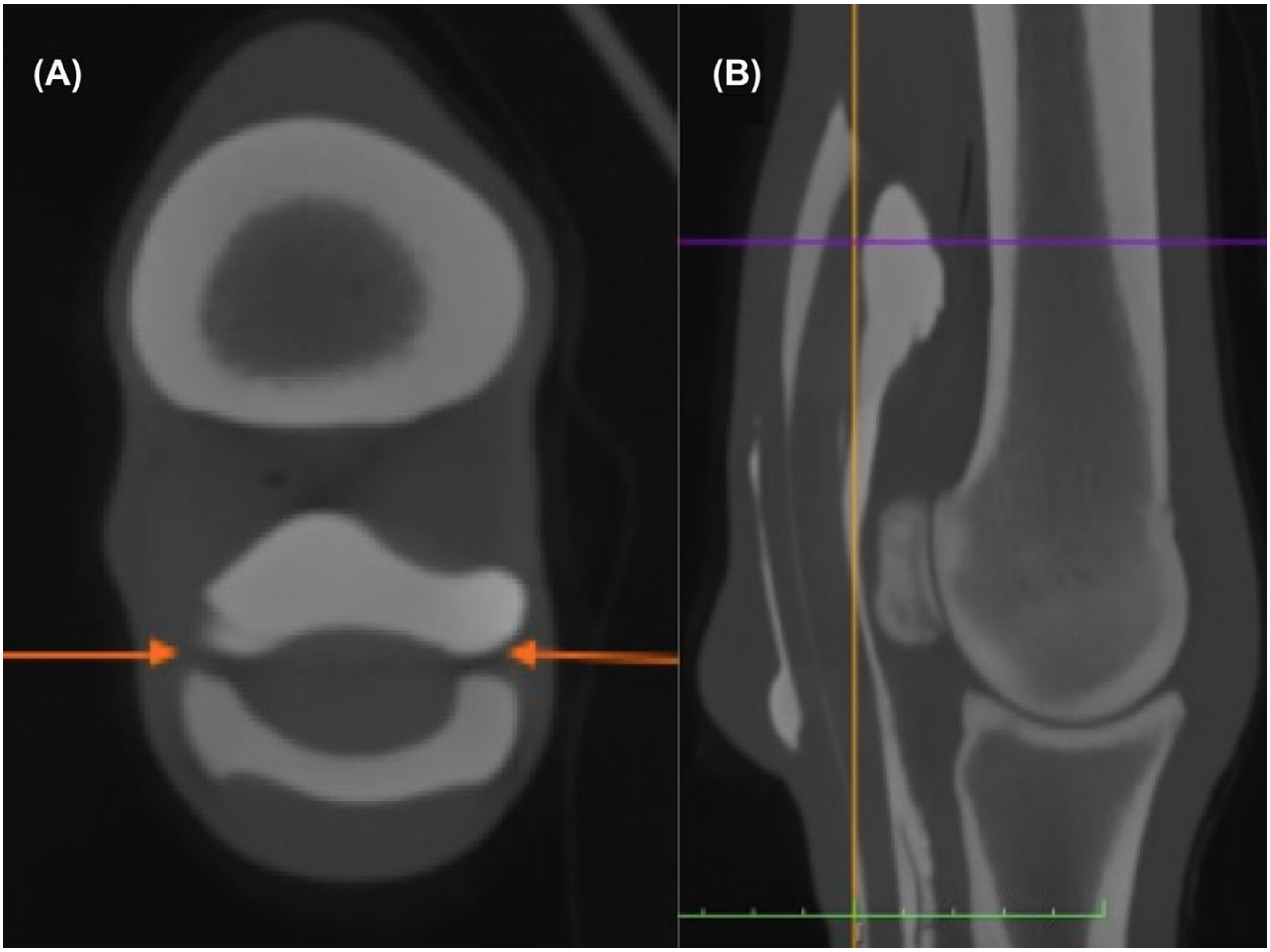

FIGURE 4 Contrast CT image of the proximo-medial and lateral mesotenons of the deep digital flexor tendon (orange arrows). The horizontal purple line in (B) denotes the location of the transverse image, (A), in which dorsal is to the top [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Frequency of identification of digital flexor tendon sheath structures with each imaging modality, and with a combination of computed tomography and computed tomographic contrast tenography in 20 hind limbs

