Case Report

Use of standing low-field magnetic resonance imaging to diagnose middle phalanx bone marrow lesions in horses

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Summary

Bone marrow lesions (BMLs) (also known as ‘bone bruises’, ‘bone oedema’, ‘bone contusions’ and ‘occult fractures’) within the middle phalanx were diagnosed by standing low field magnetic resonance imaging (MRI) in 7 horses. The lesions were characterised by low signal intensity on T1- and T2*-weighted gradient echo sequences, mildly increased signal intensity on T2 fast spin echo sequences, and high signal intensity on short tau inversion recovery (STIR) sequences. Four distinct patterns of abnormal signal were identified: BML associated with osteoarthritis of either the proximal or distal interphalangeal joints; BML associated with soft tissue injury; BML associated with acute trauma; and BML unassociated with any other injury or lameness (assumed to represent bone response to biomechanical stress). Repeat MRI was undertaken in 4 cases. In most cases the BML resolved with rest and time, although lameness was persistent in 2 horses (one of which had an associated osteoarthritis of the proximal interphalangeal joint).

Introduction

Macroscopically, bone consists of compact bone and cancellous bone. Cancellous bone, also designated as trabecular or spongy bone, is a ‘honeycomb’ of large cavities with an internal latticework of trabeculae. It lies in the inner part of the bones, and, in the case of long bones, within the metaphyses and epiphyses. Cancellous bone gives additional strength to the cortical bone and supports the bone marrow (Soames 1995). Before the advent of magnetic resonance imaging (MRI), trauma to the trabecular bone could be difficult to assess by radiography.

‘Bone bruise’ was first described in the human knee by Yao and Lee (1988). The term ‘bruise’ was used to indicate the traumatic origin of such intraosseous changes. It was defined as a region of T2-hyperintensity on MRI in the absence of any obvious osseous fracture or subchondral cyst. MRI showed abnormal intraosseous areas, hyperintense on T2-weighted and STIR images, and to a lesser degree hypo-intense on T1-weighted images, in acutely injured bone with no abnormalities on plain radiographs. Since then the terms ‘bone bruise’, ‘bone contusion’, ‘bone oedema’, ‘occult fracture’ and ‘bone marrow lesion’ (BML), which is a more general expression regarding the cause, have been used interchangeably.

Bone oedema pattern, seen as a high signal on MR fat-suppressed (STIR) sequences, is a commonly recognised finding in the equine navicular bone (Dyson et al. 2005). It has also been reported in both distal and middle phalanges, with favourable prognosis in one report (Dyson et al. 2005).

Here we report on the MRI features of 7 horses, with or without distal limb lameness, diagnosed with changes compatible with bone marrow lesions in the middle phalanx, and we review the literature on BML in human medicine.

Materials and methods

The standing MRI technique has been described in greater detail elsewhere (Mair et al. 2005; Sherlock et al. 2007). Briefly, following sedation with an α2 agonist agent and butorphanol, a transmitter and receiver radiofrequency coil was fitted around the foot and pastern. The 0.27 Tesla C-shaped magnet was then moved around the leg such that the region of interest was central. Pilot sequences were used to check positioning and to set the location and angle of subsequent scans. A standard foot imaging protocol able to scan both the distal and middle phalanges was employed in each clinic using a combination of 2D or 3D T1-weighted gradient echo (GRE), 2D or 3D T2*-weighted GRE, T2 fast spin echo (FSE) and short tau inversion recovery (STIR) sequences (Sherlock et al. 2007). Images were obtained in sagittal, transverse and frontal planes.
Case details

Seven cases were selected from the distal limb MRI database of horses presented to the Bell Equine Veterinary Clinic and the Equest Diagnostic Imaging Center. Inclusion criteria included cases with complete lameness and distal limb radiographic examinations, and retrospectively diagnosed with high signal intensity on STIR sequences located in the trabecular bone of the middle phalanx. The MRI lesion had to be confidently differentiated from a fracture or an isolated osseous cyst-like lesion.

