The tarsus is the source of hind limb lameness in up to 80% of affected horses.1 Because of its complex structural arrangement, lesions can be difficult to effectively image or definitively diagnose with standard imaging techniques. Pathological changes can involve bone, cartilage, tendon, ligament, or synovium. The distal tarsal bones have a minimal range of motion and primarily undergo compression.2 Changes in the distal tarsal bones are frequently implicated as the source of lameness within the tarsus; however, there are few studies that have examined pathological changes of these bones in vivo or compared the usefulness of various imaging modalities available to practitioners.

Radiography can be useful when examining the tarsus, especially for osteoarthritis,4,5 but the relationship between radiographic changes and signs of lameness is considered inconsistent. There is a substantial amount of superimposition of the distal bony structures, and up to a 30% to 50% decrease in bone density must occur before it is evident on radiographic images.6 Despite this, radiography is often one of the first imaging modalities chosen because of its availability, low cost, and effectiveness in detecting osteochondrosis and fractures.6

Nuclear scintigraphy is also often used, particularly to help localize hind limb lameness. With respect to the distal tarsal bones, much work has been done to describe patterns of RU in sound7 and lame8 horses. Abnormal RU demonstrates an increase in osteoclast and osteoblast activity, and although this is a sensitive imaging modality (for acute and chronic lameness), the findings are not specific in terms of lesion type.

### Objective
To describe pathological findings identified with MRI in the distal tarsal bones of horses with unilateral hind limb lameness attributable to tarsal pain and to compare the usefulness of MRI with that of radiography and nuclear scintigraphy in evaluation of this region.

### Design
Retrospective case series.

### Animals
20 lame horses.

### Procedures
In all horses, MRI, radiography (4 standard projections), and nuclear scintigraphy of the tarsus had been performed. Horses were excluded if the results of all 3 imaging modalities were not available or if lameness was detected in more than 1 limb. Pathological changes identified with MRI were cross-referenced with the findings determined by other imaging modalities.

### Results
Compared with MRI findings, the following lesions were identified with radiography: medullary and subchondral bone sclerosis in 9 of 16 horses, pathological changes related to osseous hyperintensity in 0 of 10 horses, and osteoarthritis in 5 of 8 horses. Standard radiographic projections did not aid in the identification of fracture of the distal tarsal bones (3 horses). Location of increased radiopharmaceutical uptake with nuclear scintigraphy corresponded with the location of pathological changes detected with MRI in all horses. The intensity of the radiopharmaceutical uptake on nuclear scintigraphic images did not correspond with the severity of the pathological changes identified with MRI.

### Conclusions and Clinical Relevance
Radiography was unreliable for the detection of pathological changes related to osseous hyperintensity identified with MRI, fracture, and subchondral bone sclerosis in the equine tarsus. Nuclear scintigraphy was effective in localizing pathological changes, but MRI provided superior anatomic detail. (J Am Vet Med Assoc 2012;240:1109–1114)

### Abbreviations
<table>
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<th>Description</th>
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<tr>
<td>OH</td>
<td>Osseous hyperintensity</td>
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<td>ROI</td>
<td>Region of interest</td>
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<td>RU</td>
<td>Radiopharmaceutical uptake</td>
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<td>SCB</td>
<td>Subchondral bone</td>
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<td>STIR</td>
<td>Short-tau inversion recovery</td>
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Magnetic resonance imaging in horses has received much attention in the past 10 years. Gross normal anatomy of the tarsus has been shown to correspond well with MRI findings obtained with high-field and low-field scanners. Little work has been done to describe pathological changes of the tarsus in vivo, although cadaver specimens have been used to describe SCB thickenings and patterns in horses with lameness caused by signs of tarsal pain.

Equine practitioners must consider which of these diagnostic imaging modalities is the most appropriate to recommend to their clients when treating horses with lameness attributable to the tarsus. The purposes of the study reported here were to describe pathological findings identified with MRI in the distal tarsal bones of horses with unilateral hind limb lameness attributable to tarsal pain and to compare the usefulness of MRI with that of radiography and nuclear scintigraphy in the evaluation of this region. We hypothesized that radiography would not be a sensitive imaging modality; compared with nuclear scintigraphy and MRI, for the detection of specific conditions of the tarsal region.

