Injuries Associated With Ossification of the Cartilages of the Foot

Sue J. Dyson, Vet MB, PhD, FRCVS; and Rachel C. Murray, Vet MB, PhD, Diplomate ACVS

Ossification of one or both of the cartilages of the foot may be a significant risk factor for lameness associated with trauma of the ossified cartilage and associated ligaments and trauma of the distal phalanx. There is an association between desmopathy of the collateral ligaments of the distal interphalangeal joint and ≥ grade 3 ossification of the cartilages of the foot. Authors’ address: Centre for Equine Studies, Animal Health Trust, Lanwades Park, Kentford, Newmarket, Suffolk CB8 7UU, England; e-mail: sue.dyson@aht.org.uk. © 2010 AAEP.

1. Introduction

The cartilages of the foot provide support to the palmar (plantar) aspect of the foot, dissipate forces of the foot's impact with the ground, and are involved in venous return from the digit.\(^1\) Ossification of the cartilages of the foot (sidebone) normally starts at the base of the cartilage and extends proximally, or it can originate from a separate center of ossification (SCO).\(^2\) Lateral ossification is frequently more extensive than medial,\(^3\)–\(^9\) although heritability of ossification in Finnhorses is similar for both lateral and medial cartilages.\(^5\) A grading system (0–5) was described for description of the degree of ossification of the cartilages of the foot based on weight-bearing dorsopalmar (DP\(\alpha\)) radiographic views,\(^3\) which was subsequently modified.\(^10\) The term possibly significant ossification (PSO) was introduced,\(^4\) defined as grade 3 plus a separate center of ossification (SCO), grade 4, and grade 5.

Marked mediolateral asymmetry of cartilages of the foot is unusual\(^5,7\) but has been linked with injuries,\(^11,12\) including fractures of the ossified cartilage,\(^13\) trauma to the base of the ossified cartilage, and injury of the distal phalanx.\(^12,14\) An association between extensive ossification of the cartilages of the foot and collateral desmopathy of the distal interphalangeal (DIP) joint was suggested in a small study (\(n = 9\))\(^9\) and subsequently, verified by a much larger study (\(n = 462\)).\(^16\) The frequency of occurrence of PSO was significantly higher in horses with collateral desmopathy of the DIP joint than in horses with other injuries of the digit.

The cartilages of the foot are connected to surrounding structures, such as the digital cushion, proximal, middle, and distal phalanges, and navicular bone by small ligaments, including the chondroungular, chondrocoronal, chondrocompedal, and chondrosesamoidean ligaments. Injuries of these ligaments have not been well-described.

The purposes of this study were: (1) to describe the normal magnetic resonance imaging (MRI) appearance of the cartilages of the foot, (2) to describe injuries seen in association with ossification of the cartilages of the foot (ossification grade ≥ 3), their clinical features, and the results of diagnostic imag-
TABLE 1. Definitions of Injury Categories

<table>
<thead>
<tr>
<th>Group</th>
<th>Diagnostic Criteria</th>
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<tbody>
<tr>
<td>1</td>
<td>Primary injury of an ossified cartilage of the foot (no MRI)</td>
</tr>
<tr>
<td>2</td>
<td>Radiological abnormalities suggestive of a fracture or trauma at the junction between SCsO associated with moderate or intense IRU</td>
</tr>
<tr>
<td>3</td>
<td>Increased SI in T1- and T2-weighted images ± STIR images in part or all of the CL, with enlargement or change in shape, or altered definition of the margins, ± alteration in SI in the periligamentar tissues, and ± associated osseous abnormalities</td>
</tr>
<tr>
<td>4</td>
<td>Other injury in association with ≥ grade 3 ossification of a cartilage of the foot</td>
</tr>
</tbody>
</table>

MRI, magnetic resonance imaging; DIP, distal interphalangeal; SCsO, separate centers of ossification; IRU, increased radiopharmaceutical uptake; SI, signal intensity; STIR, short tau inversion recovery; CL, collateral ligament; DDFT, deep digital flexor tendon; DSIL, distal sesamoidean impar ligament.

ing, and (3) to describe follow-up outcomes for horses with primary injuries of the ossified cartilages of the foot.