There were 5 Warmbloods, one Irish cross and one Thoroughbred x Quarter Horse. Ages ranged from 8–14 years with a mean of 10.3 years. Six were geldings and one was a stallion. The horses were used for a variety of activities, including 3 high level jumpers, 2 low to medium level jumpers, one dressage and one riding club horse. Six horses were examined for lameness and one was presented for prepurchase examination. The lameness duration before MRI was 2–7 months for the 6 lame horses. There was no history of any traumatic event except for one horse in which trauma was suspected since he went mildly lame after a long journey and then the condition deteriorated over several months. All of the lame horses had been previously treated by the referring veterinarians with various combinations of rest, oral phenylbutazone, DIP joint medication with corticosteroids, hyaluronic acid and autologous conditioned serum, with only transient or mild improvement. Five horses had forelimb lameness (one with right forelimb [Case 1], one with left forelimb [Case 4], and 2 with bilateral lameness [Cases 3 and 7]). One horse was left hindlimb lame (Case 2), and one horse was both left hindlimb and left forelimb lame (Case 5). This last case was diagnosed with distal tarsal arthrosis following examination and radiographs of the left hindlimb. Case 6 was presented for prepurchase examination and was sound at clinical inspection and no significant lesions were found by radiography. Six of the 7 horses had palpable enlargement or swelling of the limb. The horse with left hindlimb lameness (Case 2) had a chronic plantar pastern swelling. This horse also had severe left hind lateromedial hoof imbalance and would not put his heels down at rest. The lameness of one horse (Case 1) had an acute onset, was initially evaluated to be grade 4/5 by the owner and then gradually improved to a 1/5 lameness after 7 months. The lameness of the other 5 horses was insidious in onset and chronic, of which 3 (Cases 3, 5 and 7) remained unchanged and graded 2–3/5 before diagnosis, and 2 deteriorated from 1 to 3/5 (Cases 2 and 4).

All horses were negative to examination with hoof testers and 6 of the 7 horses underwent standard regional analgesic techniques to localise the site of lameness. One horse was sound and presented for an MRI as part of a prepurchase examination. A palmar digital nerve block was positive in the left front leg of Cases 3 and 5. An abaxial sesamoidean nerve block was positive in the left hind leg of Case 2, the right front leg of Case 3, the left front leg of Case 4, and both front limbs of Case 7. Case 1 had a right front limb lameness that was positive to DIP joint analgesia but negative to palmar digital nerve block. DIP joint analgesia resulted in complete soundness in Case 3 and 60% improvement in Case 4. All horses had either no or minor (equivocal) changes on standard radiographs of the distal limbs.

Results

The abnormal medullary signal indicative of BML in the middle phalanx was identified as low signal intensity on T1-weighted GRE and T2*-weighted GRE sequences, no or mild increased signal intensity on T2 FSE sequences and a high signal intensity on STIR sequences. Four distinct patterns of abnormal signal were identified.
The first pattern was identified in 3 horses (Cases 2, 3, and 4) and consisted of a BML in the subchondral bone area with associated signs of osteoarthrosis. In Case 2, the lesion involved the entire proximo-medial quarter of the middle phalanx (Fig 1). There were associated signs of arthropathy of the proximal interphalangeal (PIP) joint with severe thickening of the entire width of the subchondral bone plate, moderate osteophyte formation at the articular margins and subchondral bone cyst formation in the proximomedial aspect of the middle phalanx. Arthrocentesis of the PIP joint yielded fluid with a low total nucleated cell count (0.5 x 10^9/l) but an increased total protein concentration (40 g/l) suggestive of aseptic synovitis. Case 3 (bilateral lameness) showed a severely abnormal signal intensity at the dorsal aspect of the lateral condyle of the left front middle phalanx (Fig 2) and at the dorsal aspect of the sagittal groove of the right front middle phalanx. There were associated bilateral moderate synovial distension and osteophyte formation of the distal interphalangeal (DIP) joint. This horse had had 3 previous MR examinations of both front feet at another clinic since the onset of lameness 7 months previously, but these studies were all reported to be unremarkable. A subsequent bone-phase scintigraphic examination showed severe diffuse increased radiopharmaceutical uptake in the distal half of the middle phalanx. Case 4 showed more focal abnormal medullary signal intensity in the distal dorsolateral aspect of the left front middle phalanx with associated proliferative synovitis of the DIP joint. There was a line of decreased signal intensity in all sequences departing from the previously described lesion in the middle phalanx and extending palmaromedially, which may have represented an occult fracture.