Materials and Methods

Case selection criteria—Medical records were reviewed of all horses admitted to the Alamo Pintado Equine Medical Center, Los Olivos, Calif, between January 2006 and May 2010. All horses included in the present study had undergone a thorough lameness examination and were identified as having unilateral hind limb lameness. Lameness was localized to the tarsal region on the basis of the horse’s response to perineural or intra-articular anesthesia or following the results of nuclear scintigraphy. Case selection was further refined to those horses with abnormal RU in the distal tarsal bones. Radiography and MRI of the affected tarsus were also performed. Horses were excluded from the study if the results of all 3 imaging modalities were not available or if lameness was detected in > 1 limb.

Diagnostic imaging procedures—All horses underwent nuclear scintigraphy. Technetium Tc 99m methylene diphosphonate (1 Gbq/100 kg [0.45 Gbq/100 lb]) was administered IV via a 14-gauge catheter in the jugular vein. Horses were sedated by administration of detomidine HCl (0.01 to 0.02 mg/kg [0.005 to 0.01 mg/lb], IV) and butorphanol tartrate (0.02 to 0.03 mg/kg [0.009 to 0.014 mg/lb], IV). Early vascular–soft tissue phase and delayed bone phase images were acquired. Quantitative image analysis was used to assess ROIs in the tarsi of both limbs to aid in determining clinical importance of areas with abnormal RU. One ROI was selected from the distal tarsal bones and a second from the reference region (diaphysis of the third metatarsal bone), which was then cross-referenced with the contralateral limb. A difference of ≥10% in RU between the lame and sound limb was considered clinically relevant, and total acquisition counts were > 200,000. Region of interest placement was made freehand (software not available).

Digital radiographs of the affected tarsus were obtained in standing horses. Radiographic images included dorsoplantar, lateromedial, dorsal 45° lateral-plantaromedial oblique, and plantar 45° lateral-dorsomedial oblique views of the tarsus.

Magnetic resonance imaging was performed on both tarsi while horses were under general anesthesia. Each horse underwent a physical examination, ECG evaluation, and CBC prior to general anesthesia. All horses were anesthetized with a combination of xylazine (1.1 mg/kg [0.5 mg/lb], IV), diazepam (0.05 mg/kg [0.023 mg/lb], IV), and ketamine HCl (2.2 mg/kg [1 mg/lb], IV), and general anesthesia was maintained with 2% to 5% isoflurane in oxygen. Horses were placed in right lateral recumbency, and numerous sequences were obtained, including 3-plane localizers, multiple planes with proton density, and T2-weighted sequences; T2-weighted fast imaging with steady-state precession sequences; STIR sequences; and T1-weighted volumetric interpolated breath-hold examination fat saturation sequences. Magnetic resonance images were then reviewed by a board-certified surgeon and board-certified radiologist.

Statistical analysis—To assess differences in findings from nuclear scintigraphy ROI analysis among horses with differing MRI findings, horses were placed into 2 groups: those that had either a fracture or OH identified with MRI (group A) and those without a fracture or OH identified with MRI (group B). A Student paired t test was used to assess differences in ROI analysis results between the 2 groups. Values of P < 0.05 were considered significant.

Results

A total of 20 horses were available for the study. Mean ± SD age was 8.0 ± 3.4 years (range, 3 to 13 years). There were 12 geldings and 8 mares. The study included 10 Quarter Horses, 8 warmbloods, 1 Thoroughbred, and 1 American Paint Horse. Complete histories, medical records, and MRI reports were available for all horses. Of the 20 horses, 10 horses had chronic lameness (diagnostic testing commenced after 14 days of lameness) and 10 horses had acute lameness (diagnostic testing commenced within 7 to 14 days after the onset of lameness). A follow-up MRI evaluation was available for 1 horse. On the basis of the American Association of Equine Practitioners 5-point lameness scale, 1 horse had a grade 1 lameness, 9 horses had a grade 2 lameness, 7 horses had a grade 3 lameness, and 3 horses had a grade 4 lameness.