2. Materials and Methods

Normal MRI Appearance of the Cartilages of the Foot

The description of the normal MRI appearance of the cartilages of the foot was determined by examination of the non-lame foot of 50 consecutive horses with a unilateral forelimb lameness that underwent high-field MRI at the Animal Health Trust in 2008 and 2009. Images were analyzed for signal intensity and homogeneity on different imaging sequences as well as shape, margin definition, relative size, and anatomical relationship with other structures within the foot.

Injuries Associated With Ossification of the Cartilages of the Foot

All horses (n = 78) were examined at the Centre for Equine Studies of the Animal Health Trust between January 2001 and December 2009. Horses were categorized into four groups (Table 1): Group 1, primary injury of an ossified cartilage of the foot (no MRI performed); Group 2, primary injury of an ossified cartilage; Group 3, injury of a collateral ligament (CL) of the DIP joint in association with ≥ grade 3 ossification of a cartilage of the foot; Group 4, other injuries in association with ≥ grade 3 ossification of a cartilage of the foot. All horses in Groups 2–4 were examined using high-field (1.5 T) or low-field (0.27 T) MRI.

Injury diagnosis was based on the prospective results of clinical examination, diagnostic local analgesia, radiography, nuclear scintigraphy, and ultrasonography ± MRI. Local analgesic techniques included a minimum of perineural analgesia of the palmar digital nerves and the palmar nerves at the base of the proximal sesamoid bones (in selected horses, a uniaxial palmar nerve block was also performed) and intra-articular (IA) analgesia of the DIP joint. Radiographic examination included DPa, lateromedial (LM), dorsoproximal-palmarodistal oblique (DPr-PaDiO) and flexed dorsolateral-palmaromedial oblique (DL-PaMO), and dorsomedial-palmarolateral oblique (DM-PaLO) views.15 Examinations performed before 2005 used conventional film-screen radiography; examinations performed after 2005 used computed radiography. Lateral and dorsal pool-phase scintigraphic images and lateral, dorsal, and solar bone-phase images were acquired, with a minimum acquisition time of 2 min for bone-phase images.16 High-field MR image acquisition was performed as previously described.17 Low-field image acquisition was performed in standing horses sedated by continuous infusion with detomidine and butorphanol, using the technique described by Mair et al.,18 plus acquisition of fast-spin echo sequences.

Lameness was assessed in straight lines on a hard surface and on circles on the lunge on both soft and firm surfaces. Some horses were also evaluated when ridden. All horses were examined by the same experienced clinician (S.J.D.). Lameness was graded at both the walk and trot under each circumstance on a scale of 0–8: mild, grade 2; moderate, grade 4; severe, grade 6; non–weight-bearing, grade 8. The effect of local analgesic techniques was assessed 5–10 min after injection; improvement was categorized as ≥50% improvement in lameness. Prospective diagnosis was dependent on analysis of the radiographic and scintigraphic images by S.J.D. and analysis of the MR images by one of two trained...
analysts (R. Murray or G. Greet) and S. J. Dyson. For the purposes of this study, all radiographic, scintigraphic, and MR images were subsequently independently reevaluated retrospectively in random order by S.J.D.

Breed categories were Thoroughbred (TB), TB cross (including TB-cross Warmblood [WBL] or TB-cross Irish Draught), WBL, cob-type, and other. Discipline groups were eventing, showjumping, dressage, general purpose, and racing. Horses competing at unaffiliated levels were defined as general purpose. Signalment data were compared with the overall clinic population over the same period. Differences in signalment between groups and the overall clinic population were evaluated using Chi squared analysis, with a significance level of \( p < 0.05 \).

Follow-up information on all horses with primary injury to cartilages of the foot was obtained by telephone questionnaire. Outcome was divided into return to athletic function at the same level as before injury, return to a lower level of work, or continued lameness.

3. Results

Normal MRI Appearance of the Cartilages of the Foot

The cartilages of the foot extended in a dorsopalmar direction from dorsal to the dorsal aspect of the middle phalanx to the palmar aspect of the distal phalanx and sometimes beyond and proximodistally from the proximal aspect of the distal phalanx to the proximal aspect of the middle phalanx. They were usually curved proximodistally, being convex abaxially. The degree of curvature was variable. The cartilages of the foot were generally similar in mediolateral thickness from proximal to distal and had heterogeneous intermediate signal intensity in T1- and T2-weighted MR images, with well-defined margins. At the level of the middle phalanx, there were frequently large blood vessels axial to the proximal aspect of the cartilage. The number of blood vessels within the cartilages of the foot was variable; these were characterized by focal or linear areas of low signal intensity in T1-weighted images and high signal intensity in T2-weighted images. In horses with ossification, the cartilages of the foot were usually cartilaginous at their most dorsal extent, ossification extending palmar from the dorsal aspect of middle phalanx or more commonly, from the navicular bone palmar (Fig. 3). Ossified cartilages usually had smooth cortices of even thickness that had low signal intensity in all image sequences. In T1- and T2-weighted MR images, the medulla of ossified cartilages were visible as areas of low signal intensity.