The second pattern was identified in one horse (Case 7) and was characterised by a BML in association with soft tissue injury. That horse had proximolateral abnormal signal further extending along the lateral cortex of the middle phalanx in both front limbs. There was an associated increased signal intensity on T2*-weighted GRE and STIR sequences in the lateral aspect of the collateral sesamoidean ligament (collateral ligament of the navicular bone) indicative of desmitis.

The third pattern was identified in one horse (Case 1) and consisted of an extensive BML in the absence of other

Fig 2: MR images of the left front foot of Case 3 showing DIP osteoarthrosis-related bone marrow lesion (BML) pattern. Lateral is to the right on the transverse image. There are osteophytes at the joint margins, synovial distension and subchondral bone irregularities at the palmar aspect of the middle phalanx condyle (b). Both the sagittal T1 weighted GRE (a) and the sagittal T2*-weighted GRE (b) images demonstrate decreased signal intensity at the dorsodistal aspect of the middle phalanx, which could have corresponded either to sclerosis or to a BML. However, the sagittal (c) and transverse (d) STIR sequences show associated highly increased signal intensity in the lateral condyle of the middle phalanx, which indicates a BML. Therefore the low signal area on the T2*-GRE sequence is also due to a phase cancellation artefact. There is a lack of fat saturation artefact on the sagittal STIR in the distal phalanx (c). Similar BML findings are present in the distal sesamoid bone.
significant contributing damage, compatible with bone bruising secondary to acute trauma. The abnormal signal was characterised by patchy and diffuse abnormal signal intensity in the distal half and along the dorsal cortex of the right front middle phalanx (Fig 3). In this case, there were associated moderate signs of chronic degenerative changes in the navicular bone and moderate distension of the navicular bursa. These changes were present bilaterally, although slightly more pronounced in the right front. However, the horse was lame only in the right front leg where the lesion in the second phalanx was identified, and he was negative to a palmar digital nerve block but positive to DIP joint analgesia. Therefore, the lameness was considered most likely to be emanating from the middle phalanx contusion.

Finally, 2 horses (Cases 5 and 6) had the last identified pattern, which consisted of a focal BML not associated with any other significant imaging sign or with any lameness in the affected leg. At the time of the initial MRI interpretation, considerations for the cause of this abnormal signal were either nonpathological bone response to biomechanical stress or an early detected pathological process that had not yet resulted in lameness.

Fig 3: Sagittal T1-weighted-GRE image of Case 1 showing bone marrow lesion (BML) pattern with marked and diffuse decreased signal intensity mainly distally and dorsally in the middle phalanx. Other abnormalities not presented in the figure, including hypersignal on the STIR sequence, helped in the differentiation of that T1 decreased signal from bone sclerosis.

