Received: 2 January 2017 | Revised: 11 February 2018 | Accepted: 16 February 2018
DOI: 10.1111/vru.12628

ORIGINAL INVESTIGATION

WILEY

Mineralization can be an incidental ultrasonographic finding in equine tendons and ligaments

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Abstract

Tendon/ligament mineralization is recognized in horses but information regarding its clinical significance is limited. The aims of this observational study were to report the structures most commonly affected by ultrasonographically detectable mineralization and, for these, determine frequency of diagnosis and key clinical features. Cases presented at our hospital in April 1999–April 2013 and September 2014–November 2015 were included: a total of 27 horses (22 retrospective, five prospective). Mineralizations were most common in deep digital flexor tendons (10) and suspensory ligament branches (eight), representing 10% and 7% (estimated), respectively, of horses diagnosed with injuries to these structures during the study. Two deep digital flexor tendon and three suspensory ligament branch cases showed bilateral mineralization. Deep digital flexor tendon mineralization was restricted to the digital flexor tendon sheath, most commonly in the proximal sheath (±sesamoidean canal), and seven of 10 cases involved hindlimbs. Suspensory ligament branch mineralization was visible in the same ultrasound window as the proximal sesamoid bones in 10/11 limbs and six of eight cases involved forelimbs. Previous corticosteroid medication was a feature of one deep digital flexor tendon and one suspensory ligament branch case. Mineralization was associated with lameness in some but not all limbs. Mineralized foci within the deep digital flexor tendon preceded hypoechoic lesion formation in two limbs. Of the cases with deep digital flexor tendon or suspensory ligament branch injury only, one of three and two of three cases, respectively, became sound. Findings indicated that tendon/ligament mineralization can be associated with lameness in some horses, but can also be an incidental finding.

KEYWORDS
calcification, Doppler, horse, ossification

1 | INTRODUCTION

Mineralization of tendons and ligaments has been reported in both equine and human patients. In horses, mineralization is an occasional finding during ultrasound examination and has been described within the superficial and deep digital flexor tendons, the suspensory ligament, the peroneus tertius tendon, the plantar ligament, the nuchal/supraspinous ligament and the biceps brachii tendon, and the palmar/plantar annular ligament.[1–4] It has been suggested that deep digital flexor tendon mineralization is most prevalent in middle aged Warmblood horses used for dressage or show jumping and that previous intrathecal corticosteroid medication may be a risk factor.[5] In addition, superficial digital flexor tendon mineralization has been reported as a complication of intratendinous injection with methylprednisolone acetate.[6] However, published information regarding the clinical significance of tendon and ligament mineralization in horses is currently limited.

Half of the human patients with mineralization of the rotator cuff tendons are asymptomatic,[7] but in symptomatic individuals, treatment aimed at resolving mineralization can improve comfort.[8,9] These observations suggest that mineralization can be a primary cause of tendon pain. In addition, in human patients, associations between pain and both mineralization morphology and the presence of Doppler signal have been reported.[7]

The diagnosis of rotator cuff mineralization using ultrasonography and radiology has been compared and three types of mineralization are described.[10] The first type was a hyperechoic focus with well-defined shadow, the second was a hyperechoic focus with faint shadow, and the third was a hyperechoic focus with no shadow, although some false positive diagnoses were identified in the latter group. Equine tendinopathy has been reported to frequently have a bilateral presentation[11] while, in human patients, mineralization of the rotator cuff tendons was only present bilaterally in 10% of affected patients.[12] In contrast, a murine model of unilateral tendon injury resulted in accelerated mineralization both at the site of injury and in the contralateral tendon.[13]

Our first aim was to identify the structures most commonly affected by ultrasonographically detectable mineralization in horses. Second, we aimed to determine for these commonly affected structures (the deep digital flexor tendon and suspensory ligament branch) the frequency of diagnosis and bilateral occurrence of mineralization. Our third aim was to report the clinical features of these cases including the relationship of mineralization with corticosteroid medication, lameness, Doppler signal, other evidence of injury, and outcome.

2 | MATERIALS AND METHODS

The study employed a retrospective and prospective observational design. For the retrospective phase, hospital records for patients examined between April 1999 and April 2013 at the Royal Veterinary College were searched for cases of tendon/ligament mineralization diagnosed by the second author using ultrasonography. A 'case' was defined as a single animal affected by mineralization within a single structure (for example, the deep digital flexor tendon on one limb) or bilaterally within the same structure. The occurrence of mineralization in more than one structure within the same animal was considered as a separate case for each affected structure. Ultrasonographic examinations performed in each pair of fore or hind limbs included weight bearing transverse and longitudinal grayscale scans with a standoff. Later examinations also included transverse off incidence (Figure 1)[14] scans and examination for color Doppler signal (non-weight bearing, without standoff). Most animals were sedated (alpha 2 agonist ± butorphanol) to enable examination. Diagnostic criterion was the presence of hyperechoic foci casting acoustic shadows within or on the surface of a tendon or ligament visible in either or both transverse and longitudinal planes. Surface hyperechoic foci casting a shadow were included because of the difficulties in establishing the deep surface of the mineralization and their intimate relationship implied involvement with the structure.

Cases of enthesiopathy (categorized as echogenic shadows continuous with bone), avulsion fractures (categorized as echogenic shadows within tendon/ligament adjacent to bone with corresponding defects within the bone), mineralization adjacent but outwith the tendon or ligament were excluded. Cases of foreign body penetration were excluded based on the absence of the following three features: visible or reported wounding, reverberation artifacts, and defined foreign body shape.

For the prospective phase, horses diagnosed with tendon/ligament mineralization at the Royal Veterinary College during the period of September 2014–November 2015 were included. The ultrasonographic examination of cases in this phase was the same as for the later cases of the retrospective study. In both phases, animals underwent single or multiple examinations depending upon clinical progress. Oversight of study protocols was provided by the Royal Veterinary College Clinical Research Ethical Review Board (Project number URN 2015 1364).