Fig. 1. Dorsal T1-weighted spoiled gradient echo high-field MR image of normal unossified cartilages of the foot at the level of the middle phalanx. Medial is to the left. The medial cartilage of the foot is indicated by arrows. Note the convex abaxial contour of the cartilages of the foot proximally. Compare with Fig. 3.

Fig. 2. Dorsal T1-weighted spoiled gradient echo (A) and T2*-weighted gradient echo (GRE) (B) high-field MR image of a foot. Medial is to the left. There are blood vessels (arrows) axial to the proximal aspect of the cartilages of the foot, most obvious medially.
cartilages had moderately high signal intensity. In some horses, there was one or more separate centers of ossification (SCsO) proximally, occurring most often at the junction between the proximal and distal halves of the cartilage of the foot (Fig. 4). At the junction between SCsO, the cortices were regular and of uniform thickness. Toward the palmar aspect of the foot, there was often separation present between the ossified cartilage and the palmar process of distal phalanx (Fig. 5). The chondrocoronal, chondrosesamoidean, and chondrocompedal ligaments blended smoothly with the cartilages and had uniform low signal intensity in T1- and T2-weighted images; occasionally, there was mild increased signal intensity in fat-suppressed images at their origins.

Injuries Associated With Ossification of the Cartilages of the Foot

In all lameness groups, middle-aged geldings predominated (Table 2). There were significant differences between the signalment of horses within the injury groups and the overall clinic population (p < 0.001). Horses used for general-purpose riding were overrepresented compared with the normal clinic population. Cob, Thoroughbred cross, and other breeds were overrepresented compared with the overall clinic population; Thoroughbreds were underrepresented. Mean body weight was also higher than that of the general clinic population.

In the majority of horses, the cartilages of the foot felt firm, but there were no other detectable localizing clinical signs, even after clipping the hair coat. Digital pulse amplitudes, when palpable, were normal. Conformational abnormalities of the lame(r) foot included tall and narrow (n = 9), toe in (n = 8), toe out (n = 1), mediolateral imbalance (n = 12), long toes (n = 6), low heel (n = 6), and a flat sole (n = 5) and were seen in 65.4% of horses. The frequency of occurrence of mediolateral imbalance was higher in Group 3 (22.0%) compared with Groups 1, 2, and 4 (8.3%, 9.1%, and 13.6%, respectively). There was generally no response to hoof testers. Lameness was invariably worse on a circle on a soft or firm surface and in some horses, was barely apparent in straight lines. Lameness was generally more severe in horses from Group 4 than horses from Groups 1 to 3 (Table 2). In most horses (n = 51; 66.2%), lameness was most obvious with the lame(r) limb on the inside of a circle, but in some horses,
lameness was similar in degree on both reins (n = 14; 18.2%) or worse with the lame(r) limb on the outside of a circle (n = 12; 15.6%). This did not seem to be related to the side of maximum injury within the foot. One horse was not assessed moving in circles. The responses to local analgesia are summarized in Table 3.

Group 1: Primary Injury of an Ossified Cartilage of the Foot (No MRI; n = 12)

Eleven horses had unilateral forelimb lameness, and one horse had bilateral forelimb lameness; results are reported for the lamer limb. Ossification grade (Table 4) of the maximally ossified cartilage of the foot was 3 + SCO (n = 1), 4 (n = 5), or 5 (n = 6). Ossification grade of the less-ossified cartilage was 2 (n = 2), 3 (n = 2), 4 (n = 4), or 5 (n = 4). The lateral cartilage usually had a similar or greater ossification grade than the medial cartilage. Four horses were determined to have sustained trauma at the base of an ossified cartilage (four lateral and two medial) defined as modeling changes and moderate or intense focal increased radiopharmaceutical uptake (IRU; two lateral and two medial), and six horses had either a suspected fracture or trauma at the junction of a SCO at the base of an ossified cartilage (four lateral and two medial) defined as a variable defined radiolucent line, modeling, and IRU (Fig. 6). One horse had modeling around the junction between a SCO in the middle of the lateral ossified cartilage with focal IRU. One horse had modeling of the proximal aspect of the lateral ossified cartilage, with focal intense IRU. In six horses, there was patchy increased radiopacity throughout the injured ossified cartilage.