Structure	Plain CT Number (%) $n = 20$	Contrast CT Number (%) $n = 20$	Anatomical Dissection Number(%) $n = 20$	Total Number (%) Visible with a Combination of CT and cCT
Superficial digital flexor tendon border	17 (85%)	20 (100%)	20 (100%)	20 (100%)
Deep digital flexor tendon border	17 (85%)	20 (100%)	20 (100%)	20 (100%)
Manica flexoria	14 (70%)	18 (90%)	20 (100%)	19 (95%)
Plantar annular ligament	16 (80%)	4 (20%)	20 (100%)	19 (95%)
Proximal digital annular ligament	17 (85%)	7 (35%)	20 (100%)	18 (90%)
Distal digital annular ligament	6 (30%)	2 (10%)	20 (100%)	8 (40%)
Distal digital manica	2 (10%)	19 (95%)	20 (100%)	19 (95%)
Proximomedial and lateral mesotenons of deep flexor tendon (4)	0 (0%)	18 (90%)	20 (100%)	18 (90%)
Vinculum of superficial flexor tendon	0 (0%)	20 (100%)	20 (100%)	20 (100%)
Dorsal mesotenon[a] of deep digital flexor tendon	0 (0%)	20 (100%)	20 (100%)	20 (100%)
Dorsal mesotenon[b] of superficial flexor tendon	0 (0%)	20 (100%)	20 (100%)	20 (100%)
Plantar mesotenon[c] of the deep flexor tendon	0 (0%)	4 (20%)	20 (100%)	4 (20%)

Notes. [a]From the deep digital flexor tendon to the sheath wall.
[b]From superficial flexor tendon to straight sesamoidean ligament.
[c]From the deep digital flexor tendon to the sheath wall in the distal recess.
CT, computed tomography; cCT, computed tomographic contrast tenography.