Clinical features of the two most common categories (deep digital flexor tendon and suspensory ligament branch) were re-evaluated by

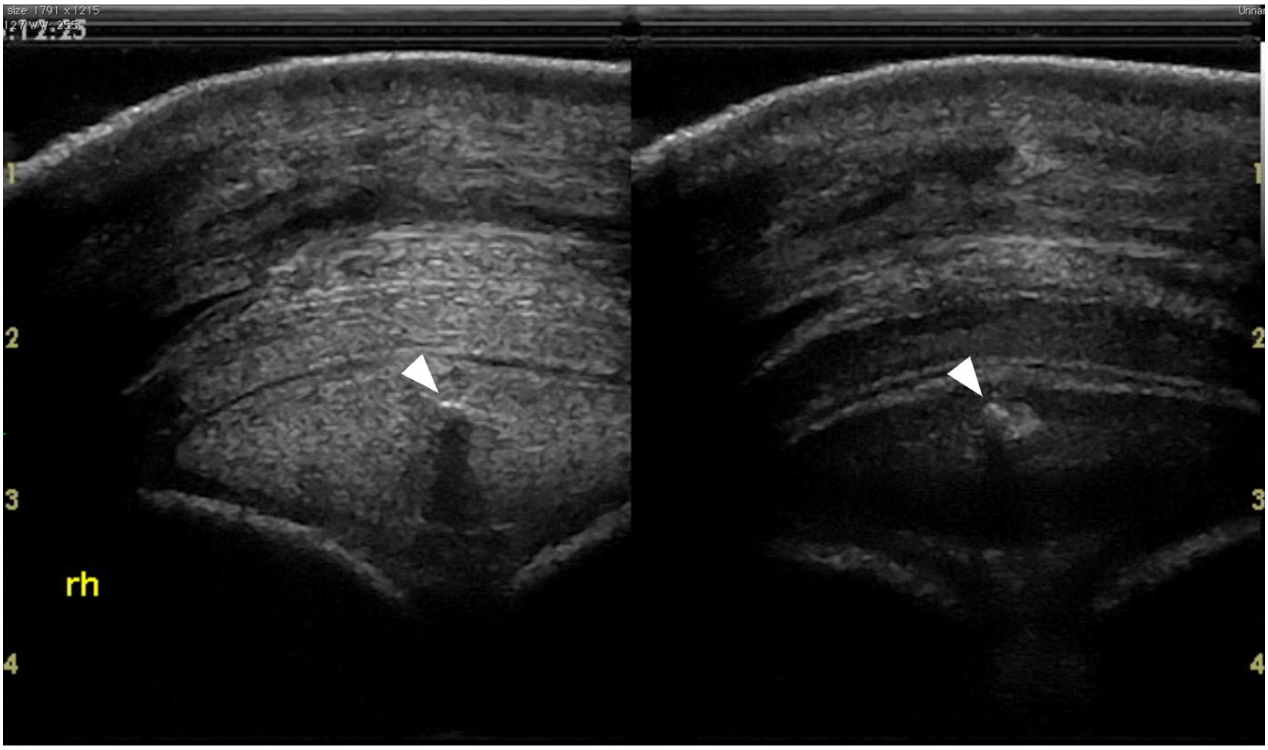

FIGURE 1 Examples of the use of on- (left) and off- (right) incidence transverse views to aid identification of mineralization (arrowheads). This mineralization was poorly defined but focal [Color figure can be viewed at wileyonlinelibrary.com]

the first author. For the retrospective phase, ultrasound images, where available, were reviewed to verify the written reports. For both phases, the dimensions of the mineralization were measured from representative images (both phases) using image analysis freeware (the Fiji distribution of ImageJ[15]). Mineralization morphology was subjectively graded as 'well defined' or 'poorly defined' and distribution assessed as 'focal' or 'diffuse'. Information on return to work was obtained by telephone call to the owner (retrospective and prospective cases).

The frequency of mineralization diagnosis in lame horses was estimated as follows: first, for the deep digital flexor tendons and suspensory ligament branches, the number of animals with any ultrasonographic lesions (i.e., not limited to mineralization) diagnosed by the second author during the years 2000, 2006, and 2012 was determined from hospital records and expressed as an estimated annual mean. Then, for each structure, estimated frequency of mineralization diagnosis (%) was calculated as 100 × (Sum of mineralization cases April 1999–April 2013)/ [14 × (estimated annual mean number of cases with any ultrasonographic lesions)].

Data collected from medical records of cases included the following: signalment when mineralization was identified and limbs involved; location of mineralization; treatment history including peritendinous/ligamentous medication; alteration of mineralization (assessed subjectively); association of mineralization with lameness; duration of lameness prior to identification of mineralization; relation of mineralization to other signs of tendinopathy/desmopathy; presence of color Doppler signal (not all cases); relation of mineralization to surgical findings; and outcome. Association with lameness was defined as 'associated', 'not associated', or 'unproven association', based on intrathecal analgesia or history (deep digital flexor tendons), and regional analgesia or pain on palpation (suspensory ligament branches).

3 | RESULTS

3.1 | Identification of most commonly affected structures

The distribution of tendon/ligament mineralization in 27 cases is listed in Table 1. The majority of mineralization was detected in the deep digital flexor tendons and the suspensory ligament branches (37% and 30% of cases, respectively). Mineralization was not documented in more than one type of tendon or ligament in any horse.

TABLE 1 Distribution of mineralization detected ultrasonographically within equine tendons and ligaments

Structure	Number of cases
Deep digital flexor tendon	10 (2)
Suspensory ligament branch	8 (1)
Superficial digital flexor tendon	2
Intersesamoidean ligament	2 (1)
Oblique distal sesamoidean ligament	2 (1)
Lateral collateral ligament of stifle	1
Manica flexoria	1
Palmar carpal ligaments	1
Total number of cases	27

(Number of cases examined prospectively)

For the retrospective phase, ultrasound images were available for all deep digital flexor tendon cases and all ligament branch injury cases but one.