Six horses showed improvement in lameness after palmar digital nerve blocks (Table 3). In 10 horses, lameness was substantially improved by palmar nerve blocks performed at the base of the proximal sesamoid bones, but in two horses, palmar (at the junction of the proximal ¾ and distal ¼ of the metacarpal region) and palmar metacarpal nerve blocks were required to improve lameness. These two horses showed no response to IA analgesia of the metacarpophalangeal (MCP) or proximal interphalangeal (PIP) joints or intrathecal analgesia of the digital flexor tendon sheath (DFTS). No horse showed improvement after IA analgesia of the DIP joint. A uniaxial palmar nerve block was per-

TB, Thoroughbred; TBX, Thoroughbred cross; WBL, Warmblood; E, eventing; SJ, showjumping; Dr, dressage; GP, general purpose, including unaffiliated competition.
formed in seven horses ipsilateral to the postulated injured ossified cartilage of the foot, and all showed improvement.

All horses were treated by rest for a minimum of 3 mo combined with corrective trimming to correct any imbalance and use of an open broad-web shoe or bar shoe. Ten horses (83.3%) returned to full athletic function, with a follow-up period of 6 mo to 4 yr.

Group 2: Primary Injury of an Ossified Cartilage (n = 12)
Seven horses had unilateral forelimb lameness, and five horses had bilateral forelimb lameness; results are reported for the lamer limb. Eight horses showed improvement in lameness after palmar digital nerve blocks, two horses were sound, and two showed no change. In all horses, lameness was substantially improved by palmar nerve blocks performed at the base of the proximal sesamoid bones.

Table 3. Comparison of the Responses to Local Analgesic Techniques in Groups 1–4 Given as Percentages

<table>
<thead>
<tr>
<th></th>
<th>Group 1 (N = 12)</th>
<th>Group 2 (N = 12)</th>
<th>Group 3 (N = 32)</th>
<th>Group 4 (N = 22)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palmar Digital Nerve Blocks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not performed</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2 horses</td>
</tr>
<tr>
<td>No change</td>
<td>0</td>
<td>16.7</td>
<td>37.5</td>
<td>5.0</td>
</tr>
<tr>
<td>Improved</td>
<td>50</td>
<td>66.7</td>
<td>40.6</td>
<td>50.0</td>
</tr>
<tr>
<td>Sound</td>
<td>0</td>
<td>16.7</td>
<td>21.9</td>
<td>50.0</td>
</tr>
<tr>
<td>Palmar Nerve Blocks*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No change</td>
<td>16.7</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Improved</td>
<td>83.3</td>
<td>0</td>
<td>8.0</td>
<td>9.1</td>
</tr>
<tr>
<td>Sound</td>
<td>0</td>
<td>100</td>
<td>88.0</td>
<td>90.9</td>
</tr>
<tr>
<td>Worse</td>
<td>0</td>
<td>0</td>
<td>4.0</td>
<td>0</td>
</tr>
<tr>
<td>IA Analgesia DIP Joint</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not performed</td>
<td>0</td>
<td>1 horse</td>
<td>0</td>
<td>2 horses</td>
</tr>
<tr>
<td>No change</td>
<td>100</td>
<td>81.8</td>
<td>84.4</td>
<td>52.6</td>
</tr>
<tr>
<td>Improved</td>
<td>0</td>
<td>18.2</td>
<td>15.6</td>
<td>31.6</td>
</tr>
<tr>
<td>Sound</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>15.8</td>
</tr>
</tbody>
</table>

*Performed at the base of the proximal sesamoid bones.

Improvement was defined as at least 50% improvement in lameness. IA, intra-articular; DIP, distal interphalangeal.

Nine horses showed no improvement after IA analgesia of the DIP joint, and two were improved. There was no response to IA analgesia of the PIP joint in those horses in which this was performed (n = 6). A uniaxial palmar nerve block ipsilateral to the postulated injured cartilage improved lameness in five of six horses.