Fig 4: MR images of the right front foot of Case 6 showing sports related, probably nonpathological bone marrow lesion (BML) pattern (on the basis of the clinical findings). Lateral is to the left on the dorsal and transverse images. The dorsal T1 weighted (a) as well as the sagittal T2*-weighted (b) images demonstrate decreased signal intensity at the centrodistal aspect of the middle phalanx. However, the dorsal T2-weighted FSE image (c) shows associated moderately increased signal at the centrodistal aspect of the middle phalanx. All planes (d: sagittal, e: dorsal, f: transverse) of the STIR sequence accordingly show highly increased signal at the same location. The variably intense hypersignal in the T2 FSE and the STIR sequences is a clear signature of a BML and avoids potential confusion due to the phase cancellation artefact present on the T2*-GRE sequence.
Case 5, which was lame only in the left front, showed moderate to severe chronic remodelling of the left front navicular bone, and severely abnormal medullary signal intensity at the centrolateral aspect of the sagittal groove of the collateral sesamoidean ligament. MRI of Case 6 revealed bilateral moderate distension of the DIP joint with mixed signal indicative of chronic proliferative synovitis, and severely increased STIR signal intensity at the central dorsodistal aspect of the right front middle phalanx (Fig. 5). However, even though the horse was sound, as the MRI was part of a prepurchase examination, it was advised to rest the horse and recheck him several months later.

Follow-up MRI was performed in 4 of the 7 horses. In Case 2, repeat MRI performed one month after the initial examination showed moderate resolution of the abnormal increased signal intensity on STIR sequences with a remaining ‘patchy’ appearance of hyperintensities (Fig. 5), and similar degenerative changes of the PIP joint. The horse was still lame and resting at the time of repeat examination. The horse continued on strict box rest and had a third MR examination 6 months later. At this time, the abnormal STIR signal intensity within the medulla of P2 had further resolved, but there was more marked decreased signal intensity in all sequences in the proximo-medial medulla, suggestive of extensive sclerosis. In addition, more severe degenerative changes were present in the PIP joint with a large focal area of high signal intensity in all sequences in the subchondral bone of the medial proximal aspect of the middle phalanx, suggestive of osseous cyst formation. The horse was retired at this time. Case 4 was re-examined after 2 months, and the lesion in the medulla of the middle phalanx had completely resolved. However, the horse was still lame at that time. The horse was rested for a further 3 months but remained lame and was finally retired. In Case 6, the abnormal medullary signal in the right front middle phalanx had completely resolved after 3 months, and the horse was brought back to full work (Grand Prix jumping) with no observed lameness. Given the results of the clinical examination of that horse, BML was retrospectively considered to be nonpathological. Case 7 showed complete resolution of the abnormal signal in both front middle phalanges after 3 months, and complete resolution of the increased signal intensity on STIR sequences and partial resolution of the increased signal intensity on T2* GRE sequences in the collateral sesamoidean ligament. It was considered that the remaining abnormal signal may have represented permanent changes and scanning. The horse was progressively brought back to its previous level of hunter activities after a total of 6 months of rest and rehabilitation, and remained sound. Case 1 was not re-examined for financial reasons, but was treated with 4 months of rest and corrective shoeing for navicular disease, and was reported to be sound and undertaking light riding club activities as before. Case 3 received a 4 month period of rest and rehabilitation, and was reported to be sound and in full work at its previous level of performance (Grand Prix jumping). The left front lameness in Case 5 was treated with a 2 month period of rest and rehabilitation, tiludronate, isoxsuprine and oral phenylbutazone for 30 days; he was then sound and back to full work (Grand Prix jumping).

Given the horse’s soundness in the right front leg, the BML seen on MRI was retrospectively considered to be a sports-related, nonpathological finding.