3.2 | Ultrasound technical parameters (retrospective and prospective phases)

During the study, two ultrasound machines (Vingmed System 5 and Vivid 7; GE Medical Systems Limited, Chalfont St Giles, Bucks, UK) with linear probes (7.5–14 MHz) were used. To examine color Doppler signal with the Vivid 7, a Doppler frequency of 7.5 MHz with a pulse repetition frequency of 1.0 kHz was used. The settings used for examinations with the Vingmed System 5 were not available.

3.3 | Estimated frequency of mineralization diagnosis

For deep digital flexor tendons and suspensory ligament branches, mineralization was estimated to be present in 10% and 7%, respectively, of animals with ultrasonographic abnormalities of these structures. During the 3 years used to estimate these frequencies, the mean number (±standard deviation) of deep digital flexor tendon and suspensory ligament branch injury diagnoses were 5.7 (±0.6) and 7 (±2.6), respectively.

3.4 | Details of cases including bilateral occurrence of mineralization

Ten cases of deep digital flexor tendon mineralization were reported, four were female and the remainder were geldings. Breed type was reported as follows: Thoroughbred (1); Arab (1); Cleveland Bay (1); Thoroughbred cross or Warmblood (5); Cob (1); or Unknown (1). Mineralization was found in mature horses with a median age of 13.5 years (range 3–18 years). In seven cases, one or both hind limbs were affected, the remaining cases involved the forelimbs. In two cases, mineralization was identified bilaterally (one forelimb and one hindlimb pair).

Of the eight cases of suspensory ligament branch mineralization, two were female and the remainder geldings. Breed type was reported as follows: Thoroughbred (2); Thoroughbred cross or Warmblood (4); Irish Sports horse (1); or Crossbreed (1). The median age was 8 years (range 5–17 years). In six cases, the forelimbs, and in the remainder, the hind limbs, were involved. Mineralization was documented unilaterally in four cases, bilaterally (two or more branches on contralateral limbs) in three cases and either uni- or bilaterally in the other cases (record unclear).

3.5 | Clinical features

3.5.1 | Location of mineralization

Deep digital flexor tendon mineralization was recognized only within the digital flexor tendon sheath which was divided into two anatomic

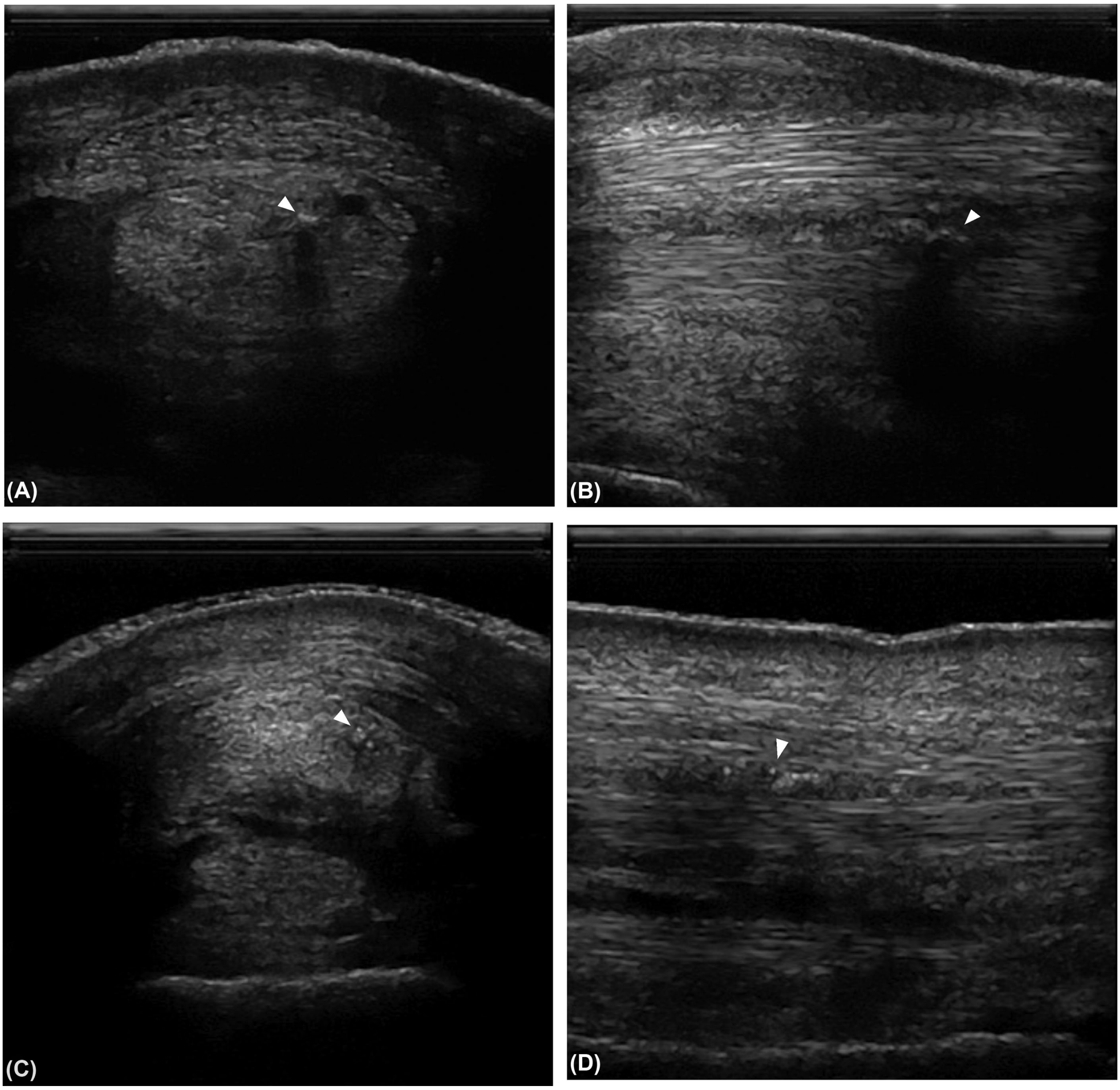

FIGURE 2 Transverse and longitudinal ultrasound images from deep digital flexor tendon case 3 (A and B) and deep digital flexor tendon case 4 (C and D) showing mineralization (arrowheads) in the proximal and distal digital flexor tendon sheath. In both locations the mineralization was poorly defined but focal

levels: proximal sheath (±sesamoidean canal) and distal. Mineralization was restricted to the proximal sheath (±sesamoidean canal) in six cases (one bilateral, five unilateral; Figure 2) and was within both the proximal (±sesamoidean canal) and distal digital flexor tendon sheath in four cases (one bilateral, three unilateral).