Ossification grade of the maximally ossified cartilage of the foot was 3 (n = 3), 4 (n = 6), or 5 (n = 3). Ossification grade of the less-ossified cartilage was 0 (n = 1), 1 (n = 2), 2 (n = 2), 3 (n = 2), 4 (n = 4), or 5 (n = 1). The lateral cartilage usually had a similar or greater ossification grade than the medial cartilage. On radiological examination, four horses had ill-defined radiolucent lines at the base of the injured ossified cartilage, with local alterations in radiopacity.

On the basis of MRI, five horses had a fracture or trauma at the base of an ossified cartilage (four lateral and one medial) (Fig. 7); two horses had trauma to the junction between SCsO (both lateral) (Fig. 8), and five horses had more generalized trauma of the ossified cartilage (two lateral and three medial) (Fig. 9). In 6 of 12 horses, there were focal or diffuse areas of reduced signal intensity in the ossified cartilage in T1- and T2-weighted images, consistent with mineralization. Seven horses also had alterations in signal intensity in the ipsilateral aspect of the distal phalanx characterized either by diffuse areas of hypointense signal in T1- and T2-weighted images consistent with mineralization or areas of hyperintense signal in short tau inversion recovery (STIR) images (Fig. 10). One horse had an incomplete fracture of the axial aspect of the distal phalanx (Fig. 11). Increased signal intensity in STIR images ± enlargement of the chondrocoronal ligament (n = 3) or chondroseamoidean ligament (n = 3) was also seen in three

Table 4. Radiological Grade of Ossification of the Cartilages of the Foot Based on Weight-Bearing Dorsopalmar Radiographic Views10

<table>
<thead>
<tr>
<th>Grade</th>
<th>Radiological Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No ossification</td>
</tr>
<tr>
<td>1</td>
<td>Ossification up to the level of the medial or lateral margins of the DIP joint</td>
</tr>
<tr>
<td>2</td>
<td>Ossification up to the level of the central (axial) aspect of the DIP joint</td>
</tr>
<tr>
<td>3</td>
<td>Ossification up to the most proximal aspect of the navicular bone (excluding proximal entheseophytes)</td>
</tr>
<tr>
<td>4</td>
<td>Ossification up to the midpoint of the middle phalanx (based on the most proximal aspect of the joint surface)</td>
</tr>
<tr>
<td>5</td>
<td>Ossification proximal to the midpoint of the middle phalanx</td>
</tr>
</tbody>
</table>

DIP, distal interphalangeal.
horses (Fig. 12). In five horses, there was focal increased signal intensity in the contralateral cartilage of the foot in STIR images at the site of origin of the chondrosesamoidean ligament.

Seven of twelve horses underwent nuclear scintigraphy. Moderate or intense IRU was identified in an ossified cartilage (consistent with the location of pathological change noted in MR images) and/or distal phalanx in all seven (base of the ossified cartilage, n = 1; base of the ossified cartilage and the ipsilateral palmar process of the distal phalanx, n = 3; diffuse IRU throughout an ossified cartilage, n = 1; focal IRU at the apex of an ossified cartilage, n = 1; IRU in one side of the palmar one-half of the distal phalanx, n = 1).

Horses were treated similarly to Group 1. Five of nine horses (55.5%) for which follow-up is available have returned to full athletic function for a minimum of 6 mo and up to 2 yr; three of these horses subsequently developed other foot-related lameness 9–12 mo after resuming full work; four remained lame but were suitable for light work. Three horses are still convalescing.

Group 3: Injury of a CL of the DIP Joint in Association With Grade 3 Ossification of a Cartilage of the Foot (n = 32)

Twenty horses with injury of a CL of the DIP joint had unilateral forelimb lameness, and 12 horses had bilateral lameness; results are presented for the lame limb. Palmar digital analgesia resulted in no change in lameness in 12 horses, improvement in 13 horses, and resolution of lameness in 7 horses. Twenty-two horses were sound after palmar nerve
blocks performed at the base of the proximal sesamoid bones; two horses with concurrent proximal suspensory desmitis were improved; one horse was worse. This horse showed mild improvement after IA analgesia of the MCP joint and no change after IA analgesia of the PIP joint or intrathecal analgesia of the DFTS. Twenty-seven horses showed no change in lameness after IA analgesia of the DIP joint, and five were improved.