Discussion

Magnetic resonance imaging is the only imaging technique that allows complete evaluation of trabecular bone lesions. The use of fat suppressed MR images was particularly appropriate to detect BMLs in the middle phalanx of these horses. This pattern is well described in the navicular bone (Dyson et al. 2005). Although this affliction seems to be a less prevalent condition in the middle phalanx, its identification by standing low-field MRI is straightforward. Lesions were bilateral in 2 lame horses, unilateral in 3 lame horses, and unilateral in the other 2 horses which were either not lame at all or not lame in the leg in which the lesion was identified. From the data of our report, it is not possible to establish a clear prognosis for such lesions. BMLs may be associated with arthropathy of the PIP or DIP joints or soft tissue injury, such as desmitis of the collateral sesamoidean ligament. BML may also be found as an isolated lesion, possibly secondary to acute trauma. Finally, it may relate to sports biomechanical stress. Indeed in 2 cases, it was concluded that BMLs were probably associated with nonpathological changes since clinical signs were not present and did not develop afterwards. Therefore BMLs may be nonpathological in some cases, but may carry a poor prognosis for soundness in others. Consequently, associated joint or soft tissue lesions are important to identify. In one case, MRI identified osteophytes that were not clearly visible on radiographs.
executed the same day. This may be due either to the tomographic nature of MRI, facilitating detection of subtle lesions, or to incompletely ossified osteophytes in an early osteoarthrosis process (d'Anjou et al. 2008a). Follow-up clinical examination and response to treatment were important in helping to establish the prognosis. We have not yet identified useful specific signs or patterns on MR images to anticipate the probable evolution of the condition. On the basis of our limited number of cases, we can suggest that if a favourable clinical improvement is not observed within 3 or 4 months following MR diagnosis, then the prognosis for return to soundness worsens significantly.

In interpreting MR images of bone, it is important to assess the T1-weighted images in which reduced signal intensity implies a loss of trabecular fat, which could relate to bone sclerosis, necrosis, fibrosis or oedema (Werpy et al. 2006). Subsequent analysis of other sequences allows a more precise diagnosis. Indeed, bone sclerosis shows signal void on all sequences, whereas other histological processes may show abnormal signals of various intensities depending on the MR sequence and the time of examination (d'Anjou et al. 2008b). Both T2*-weighted GRE and T2-weighted spin echo images (spin echo, fast spin echo or STIR) would have been expected to show increased signal associated with altered content in the medulla of the middle phalanx in the cases described in this report. This is indeed the basis for their diagnostic use in detecting water. However, under some circumstances, T2*-GRE images can show low signal intensity (Fig 4b) whereas T2-FSE images show high signal intensity (Fig 4c). This paradoxical phenomenon on the T2*-GRE images may be due to phase cancellation artifact (McGibbon et al. 2003), which results from out-of-phase precession of the spins from water and fat during the evolution of the signal decay. It can be understood as signal from fat and from water cancelling each other out, causing a dark area in both frequency and phase-encoded directions. This artifact must be recognised and understood to avoid confusion and potential misdiagnosis.

Radio waves generated by protons in water are at a slightly different frequency from those from fat. In a spin echo sequence, the difference in resonance frequency causes the 2 waves to gradually get out of phase with each other until a 180° radiofrequency (RF) pulse at half the echo time is applied. The phase difference between the fat and water signals thus increases until halfway through the echo time and then decreases again to be eliminated exactly at the echo time. The signals from fat and water are back in phase at the time of signal collection and always add, irrespective of the echo time and the proportions of fat and water in the tissue. In a T2*-gradient echo sequence, which does not include any 180° RF pulse, the mix of signals is received by the coil at around an echo time (echo time 13 ms in our study, or its multiples), which is close to the time that fat and water signals are exactly out of phase. Thus, when fat and water are present and generate almost equal signals, these cancel each other out and a low signal results on the image. The use of T2-FSE sequences in parallel with T2*-GRE sequences is therefore recommended to assess the presence of this phase cancellation artifact and definitely identify the pathological process. Indeed, for identical low signal intensity in the trabecular bone on a T1-weighted sequence, low signal on the T2-FSE would suggest a diagnosis of bone sclerosis, whereas isointense or increased signal on the T2-FSE would lead to the conclusion of a BML.

A second potentially misleading artifact is the lack of fat suppression on STIR sequences at the most peripheral parts of the image using the standing low-field magnet. The distal aspect of the distal phalanx or the proximal extent of the middle phalanx may sometimes show hyperintense signal on STIR sequences (Figs 1a, 2c, 4d and 5), not associated with low signal intensity on T1 weighting, and which disappears when the region of interest is placed in the centre of the magnet. This artifact that creates the high signal intensity on the STIR sequence should not be interpreted as a BML pattern.