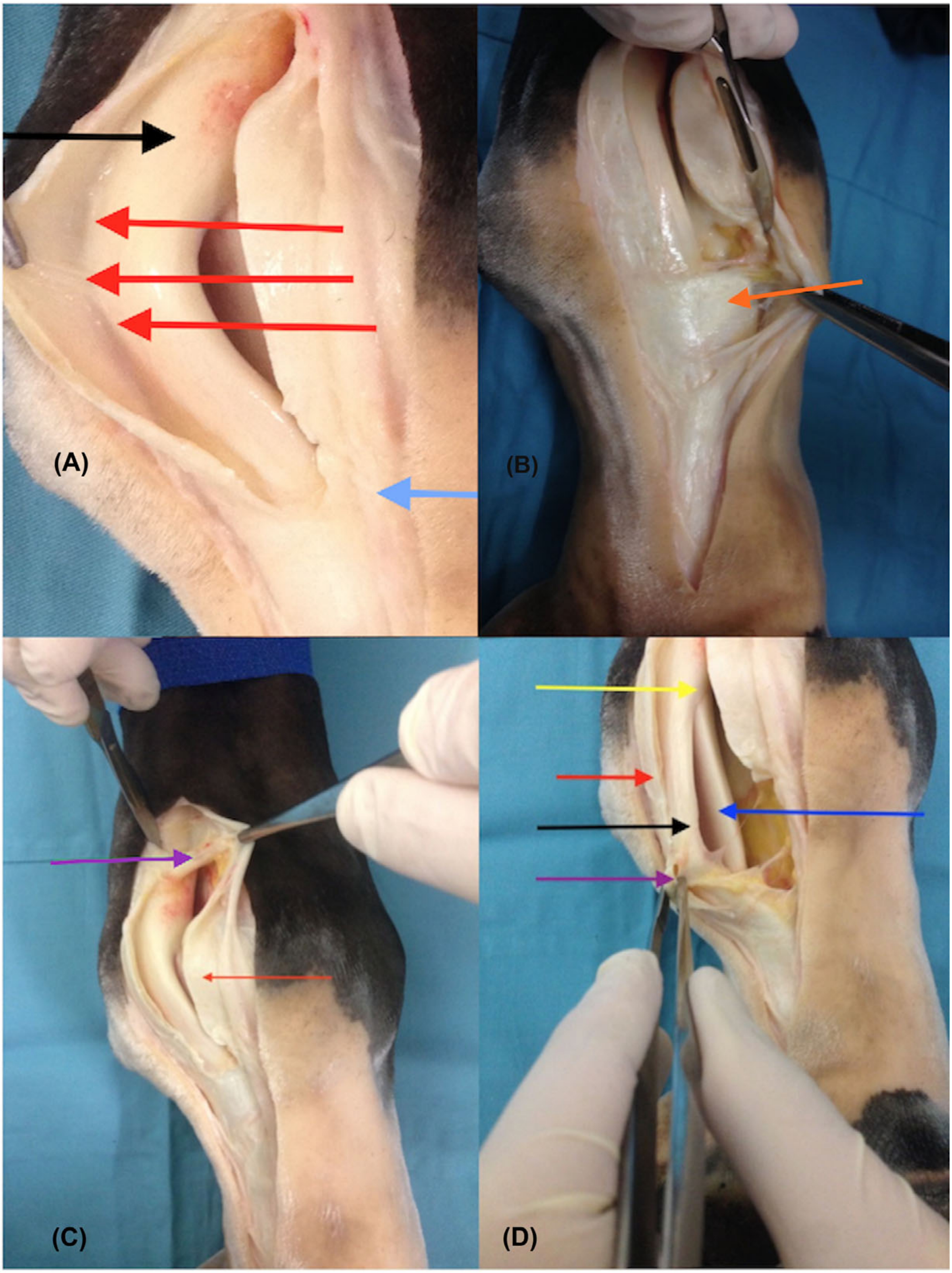

FIGURE 5 All images show a medial view, with dorsal to the right. A, (top left); Superficial dissection of the digital flexor tendon sheath; the black arrow points to the superficial digital flexor tendon. The plantar annular ligament is transected and reflected, demonstrating vinculum of superficial digital flexor tendon; red arrows. The neurovascular bundle is labelled with a pale blue arrow. B, (top right); Superficial dissection of the proximal digital annular ligament. The proximomedial proximal digital annular ligament fibres can be seen coursing to their attachment on the proximal phalanx; orange arrow. C, (bottom left); the purple arrow demonstrates a mesotenon from the edge of the superficial digital flexor tendon to the sheath wall. The plantar annular ligament is transected; orange arrow. D, (Bottom right); proximal digital annular ligament transected. The distal extent of manica flexoria can be seen (yellow arrow). The superficial digital flexor tendon (black arrow) and deep digital flexor tendon (blue arrow) are visualized coursing distally. The purple arrow demonstrates the transected edge of the proximal digital annular ligament. The red arrow shows the cut edge of the plantar annular ligament [Color figure can be viewed at wileyonlinelibrary.com]