Ossification grade of the maximally ossified cartilage of the foot was 3 (n = 2), 4 (n = 12), or 5 (n = 18). Ossification grade of the similarly or less-ossified cartilage was 1 (n = 3), 2 (n = 6), 3 (n = 6), 4 (n = 9), or 5 (n = 8). The lateral cartilage usually had a similar or greater ossification grade than the medial cartilage. Radiological abnormalities of one or both ossified cartilages were identified in 15 horses and included mediolateral thickening, generalized or focal increased radiopacity, cortical irregularity especially axially, fracture at the base or modeling around the base, or modeling at the junction between SCsO or an old fracture site midway between the apex of the cartilage and its base.

Fifteen horses had injury to the medial CL of the DIP joint, eight horses had injury of the lateral CL, and nine horses had biaxial injuries. Fifteen horses also had evidence of trauma of one or both ossified cartilages characterized by focal or diffuse increased signal intensity in STIR images, with or without areas of abnormal mineralization characterized by reduced signal intensity in T1- and T2-weighted images; seven horses had focal or diffuse mineralization of one or both ossified cartilages of the foot without evidence of trauma. Thirteen horses had abnormalities of the distal phalanx reflecting abnormal mineralization or trauma. In eight horses, concurrent abnormalities of the chondrocoronal (n = 5) or chondrocoronal and chondro-sesamoidean (n = 3) ligaments were also identified. It was considered likely that these concurrent

Fig. 7. (A) Lateral (i), dorsal (ii; right forelimb to the left), and solar (iii; lateral to the left) scintigraphic images. There is moderate increased radiopharmaceutical uptake at the base of the lateral ossified cartilage of the right front foot (arrows). (B) High-field lateral parasagittal T1-weighted spoiled gradient echo MR image. (C) High-field lateral parasagittal T2*-weighted gradient echo image. (D) Dorsal (frontal) high-field short tau inversion recovery image. Lateral is to the right. There is reduced signal intensity in both (arrow) between the base of the ossified cartilage and the distal phalanx. There is increased signal intensity in the STIR image. This is evidence of trauma to the junction between separate ossification centers or possibly, a fracture at the base of an ossified cartilage, with associated mineralization. This was the primary cause of lameness in this 7-yr-old event horse.
injuries of the cartilage of the foot and/or the distal phalanx may have contributed to pain and lameness.

Twenty horses underwent nuclear scintigraphic examination, in 15 of which, there was moderate to intense focal or diffuse IRU in an ossified cartilage and/or the distal phalanx (focal IRU at the base of the ossified cartilage, n = 2; focal IRU at the base of the ossified cartilage and in the ipsilateral palmar process of the distal phalanx, n = 3; diffuse IRU in the ossified cartilage, n = 2; diffuse IRU in the ossified cartilage and the ipsilateral palmar process of distal phalanx, n = 2; diffuse IRU in the distal phalanx on the side of the maximally ossified cartilage, n = 2; focal IRU in a palmar process of the distal phalanx, n = 3; focal IRU in the distal phalanx abaxial to the region of insertion of a CL of the DIP joint, n = 1).

Group 4: Other Injuries in Association With ≥ Grade 3 Ossification of a Cartilage of the Foot (n = 22)

Twenty-two horses, thirteen unilaterally lame and nine bilaterally lame (results are presented for the lammer limb), had other injuries in association with ≥ grade 3 ossification of one or both cartilages of the foot, including injury of the deep digital flexor tendon (DDFT; n = 6) (Fig. 13), the DDFT and a CL of the DIP joint (n = 2), the DDFT and the navicular bone and a CL of the DIP joint (n = 5), the navicular bone ± the distal sesamoidean impar ligament (DSIL) (n = 4), the navicular bone and a CL of the DIP joint (n = 2; one horse had an unstable bipartite navicular bone), the
DSIL and a CL of the DIP joint (n = 1), an osseous cyst-like lesion in the distal phalanx at the abaxial insertion of the DSIL (n = 1) (Fig. 14), and the proximal phalanx (n = 1). Seven of these horses had evidence of trauma of one or both ossified cartilages of the foot characterized by increased signal intensity in STIR images, which may have contributed to pain and lameness, and one horse had abnormal mineralization of an ossified cartilage.