Of the 20 horses, 12 underwent perineural or intra-articular anesthesia as a diagnostic tool. Lameness improved in response to regional perineural or intra-articular anesthesia in 9 horses: 3 horses had improvement in response to injection of anesthetic into the centrodistal and tarsometatarsal joints (MRI diagnoses: central tarsal bone fracture with OH and sclerosis, osteoarththritis, and central and third tarsal sclerosis), 1 horse improved in response to injection of anesthetic into the tarsometatarsal joint alone (MRI diagnosis: central tarsal bone sclerosis), 4 horses had improvement in response to a tibial and peroneal nerve block (MRI diagnoses: central tarsal bone sclerosis and central and third tarsal bone sclerosis; 2 horses had central and third tarsal bone OH), and 1 horse had improve-
ment in response to anesthesia of the medial and lateral plantar and plantar metatarsal nerves, but this horse subsequently had a negative response to intra-articular anesthesia of the centrodigital and tarsometatarsal joints (MRI diagnosis: third tarsal OH and osteoarthritis). Lameness did not improve in response to regional perineural or intra-articular anesthesia in 3 horses: 1 horse had no improvement after injection of anesthetics into the centrodigital and tarsometatarsal joints (MRI diagnosis: third and central tarsal bone sclerosis and centrodigital osteoarthritis), 1 horse had no improvement after perineural anesthesia up through anesthesia of the medial and lateral plantar metatarsal nerves, and 1 horse had no improvement after an abaxial sesamoid nerve block. In the remaining 8 horses, no local anesthesia (ie, perineural or intra-articular) was performed and nuclear scintigraphy performed as the first diagnostic step. Nuclear scintigraphy findings revealed that all horses had abnormal RU associated with the distal aspect of the tarsus of the lame limb. Nuclear scintigraphy findings for all horses corresponded with the location of lesions found with MRI (Figure 1). Abnormal RU was located in the following locations: central tarsal bone (5 horses), third tarsal bone (4), both third and central tarsal bones (3), and in a combination of the central tarsal bone, distal intertarsal joint, and tarsometatarsal joints (8). On the basis of results of the ROI analysis and findings from MRI, horses were then placed into 2 previously described groups. For horses with either a fracture or OH identified with MRI (group A; 10 horses), the mean ± SD difference in the ROI between the lame and sound hind limbs was 51.8 ± 19.5%, and for all other horses without a fracture or OH identified with MRI (group B; 10 horses), the mean ± SD difference was 46.0 ± 27.8%. No significant (P = 0.60) difference in ROI analysis results was found between the 2 groups.

Distribution of lesions identified with MRI included the following: medullary sclerosis, SCB sclerosis, or both (16 horses); fracture (3); OH (10); osteoarthritis (8); bone cyst (1); osteochondrosis fragment of the distal intermediate ridge of the tibia (1); and deep digital flexor tendon lesion (1). The third tarsal bone cyst was also identified with CT. Of the 16 horses with sclerosis identified with MRI, 2 had medullary sclerosis, 6 had SCB sclerosis, and 8 had both. Seven of the 16 horses had lesions in the dorsal-dorsomedial aspect of the central tarsal bone, 6 had lesions in the dorsal-dorsomedial aspect of the central tarsal bone and third tarsal bone, 1 had lesions in the dorsolateral aspect of the central tarsal bone and third tarsal bone, and 2 had lesions in the third tarsal bone (Figure 2). Eight of 16 horses with sclerosis had chronic lameness, and the remaining 8 horses had acute lameness.