In general, mineralization was situated within the center and palmar/plantar aspects of the deep digital flexor tendon. Mineralization was not restricted to the dorsal tendon surface in any case. In all but one case (unilateral), suspensory ligament branch mineralization was visible in the same longitudinal ultrasound window as a portion of the respective proximal sesamoid bone.

3.5.2 | Mineralization dimensions, morphology, and distribution

All deep digital flexor tendon mineralizations were poorly defined but focal within the affected anatomic levels. (Figures 1, 2 and 4, and 6). Mineralizations in the proximal digital flexor tendon sheath (12 limbs/10 cases) measured 11.3 ± 5.9 mm long in longitudinal images and 4 ± 3.0 mm wide in the transverse images (mean ± standard deviation). Distal digital flexor tendon sheath mineralizations (five limbs/four cases) measured 13.8 ± 9.4 mm long in the longitudinal images and 2 ± 0 mm wide in the transverse images.

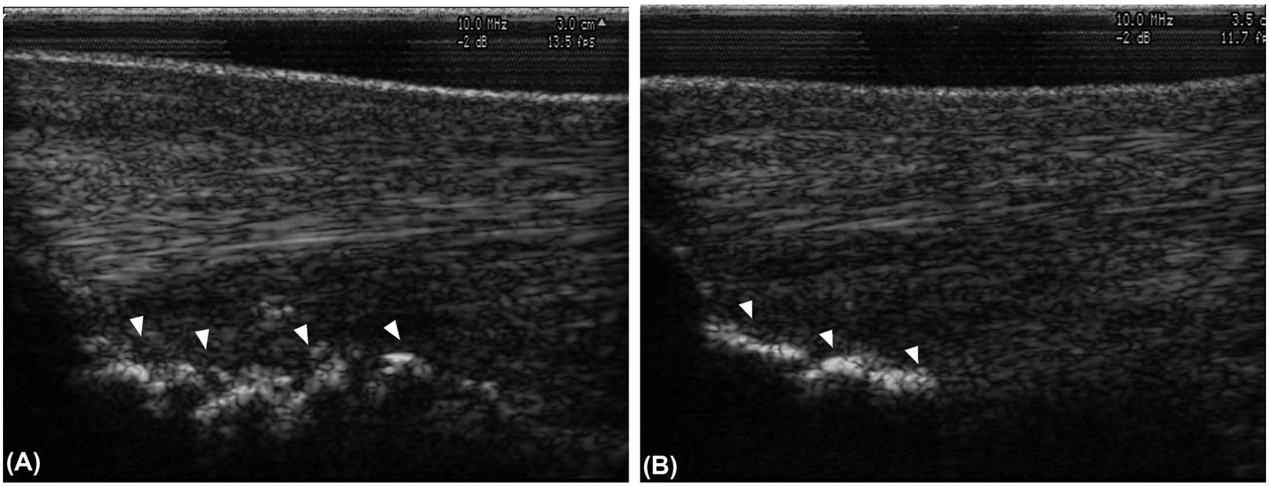

FIGURE 3 Example of mineralization of the suspensory ligament branch when first identified (A) and 7 weeks later (B) by which time it had become more focal but remained poorly defined (arrowheads)

Suspensory ligament branch mineralization was also poorly defined but diffusely distributed and difficult to accurately measure in the majority of cases (Figure 3). In longitudinal images, the length of the branch over which the mineralization was distributed varied between a few millimeters to at least 30 mm.

3.5.3 | Relationship between mineralization and corticosteroid medication

For the deep digital flexor tendon cases, there was a history of intrathecal medication prior to documentation of mineralization in only one case (unilateral). In this horse, the digital flexor tendon sheath of the affected deep digital flexor tendon had been medicated 6 weeks prior to referral.

For the suspensory ligament branch cases, in one case (unilateral), the fetlock joint had been medicated within 2 months of suspensory ligament branch mineralization being identified on the contralateral limb. In a second case, bilateral forelimb fetlock joint medication had been performed 2 years prior to the identification of unilateral forelimb suspensory ligament branch mineralization. There was no history of joint medication recorded for any other cases.

3.5.4 | Alteration of mineralization

Three cases of deep digital flexor tendon and two cases of suspensory ligament branch mineralization had sequential examinations. For two cases of deep digital flexor tendon mineralization (each unilateral), no progression was noted between examinations 1–3 months apart and in the third case mineralization was documented in the non-lame leg initially but detected in the lame leg 1 month later. Mineralization was noted to become more focal for one suspensory ligament branch case (unilateral) after 7 weeks (Figure 3) and unchanged over 10 months in the second case (bilateral).

3.5.5 | Association of mineralization and lameness

Mineralization of the deep digital flexor tendon was subjectively associated with lameness based on a positive response to intrathecal analgesia in six of 12 limbs (six cases). Of this subgroup, mineralization was within the proximal digital flexor tendon sheath (±sesamoidean canal) in two and for the other four, the mineralization was present in both the proximal and distal digital sheath. In five of these limbs, additional deep digital flexor tendon lesions were identified either ultrasonographically (in two cases after a 5–11 week delay) and/or tenoscopically, and in one limb, a superficial digital flexor tendon lesion (not mineralization), considered more likely to be the cause of the lameness, was present.