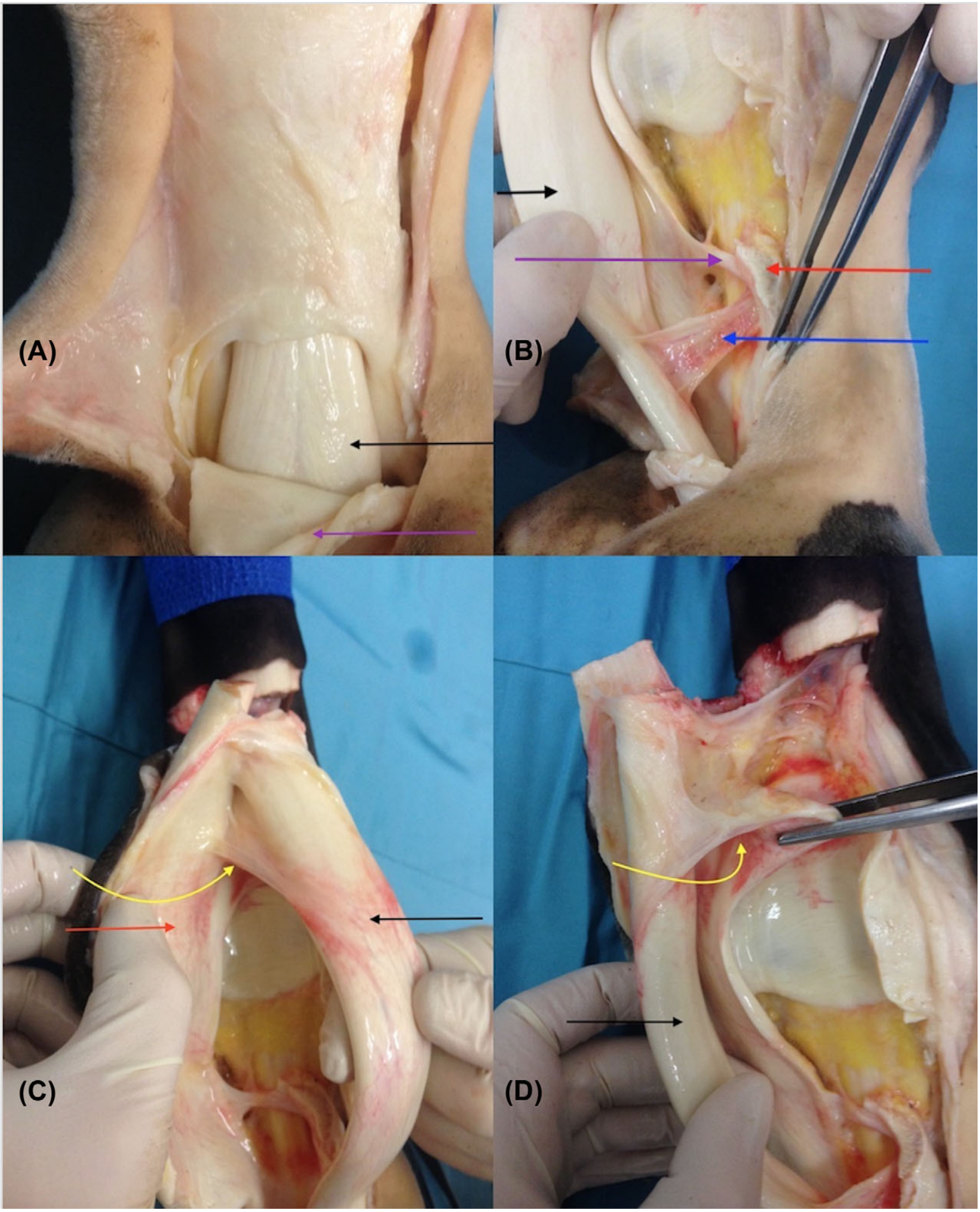

FIGURE 6 A, (Top left); Superficial dissection of the digital flexor tendon sheath, plantar view. Medial is to the right. The distal digital annular ligament and sheath wall are reflected distally (purple arrow) allowing visualization of the deep digital flexor tendon (black arrow). B, (Top right); Medial view, dorsal is to the right. The superficial digital flexor tendon medial branch has been transected (red arrow). The dorsal surface of the deep digital flexor tendon is clearly visible (black arrow). The mesotenon from the deep digital flexor tendon to dorsal aspect of the digital flexor tendon sheath wall can be seen coursing dorsomedially; blue arrow. The purple arrow demonstrates a mesotenon running from the distal digital manica (superficial digital flexor tendon) to the straight sesamoidean ligament and dorsal aspect of the sheath wall. C, (Bottom left); Plantar view, medial to the right. The superficial digital flexor tendon (red arrow) deep digital flexor tendon (black arrow) and manica flexoria are transected proximally. The proximolateral mesotenon of the deep digital flexor tendon can be seen attaching to the lateral aspect of the digital flexor tendon sheath wall within the proximal sheath (yellow arrow). D, (Bottom right); Medial view, dorsal to the right. The proximomedial mesotenon of the deep digital flexor tendon attaching to medial aspect of the digital flexor tendon sheath wall within the proximal sheath can be visualized; yellow arrow. The black arrow denotes the dorsal surface of the deep digital flexor tendon [Color figure can be viewed at wileyonlinelibrary.com]

The computed tomographic contrast tenography procedure itself is straightforward to perform. The basilar sesamoidean approach was selected for contrast administration due to its relative ease to perform in non-distended tendon sheaths, with the odds of obtaining synovial fluid 5.7 times greater than for the axial sesamoidean approach.[11] The total time taken for two CT scans along with contrast administration, allowing for sterile preparation in a clinical case is around 20 minutes. General anesthetic time is therefore short, thus reducing associated anesthetic risk.[23] The CT procedure can be carried out during the same anesthetic period as surgery, providing the imaging findings do not indicate that a change in anesthetic recumbency would be indicated. Anesthetic time is therefore prolonged by 20 minutes with the addition of CT, a risk we believe to be outweighed by the potential benefits of information gained with regard to lesion type, location, and laterality.

In conclusion, findings from this study provide the foundations for further investigation of the utility of CT and computed tomographic contrast tenography in horses with pathology involving the hind limb deep digital flexor tendon sheath. Further work is required to determine the sensitivity and specificity with which lesions can be identified in either clinical cases or artificially created pathologic specimens.

LIST OF AUTHOR CONTRIBUTIONS

Category 1

(a) Conception and Design: Fraser B, Agass R

(b) Acquisition of Data: Agass R, Fraser B

(c) Analysis and Interpretation of Data: Dixon J, Fraser B

Category 2

(a) Drafting the Article: Agass R

(b) Revising Article for Intellectual Content: Fraser B, Dixon J

Category 3

(a) Final Approval of the Completed Article: Agass R, Fraser B, Dixon J

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