Osseous hyperintensity was best identified on T2-weighted STIR MRI images (Figure 3). Of the 10 horses with OH identified with MRI, 6 had lesions in the central tarsal bone, 2 had lesions in the central and third tarsal bone, 1 had a lesion in third tarsal bone, and 1 had a lesion in the fourth tarsal bone. Three of 10 horses with OH had chronic lameness, and the remaining 7 horses had acute lameness. With MRI, medullary or SCB sclerosis (or both) was observed in 7 of 10 horses with OH.

Eight of 20 (40%) horses with no abnormalities identified on radiographs of the tarsus subsequently had pathological changes identified with MRI. Of the 12 horses with pathological changes identified on radiographs of the tarsus, 7 had additional more clinically relevant lesions identified with MRI. Therefore, on the basis of MRI findings, tarsal radiography was diagnostic for the clinically important lesions in only 5 of 20 (25%) horses. The most frequently identified lesion with MRI of the tarsus was sclerosis (medullary sclerosis, SCB sclerosis, or both). Sclerosis of the tarsus was radiographically suspected in 9 of 16 horses and was ultimately identified with MRI. Osteoarthritis of the tarsus was radiographically suspected in 5 of 8 horses and

Figure 1—Diagnostic images of the tarsus of a 9-year-old warmblood gelding with chronic unilateral hind limb lameness attributed to the tarsal area. A—Nuclear scintigraphic image of the tarsal area. Notice the abnormal RU (arrow). B—Lateromedial radiographic image of the tarsus. Radiographic findings are unremarkable. C—T2-weighted STIR sagittal MRI image of the tarsus. Notice the area of OH in the plantar aspects of the central and third tarsal bones (circle). Similar to findings for the horse in these images, nuclear scintigraphy findings corresponded with the location of lesions found with MRI in all horses of the present study.

Figure 2—Diagnostic images of the tarsus of a 7-year-old Quarter Horse gelding with chronic unilateral hind limb lameness attributed to the tarsal area. A—Nuclear scintigraphic image of the tarsal area. Notice the abnormal RU (arrow). B—Lateromedial radiographic image of the tarsus. Notice the medullary sclerosis of the central tarsal bone (arrow). C—Sagittal proton density MRI image of the tarsus. Notice the sclerosis of the central tarsal bone and dorsal aspect of the third tarsal bone (arrow).
was ultimately identified with MRI. Pathological changes in the tarsus resulting in MRI findings of OH were not identifiable on radiographs in any horse. Osteoarthritis was defined on radiographic evaluation as narrowing of the joint space with periarticular osteophyte formation and SCB sclerosis in 4 of 5 horses; 1 horse (an 8-year-old warmblood mare with chronic lameness) had a radiographic diagnosis of osteoarthritis with periarticular osteophyte formation only. Subchondral bone sclerosis was described radiographically as a separate condition when it was found in a location distant to the changes consistent with osteoarthritis.

In the present study, horses that had a fracture identified with MRI had negative results for fracture on radiographic evaluation performed before MRI. One horse (a 6-year-old Quarter Horse mare with acute lameness) that underwent radiographic evaluation after MRI had a radiolucent band running in a proximal to distal direction in the central tarsal bone, suggesting an occult fracture (Figure 4).

**Discussion**

An important finding in the present study was that pathological changes in the third and central tarsal bones that were identified with MRI were also detected with radiography in only 5 of 20 (25%) horses. However, the location of increased RU with nuclear scintigraphy corresponded with the location of pathological changes in all horses as determined with MRI. Sclerosis of the distal tarsal bones was identified with MRI in 16 of 20 (80%) horses, and pathological changes resulting in OH were detected with MRI in 10 of 20 (50%) horses; however, radiography was unreliable in the detection of either lesion type in the study reported here. Radiography was also not useful in the detection of fractures later identified with MRI (3/20 [15%] horses); however, for 1 horse, a fracture in a distal tarsal bone was evident with extensive radiographic evaluation following MRI. Although osteoarthritis is a common condition in the equine tarsus, it was underrepresented in the study reported here (8/20 [40%] horses) because nuclear scintigraphy and MRI are often not considered to be necessary for horses in which this is suspected to be the primary problem.