However, mineralization was not considered to be a cause of lameness in three of 12 limbs (three cases). One case was sound (one limb; mineralization in the proximal digital flexor tendon sheath). In another case, mineralization was bilateral but lameness was completely eliminated by unilateral intrathecal analgesia (mineralization in the proximal digital flexor tendon sheath on both limbs). In a third case (one limb; mineralization in the proximal digital flexor tendon sheath) lameness was acute onset (manica flexoria tear) in the non-mineralized limb. For the remaining three of 12 limbs (two cases), an association with lameness was unproven. In one case, unilateral lameness of the mineralized limb was markedly improved but not resolved following a palmar digital block. In the second case with bilateral mineralization, lameness was substantially improved but not eliminated by unilateral analgesia. As the lameness was not completely eliminated in these two cases, an association between mineralization and lameness could not be excluded.

Suspensory ligament branch mineralization was subjectively associated with lameness by either regional analgesia or palpation in six of 11 limbs (six cases). But, similar to the deep digital flexor tendons mineralization, not all mineralization in the suspensory ligament branch were subjectively associated with lameness (two of 11 limbs). One case was sound when examined (unilateral) and in one case with bilateral mineralization, blocking the contralateral limb eliminated the lameness and no switch occurred. For the remaining three of 11 limbs (three cases), the association of mineralization with lameness was unproven due to incomplete information or failure to eliminate lameness on the contralateral limb.

3.5.6 | Duration of lameness prior to identification of mineralization

Of the six cases with lameness localized to the mineralized deep digital flexor tendon, the duration of lameness before documentation of mineralization (by the referring clinician or at the Royal Veterinary College) was available for four cases (all unilateral) and ranged from 2 days to 6 months. For the six cases with lameness localized to the mineralized suspensory ligament branch, information on duration of lameness before documentation of mineralization ranged from 7 weeks to 5 months for three cases (one uni- and two bilateral).

3.5.7 | Concurrence with other signs of tendinopathy/desmopathy

Deep digital flexor tendon mineralization was present with other ultrasonographic evidence of tendinopathy (as defined by the presence of hypoechoic lesions and/or adjacent poor fiber pattern) in six limbs (five cases). For three of six limbs (three cases), there was other evidence of tendinopathy at the same time as the mineralization was identified and these lesions were associated with lameness in two limbs (positive intrathecal analgesia) and not associated in the third limb. In two of six limbs (two cases; retrospective phase) mineralization was the only abnormality detectable ultrasonographically at the first examination but between 5 and 11 weeks later, these cases developed hypoechoic lesions within their deep digital flexor tendons (Figure 4). In both of these cases, lameness was localized to the digital flexor tendon sheath by intrathecal analgesia at the first examination. In one of six limbs (retrospective phase), mineralization was identified 4 weeks after evidence of tendinopathy and there was a positive response to intrathecal analgesia at that time. There was no other ultrasonographic evidence of tendinopathy in the remaining six limbs (five cases). These cases were either sound (one unilateral), lame in the contralateral limb (three limbs), or had other lesions (two limbs; intrathecal superficial digital flexor tendon lesion and foot pain, respectively) within the lame limb, which were considered more likely to explain the lameness.

Eight limbs (six cases) with suspensory ligament branch mineralization showed other evidence of desmitis, including entheseopathy, heterogeneous fiber pattern/hypoechoic foci (at least five limbs), and enlargement. These lesions were associated with lameness in five limbs (five cases), not associated in one limb and had an unproven association in two limbs (two cases). Two limbs (two cases) showed no other evidence of desmitis. Of these cases, one was sound and the second underwent surgery to treat impingement on the suspensory ligament by the second metacarpal bone. In the remaining limb, mineralization was documented following surgery to remove a proximal sesamoid bone fracture and details of the pre-operative examination were not available.

3.5.8 | Mineralization and Doppler signal

Results for six deep digital flexor tendon cases (six limbs) evaluated for color Doppler signal are shown in Figure 5. In both limbs where Doppler signal was present in the tendon, the mineralization was associated with lameness (positive intrathecal analgesia). There were two limbs positive to intrathecal analgesia but without deep digital flexor tendon Doppler signal, and one of these had an intrathecal superficial digital flexor tendon lesion (with Doppler signal) thought to be the cause of the lameness.

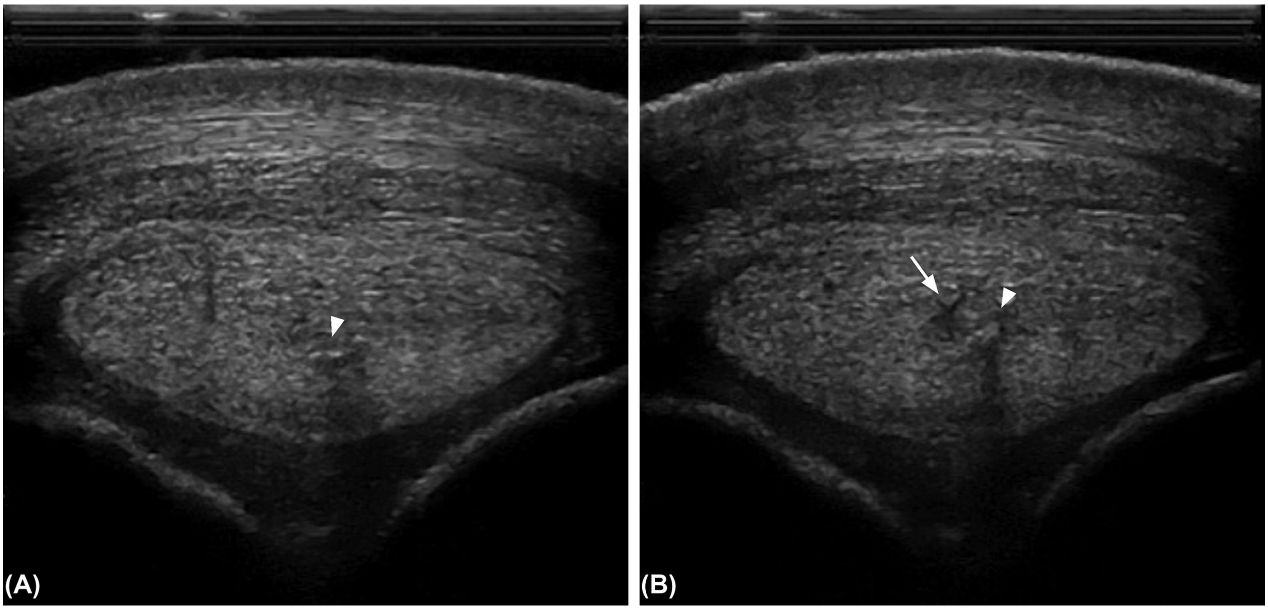

FIGURE 4 Transverse ultrasound images from deep digital flexor tendon case 5 showing poorly defined focal mineralization at first examination (A; arrowhead). There was no other ultrasonographic evidence of tendinopathy at this time. One month later a hypoechoic lesion (arrow) had developed adjacent to this mineralization (B)