In man, BMLs associated with sports activities are most frequently of traumatic aetiology, and the underlying mechanism may be either acute or chronic (Sanders et al. 2000). Variable incidences have been published, but BMLs are often encountered in acute trauma (Vanhoenacker and Snoeckx 2007). Most of the horses of our report had an insidious onset of lameness and there was no well documented episode of trauma for any of them. The extent of BML reflects the biomechanics of trauma (Hayes et al. 2000). Compressive forces between 2 bony structures will result in extensive areas of BML, whereas distraction forces provoke more subtle areas of BML at the insertion of supporting structures of joints. In most clinical situations, a combination of compression and distraction forces is present, causing a complex pattern of bone lesions (Ryu et al. 2000). A meticulous pattern approach of the distribution of these bone marrow changes around a joint may reveal the underlying mechanism of trauma. As the horses in the current report were scanned several months after the onset of lameness, it was difficult to know if the identified pattern corresponded to the one that may have been identified acutely. In particular, the bone bruising pattern identified in one case (Case 1) may represent an evolution of a severe form of an osteoarthrosis-related pattern. Apart from purely acute traumatic causes of BMLs, it may result from repetitive or chronic trauma in sports activities. Bone oedema syndromes without any history of trauma are being increasingly recognised on MRI in man (Mandalia et al. 2005). Distinction between traumatic and nontraumatic BMLs in sports injuries is primarily based on a clinical history of trauma, as imaging features are often indistinguishable. Chronic stress of a normally mineralised bone may result in a spectrum of MRI findings ranging from periosteal oedema over severe marrow lesions to a hypo-intense fracture line in cancellous or cortical bone. This continuum of MRI findings has been described by Fredericson et al. (1995).

A limitation to the current report is the absence of correlation with histological data. A variety of histological...
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The natural history of BMLs is not well understood, and it is unclear whether they predispose to or accompany osteoarthritis (Felton et al. 2003). Two human studies showed a relationship between oedema-like lesion and subsequent subchondral bone cyst formation (Carino et al. 2006; Vincken et al. 2006). Many studies have shown that bone lesions may have a deleterious effect on the overlying articular cartilage, although this concept is not universally accepted (Mandalia et al. 2005). The pathophysiological mechanisms by which the cartilage can undergo this degenerative process may be multifactorial. The initial blunt trauma might exceed a supraphysiological threshold and lead to progressive chondral damage (Mankin 1982). Additionally, the osseous lesion might heal with a sclerosing process. The decreased compliance of bone might then generate increased loads on the articular cartilage, leading to progressive cartilage degeneration. Interestingly, one horse in this study (Case 2) showed progressive osteoarthritis and subchondral bone cyst formation in the PIP joint over a 9 month period.

The reported time for the resolution of BMLs in man is highly variable, ranging from 3 weeks to 2 years (Costa-Paz et al. 2001; Roemer and Bohndorf 2002; Mandalia et al. 2005). This variability may be attributed to several factors, such as the severity of the initial injury, the extent of the bone lesion and other associated articular derangements. Two patterns of resolution have been described by Davies et al. (2004). The centripetal pattern is the most frequent, whilst other lesions tend to resolve towards the joint margin. The latter generally resolve more slowly and probably require longer rehabilitation because of a higher risk of premature osteoarthritis. In our report, the repeat scans performed between 2 and 9 months after the initial examination showed resolution in most cases, and in one case a rescan performed one month after the initial diagnosis showed centripetal resolution. However, clinical improvement did not always accompany the resolution of the BML. One horse remained lame even with normalised

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MR images, and another horse remained lame with progressive damage to the PIP joint.

In conclusion, low-field MRI in the standing, sedated horse has the potential to be a useful tool for assessing bone marrow lesions in the distal limb. MRI has brought new insights into the field of equine lameness diagnosis in recent years. Some bone lesions may have remained undiagnosed before the advent of MRI; however, their exact significance and prognosis still have to be determined.

Manufacturer's address

Haltmaq Veterinary Imaging Ltd., Guildford, Surrey, UK.

References