In 8 of 20 horses in present study, no local anesthesia (ie, perineural or intra-articular) was performed and nuclear scintigraphy was performed as the first diagnostic step. Reasons for not undergoing local anesthesia included lameness severity, patient compliance, or owner requests. In these 8 horses, there was abnormal RU in the distal aspect of the tarsus of the lame limb; thus, nuclear scintigraphy was performed as a diagnostic tool to help locate the source of lameness. Although the 8 horses for which nuclear scintigraphy was performed as the first diagnostic step had substantial pathological changes identified with MRI, there is concern regarding the use of nuclear scintigraphy alone in determining the cause of lameness (ie, in situations when local anesthesia has not been used). Findings from nuclear scintigraphy and MRI were similar for all horses (those with both acute and chronic lameness), and where RU was focal (eg, plantar aspect of third and central tarsal bone), the pathological changes identified with MRI were similarly located. Region of interest analysis was a useful tool because it helped to identify areas with clinically relevant amounts of abnormal RU. As such, all horses of the present study had a difference of ≥ 10% in RU between the lame and sound limb. Intense and focal abnormal RU (compared with the contralateral limb) is often thought to be associated with MRI findings of a fracture or OH because these lesions are frequently associated with acute and traumatic injuries as well as severe inflammation. However, in the present study, no significant (P = 0.66) difference in ROI analysis results was found between the 2 groups of horses (ie, those that had MRI findings of fracture or OH and those that did not have these MRI findings). Nuclear scintigraphy appears to be a useful tool for lo-
calizing lesions in the distal aspect of the tarsus when used with local anesthesia; however, for all horses of the present study, MRI provided superior definition of the pathological lesion relative to anatomic detail.

As a result of the increasing use of MRI as a diagnostic tool for horses, OH is a condition that is becoming more frequently identified with MRI and implicated as the source of lameness. In the present study, OH was identified with MRI in 10 horses. Results of the present study revealed that OH is best viewed on a T2-weighted STIR image in any plane, which agrees with previously reported findings in dogs with stifl joint injuries. In studies on humans, bone marrow edema and fractures are frequently related and are evident by an increased signal on T2-weighted, fat-suppressed, or STIR images. The term bone contusion is then used for these horses in which no fracture is evident. As suggested in a previous study of osteoarthritic knee joints of humans, the term ill-defined magnetic resonance signal intensity abnormality seems to be most appropriate. This is because in this area, hyperintense regions detected with MRI are rarely due to edema alone and often involve bone marrow necrosis, bone marrow fibrosis, or trabecular abnormalities. When no fracture is visible with MRI in humans, microfractures, hyperemia, and hemorrhage are present, eventually causing edema. In the ankle region of humans, bone edema usually precedes a stress fracture. Early changes consistent with bone edema (decreased signal intensity on T1-weighted image were identified with MRI; increased signal intensity on T2-weighted and fat-suppressed images) progress to a hypointense irregular line within this edema once a fracture occurs. If this sequence of events occurs in horses as it does in humans, stress fractures may be prevented from occurring by identifying high-risk patients with MRI. Interestingly, in humans, anterior cruciate injuries are often associated with a specific bone contusion pattern (ie, intensity and location) as determined with MRI; however, in the study reported here, although the central tarsal bone was involved in 8 of 10 horses with OH identified with MRI, there was not a consistent pattern of hyperintensity within the bone. In veterinary medicine, the definition of OH is not established for horses and the terms bone edema, bone contusion, and OH are being used interchangeably to describe MRI lesions.