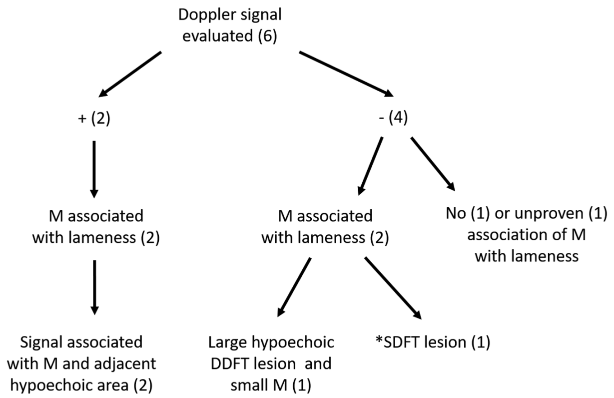

FIGURE 5 Overview of six limbs with deep digital flexor tendon (DDFT) mineralization (M) evaluated for color Doppler signal. +, positive Doppler signal in the affected tendon; −, absence of Doppler signal in the affected tendon; (number of limbs). Association of mineralization with lameness was based on positive digital flexor tendon sheath analgesia. *SDFT, intrathecal superficial digital flexor tendon lesion (not mineralization) which demonstrated Doppler signal

An example of Doppler signal related to deep digital flexor tendon mineralization and adjacent hypoechoic areas (two limbs/cases) is shown in Figure 6. Hypoechoic areas were distinguished from blood vessels by appearance, location, and absence of Doppler signal. In both limbs, the hypoechoic areas were identified at a second ultrasound examination, but in neither case was Doppler signal tested for when the horse was first scanned.

Three of the suspensory ligament branch cases (three limbs) were examined for color Doppler signal. Like the deep digital flexor tendon cases, the single limb with signal adjacent to the mineralization had lameness localized to the affected branch. The other two limbs demonstrated no Doppler signal related to the mineralization: one case diagnosed with second metacarpal bone impingement on suspensory ligament (Doppler signal related to the impingement only); and the second case was sound when examined.

3.5.9 | Relationship of mineralization with tenoscopic abnormalities

Tenoscopy was performed on six limbs (five cases) affected by deep digital flexor tendon mineralization. In five of these limbs, there was no defect on the surface of the tendon. In one limb, the epitenon overlying an intratendinous deep digital flexor tendon defect was disrupted and in another, a longitudinal deep digital flexor tendon tear was found.

3.5.10 | Outcome

Follow-up was available for eight cases of deep digital flexor tendon mineralization: three cases where deep digital flexor tendinopathy was the sole diagnosis and five cases where there was an additional injury.

Of the cases where deep digital flexor tendinopathy was the sole diagnosis, one case was competing at medium level dressage, 5 years after treatment by palmar annular ligament resection and controlled exercise (unilateral mineralization within the proximal and distal digital flexor tendon sheath). The second case (bilateral mineralization in the proximal digital flexor tendon sheath) remained lame for 14 months after diagnosis and the third was euthanized due to persistent lameness (unilateral mineralization in the proximal digital flexor tendon sheath). Of the five cases with additional injuries, one case was returned to eventing after surgical treatment of a manica flexoria tear in the non-mineralization affected limb (unilateral mineralization within the proximal digital flexor tendon sheath). Four cases were either lame at final examination (≥8 months after initial) or remained lame according to the owner.

Follow-up was available on three cases in which suspensory ligament branch mineralization was detected. One case remained sound for three months after examination (unilateral), and one raced five times following treatment (unilateral). One case remained lame for 10 months after diagnosis (bilateral). Suspensory ligament branch desmitis was the sole diagnosis in these cases.

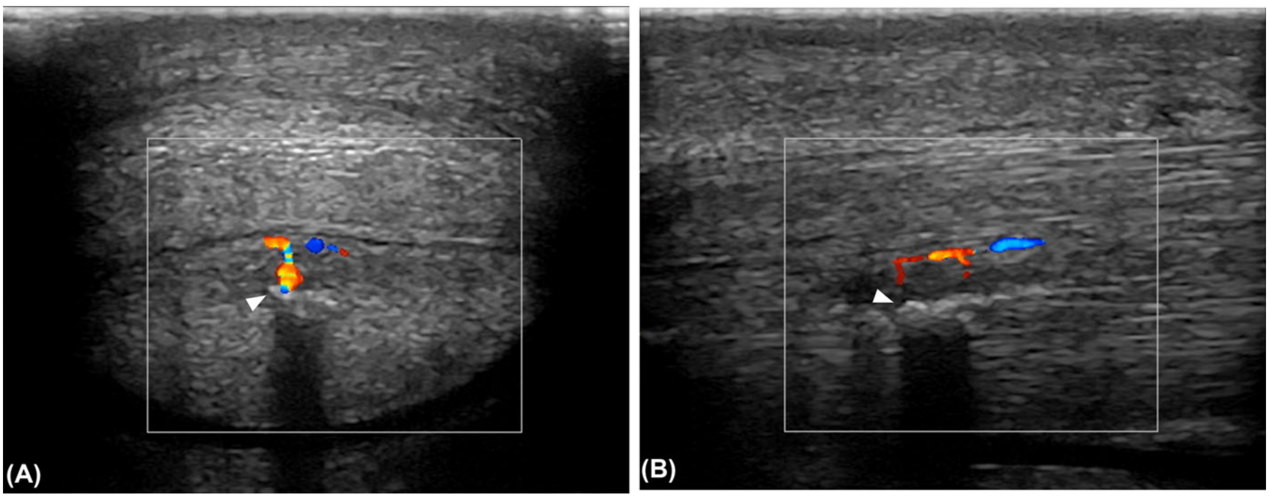

FIGURE 6 Transverse (A) and longitudinal (B) ultrasound images from deep digital flexor tendon case 7 showing Doppler signal concurrent with poorly defined focal mineralization (arrowheads). This mineralization was associated with lameness based on a positive response to intrathecal analgesia [Color figure can be viewed at wileyonlinelibrary.com]