In the present study, sclerosis was identified with MRI in 16 horses. Sclerosis is a condition that is indicative of chronic stress injury or late-stage cancellous bone stress fractures. Abnormal loading of bones was most likely the cause of sclerotic changes identified with MRI. Despite this being described as a chronic condition, sclerosis was associated with acute lameness in 8 of 16 horses. Sclerosis was present in the central tarsal bone in 14 of 16 horses and was located in the dorsal and dorsomedial aspect in 13 of these 14 horses. A previous study has shown that the SCB is thickest predominately in the dorsoproximal and dorsodistal portions of the central tarsal bone in clinically normal horses. In horses with a history of lameness, SCB was thickest on the medial aspect, a finding that agrees with the location of sclerosis in horses of the study reported here. When considering the use of intra-articular anesthesia for localizing the lameness, many SCB defects will not respond. Careful radiographic evaluation of the medullary cavity of the central tarsal bone may help to better identify this type of pathological change. If sclerosis is identified, a lesion of OH detected with MRI may also be present and contribute to lameness. In the present study, medullary or SCB sclerosis (or both) was observed in 7 of 10 horses with OH. As has been previously described, stress fractures in the distal tarsal bones are often difficult to detect radiographically. This was found in the present study in which 3 horses had MRI lesions consistent with stress fracture, yet had no obvious fracture identified on radiographs. A high index of suspicion should be maintained for fractures, and numerous radiographic images are often indicated where there is intense focal RU in the distal tarsal bones.

In the present study, an SCB cyst of the third tarsal bone was identified with MRI and CT in 1 horse. In a previous study, SCB cysts have been described within the tarsocrural joint; nuclear scintigraphy was used to localize the lesion in the limb. In 10 of 12 horses of that study, there were no radiographic changes indicative of SCB cysts. Nuclear scintigraphy and CT had been used to identify and treat the lesion. In the present study, the successful identification of SCB cysts with MRI indicates that MRI may become a reasonable alternative to CT to diagnose this condition.

The horses selected for the present study accounted for 1% of horses examined for lameness at our facility. Despite this small group size, the findings of the present study confirmed the hypothesis that radiology was not a sensitive imaging modality, compared with MRI and nuclear scintigraphy, for the detection of pathological conditions of the distal tarsal bones. Lesions of OH and sclerosis identified with MRI were frequent causes of lameness, resulting in pain in the tarsus in horses of the present study. Lesions of the distal tarsal bones can be difficult to detect and arguably requires all 3 imaging modalities described in the present study to both rule in and rule out pathological changes. The most effective treatment for OH and sclerosis has yet to be defined, although a period of rest appears to be integral to any treatment. Osteoarthritis as a pathological change is more common, but our method of case selection typically excluded this. Clearly, there is no substitute for a thorough lameness examination; however, once pain has been localized to the tarsus and radiographic findings are deemed unremarkable, MRI or nuclear scintigraphy should be considered as highly useful diagnostic imaging modalities.

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Evaluation of the aqueous humor flow rate in the eyes of clinically normal cats by use of fluorophotometry

William R. Crumley et al

Objective—To evaluate aqueous humor flow rate in the eyes of clinically normal cats by use of a noninvasive technique successfully used in other species.

Animals—20 domestic shorthair cats.

Procedures—One drop of 10% fluorescein sodium was instilled into both eyes of 5 cats every 5 minutes until 3 drops had been administered. Fluorophotometry was performed after 2, 4, 5, 6, 7, 8, 9, and 10 hours to monitor fluorescein removal and determine aqueous humor flow rate. The 3-drop protocol was used for the remaining 15 cats, and fluorophotometry was performed after 5, 6, 7, and 8 hours. Aqueous humor flow rates were calculated manually by use of established equations with minor adjustments to constant values to reflect feline anatomic features. Correlation coefficients and slope ratios were calculated to assess the legitimacy of the flow rate data. Paired t tests were calculated to assess for differences between the right and left eyes.

Results—Mean ± SD calculated aqueous humor flow rate in the right, left, and both eyes of the 20 cats was 5.94 ± 2.30 µL/min, 5.05 ± 2.06 µL/min, and 5.51 ± 2.21 µL/min, respectively. Correlation coefficients and slope ratios revealed that the aqueous humor flow rates were accurate. No significant differences in values for the right and left eyes were detected.

Conclusions and Clinical Relevance—Accurate aqueous humor flow values for cats can be determined by use of the fluorophotometric technique evaluated in this study. (Am J Vet Res 2012;73:704–708)