4 | DISCUSSION

In the horses sampled for the current study, the deep digital flexor tendon and suspensory ligament branches were the structures most commonly affected by mineralization and an estimated 10% and 7% of cases of deep digital flexor tendon and suspensory ligament branch injury, respectively, demonstrated this feature. Deep digital flexor tendon mineralization was restricted to the digital flexor tendon sheath, which is the typical location for deep digital flexor tendinopathies proximal to the foot.[5,16] However, mineralization was also present in this tendon without other evidence of tendinopathy or lameness in the limb, which is consistent with the observation in human patients that not all rotator cuff tendon mineralization is associated with pain.[7] Nevertheless, mineralization preceded the development of hypoechoic foci in some of the lame animals.

Mineralization also occurred bilaterally and was found in 20% of deep digital flexor tendon and 43% of suspensory ligament branch cases. Although Webbon[11] documented a higher rate of bilateral injury occurrence—67% of superficial digital flexor tendons examined grossly—mineralization is only one of many gross features of tendinopathy.[17] The bilateral occurrence of tendinopathy in the current study, including mineralization, could be explained by the common loading history of affected tendons or a compensatory increase in loading in the contralateral structure following unilateral injury. There is also evidence that central nervous system signaling may be involved in the bilaterality of tendon disease.[18] Rotator cuff tendon mineralization has been reported bilaterally in only 10% of human patients, which might relate to species differences in the prevalence of bilateral pathology, or differences between studies in sensitivity to detect bilateral changes.

In vivo experimental evidence supports the hypothesis that previous intrathecal or intratendinous corticosteroid injection may promote tendon mineralization.[19] However in the current study, previous medication of the affected limb was reported in only one case of deep digital flexor tendon and one case of suspensory ligament branch mineralization, and none had been treated intratendinously or intraligamentously. Not all medications may have been reported. Nevertheless, our records suggest that corticosteroid medication was unlikely to have been a predisposing factor in most cases.

It is interesting that mineralization was found much less frequently in the superficial digital flexor tendon compared with the deep digital flexor tendon, despite the former being the most commonly injured flexor tendon.[20] Differences in tendon matrix composition[21] may be a contributory factor. Tendons and ligaments are known to develop a cartilage phenotype in response to compressive load[22–24] and this phenotype is observed at the level of the fetlock joint where the deep digital flexor tendon changes direction and is compressed against the proximal scutum, offering the possibility that mineralization occurs here by endochondral ossification and could be an extreme response to compressive loading. An alternative explanation is that poorer vascularization, known to be present where tendons wrap around bony prominences,[25] contributes to mineralization within this tendon. Why the suspensory ligament branches are a predilection site for mineralization is less obvious, but similar mechanisms may apply.

The molecular events within the tendon/ligament matrix leading to mineralization are not well understood. In human patients, tendon and ligament mineralization may involve ossification (endochondral or intramembranous) or deposition of calcium salts by other mechanisms.[26] Within the rotator cuff, the most common site of tendon mineralization in human patients,[27] the process has been described as 'incomplete endochondral ossification'.[28] Rodents predictably respond to tendon injury by true endochondral ossification.[26,29] The nature of mineralization within the equine tendons and ligaments has not been clearly established and may differ between deep digital flexor tendons and suspensory ligament branches. A recent report described mineralized foci excised from the palmar/plantar annular ligaments of ponies as either osseous metaplasia or dystrophic mineralization.[4] A mineralized focus within a deep digital flexor tendon dissected by the authors had a granular consistency unlike bone. These observations suggest that, like humans, mineralization within equine tendons and ligaments may vary in composition, perhaps dependent upon location.

Histopathological examination is required for definitive diagnosis of tendon/ligament mineralization but is impractical in most clinical cases. Therefore, the lesions reported in this study were presumed mineralized based on ultrasonographic characteristics. In one study, the authors included hyperechoic foci which did not cast acoustic shadows in their criteria for ultrasonographic diagnosis of human rotator cuff tendon mineralization, which resulted in some false positives, when compared with radiography.[10] To minimize this risk, we included only cases with acoustic shadowing which may have reduced our sensitivity. It is also possible that some under-reporting occurred in the retrieval of data during the retrospective phase of the study. However, it is unlikely that these limitations will have altered the pattern of clinical features which we observed.

Fiber damage was present at the time of (three cases/four limbs) or after (two cases/limbs in retrospective phase) identification of mineralization in the deep digital flexor tendon cases. For at least one of the latter cases, our records indicated that the original images were reviewed at the time the hypoechoic lesion was first identified and supported the observation that ultrasonographic detection of mineralization may precede fiber disruption. Signs of fiber disruption were present in at least five limbs with suspensory ligament branch mineralization. Three hypotheses may explain the relationships among mineralization, lameness, and tendon/ligament fiber disruption. In healing rabbit ligaments, an association between the presence of flaws and a reduction in their material properties has been documented.[30] In the same way, mineralized foci may promote fiber failure and in turn pain. Second, mineralization may promote an inflammatory response in the adjacent tendon causing pain and fiber weakening. A vigorous inflammatory response adjacent to mineralization has been identified in human supraspinatus tendons.[31] Third, it is feasible that mineralization does not contribute directly to tendon pain or fiber rupture but is an incidental change (a 'bystander'). However, the improvement in patient comfort following surgical decompression of mineralized deposits in rotator cuff tendons suggests that mineralization can be an active contributor to tendon pain.[8,32]

The ability to discriminate clinically significant mineralization from incidental findings would be of great clinical value. In cases with existing lameness, it may be possible to treat before the development of hypoechoic lesions. Further, in non-lame animals it may be possible to identify those likely to develop lameness in the future, which would be useful in the context of a pre-purchase examination. One study reported the presence of Doppler signal within the mineralized area in 21 of 57 symptomatic human patients but in none of the asymptomatic cases ($P < 0.005$).[7] These authors also identified that larger and fragmented mineralizations were significantly associated with pain.

Doppler signal was concurrent with mineralization in two of three limbs where the lameness was thought to arise from the mineralized deep digital flexor tendon and in a single case where the lameness was associated with suspensory branch ligament desmitis. Doppler signal was absent where either the horse was sound or there were other causes of lameness identified (two suspensory ligament branch and three deep digital flexor tendon cases). Unfortunately, there was insufficient information available to conclude if Doppler signal could be used to predict the occurrence of lameness or development of hypoechoic lesions.

One of the three horses with deep digital flexor tendinopathy as the sole diagnosis returned to work. This finding was not unexpected as a guarded prognosis been reported for this condition previously (excluding cases with mineralization), with seven of 24 cases returning to intended use.[33] A guarded prognosis has also been reported for suspensory ligament branch desmitis, with 10 of 23 cases returning to intended use.[3]

Surprisingly, this case of deep digital flexor tendon mineralization with a positive outcome had the most proximodistally extensive distribution pattern (within the proximal and distal digital flexor tendon sheath). However, mineralization may vary significantly in its dorsopalmar/plantar thickness, which is difficult to assess ultrasonographically due to the anatomic constraints of this area. In a future prospective study, serial radiography could help assess mineralization size, distribution, and progression; although it may be a challenge to monitor mineralizations within the sesamoidean canal. Computed tomography may be the ideal technique in this respect, but is presently impractical for most clinical studies.[13] Magnetic resonance imaging (MRI) may also help determine which mineralizations are contributing to lameness.[34]

Typically human patients with rotator cuff tendon mineralization show clinical and radiographic/ultrasonographic resolution of signs with conservative treatment, such as nonsteroidal anti-inflammatories, corticosteroid medication, and physical therapy.[32] The marked improvement in the appearance of the mineralization in one suspensory ligament branch case is therefore unsurprising, although there was insufficient follow up to say if this occurred frequently in horses. Related to this, mineralization became detectable between examinations 1 month apart in one deep digital flexor tendon case. This observation suggests that it may be erroneous to assume that ultrasonographic evidence of mineralization reflects a tendon/ligament injury of many months duration. Indeed, osteophytes, which like some presentations of tendon mineralization form by ossification,[35] can become radiographically apparent in as little as 2 weeks.[36] Within the human population, when rotator cuff mineralization fails to resolve with minimal treatment, extracorporeal shock wave therapy, needle decompression, and arthroscopic removal may be successful.[10] Needling is probably only warranted when the deposits are focal and liquid or granular rather than ossified. With greater understanding of the mechanisms of equine tendon/ligament mineralization, these treatments may be considered appropriate.

In agreement with a previous publication, most cases in this study were middle aged and larger breed types.[5] In human patients, rotator cuff tendon mineralization and Achilles tendon mineralization are reported to occur more frequently in females and males, respectively.[26] A slightly higher proportion of cases with either deep digital flexor tendon or suspensory ligament branch mineralization were geldings rather than mares in this series. This distribution, and the frequency of mineralization which we report, may relate to differences in the activities of mares and geldings attending our hospital and should be generalized to the wider population with caution.

In humans, there is some limited evidence associating endocrine disorders with rotator cuff tendon mineralization.[37] Pituitary pars intermedia dysfunction and metabolic syndrome are the most obvious candidates for a possible similar link in equine tendon/ligament mineralization, being the most common endocrinopathies affecting horses.[38] However, investigating such a link is beyond the scope of our data. Other systemic disorders associated with tendon or ligament mineralization in human patients include ankylosing spondylitis and the rare conditions, fibrodysplasia ossificans progressiva and progressive osseous heteroplasia, which involve generalized soft tissue mineralization.[26] These disorders do not appear relevant to our patients. An association between dietary imbalance and tendon/ligament mineralization has not been reported in any species.

No cases of deep digital flexor tendon mineralization within the hoof capsule were reported in this study, despite injury to this structure being a common cause of foot pain.[16] Deep digital flexor tendon mineralization within the foot is detectable ultrasonographically.[39] However, transcuneal ultrasonography was performed less frequently by the senior author during the study compared with pastern and metacarpal/metatarsal scans. Further, the authors propose that this approach would be less sensitive than radiography or MRI to detect deep digital flexor tendon mineralization, given the limited size of the transcuneal window.

In conclusion, this study indicates that tendon/ligament mineralization diagnosed ultrasonographically can be associated with lameness, but can also be an incidental finding. Doppler imaging may offer additional support for the clinical relevance of mineralization, but more data would be required to confirm a pattern. A pathological study is also recommended to understand the nature of mineralization and better and determine if specific measures (e.g., shockwave and needling) are rational as treatment strategies.

LIST OF AUTHOR CONTRIBUTIONS

Category 1

- **(a)** Conception and Design: O'Brien EJO, Smith RKW
- **(b)** Acquisition of Data: O'Brien EJO, Smith RKW
- **(c)** Analysis and Interpretation of Data: O'Brien EJO, Smith RKW

Category 2

- **(a)** Drafting the Article: O'Brien EJO
- **(b)** Revising the Article for Intellectual Content: Smith RKW

Category 3

- **(a)** Final Approval of the Completed Article: O'Brien EJO, Smith RKW

ACKNOWLEDGMENTS

The authors are grateful to the clinicians who referred the animals included in this study to the Royal Veterinary College for examination.

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How to cite this article: O'Brien EJO, Smith RKW. Mineralization can be an incidental ultrasonographic finding in equine tendons and ligaments. *Vet Radiol Ultrasound*. 2018;59:613–623. https://doi.org/10.1111/vru.12628