Palmar digital analgesia resulted in resolution of lameness in 9 horses and improvement in 10 horses. One horse showed no change. Ten horses had resolution of lameness after palmar nerve blocks performed at the base of the proximal sesamoid bones, and one horse improved. Intraarticular analgesia of the DIP joint resulted in no change in 10 horses, improvement in lameness in 6 horses, and resolution of lameness in 3 horses.

Osification grade of the maximally ossified cartilage of the foot was 3 (n = 2), 4 (n = 17), or 5 (n = 3). Osification grade of the similarly or less-ossified cartilage was 1 (n = 3), 2 (n = 8), 3 (n = 7), 4 (n = 2), or 5 (n = 2). The lateral cartilage usually had a similar or greater osification grade than the medial cartilage. No other specific abnormalities were detected on the basis of radiological examination.

Nineteen horses underwent scintigraphic examination. Two horses had moderate diffuse IRU in one ossified cartilage. Two horses had focal IRU at the base of an ossified cartilage; the horse with an osseous cyst-like lesion (OCLL) in the distal phalanx had diffuse IRU on the ipsilateral aspect of the distal phalanx. Four horses had focal IRU in one or both palmar processes of the distal phalanx, and one horse had focal IRU in the navicular bone.

4. Discussion
This study provides further evidence that ossification of one or both cartilages of the foot (sidebone) is not necessarily an incidental observation of no clinical significance but may be associated with lame-
ness. Lameness may be caused by a primary injury of an ossified cartilage and/or injury of closely related anatomical structures, including the ipsilateral aspect of the distal phalanx, the CLs of the DIP joint, and ligaments that originate on the cartilages of the foot.

Signalment
Cob-types and cross-breed horses (particularly Thoroughbred cross Irish Draft) used for general purposes were overrepresented in the current study compared with the general clinic population. This probably reflects a heritable predisposition to ossification of the cartilages of the foot in these types of horses.5,8 However, it also highlights that extensive ossification of one or both cartilages of the foot in other breed and discipline groups should not be ignored.

Lameness
Lameness associated with injuries of the cartilages of the foot and other related injuries varied in severity.

Fig. 11. Dorsal (A), lateral (B), and solar (C) scintigraphic images of a horse from Group 2. There is moderate focal increased radiopharmaceutical uptake in the palmar lateral aspect of the distal phalanx of the left front foot (arrows), most intense on the axial aspect of the palmar process in C. In the dorsal spoiled gradient echo high-field MR image (D; lateral is to the right), there is diffuse decreased signal intensity in the lateral aspect of the distal phalanx, with an axial hyperintense line (arrow) representing an incomplete fracture. In the dorsal short tau inversion recovery image (E), there is a focal area of hyperintense signal (arrowhead), corresponding to the incomplete axial fracture in the distal phalanx, and diffuse increased signal intensity in the lateral aspect of the distal phalanx (arrows).

Fig. 12. Dorsal high-field short tau inversion recovery image. There is increased signal intensity in the cartilages of the foot at the origins of the chondrocoronal ligaments (arrows).
ity but was generally mild to moderate and most obvious on a circle, like many causes of foot pain. Many owners reported that lameness had been more severe at the time of its onset. In horses with bilateral lameness, the degree of lameness in the lame limb (reported) may, however, have been underestimated. It was notable that the mean duration of lameness was longest in Group 4 (Table 2). Nonetheless, the mean severity of lameness was higher in Group 4 compared with Groups 1, 2, and 3. In 68% of horses in Group 4, the primary source of pain causing lameness was not considered to be the ossified cartilages of the foot, based on the responses to local analgesic techniques combined with the results of diagnostic imaging. Thus, other causes of lameness may have contributed to lameness severity.

Responses to Local Analgesia

Two horses in Group 1 showed no change in lameness after palmar nerve blocks performed at the base of the proximal sesamoid bones, and one horse in Group 3 was worse. It is important to recognize that local analgesic techniques can sometimes be misleading. Foot pain is not reliably abolished in all horses, despite apparent desensitization of the foot. Although it is conceivable that the two horses in Group 1 had fetlock region pain of undetermined cause or related to chronic gait alteration, their clinical features, radiological findings, and scintigraphic findings were similar to the other horses in the group. The horse in Group 3 in which lameness deteriorated did have mild improvement in lameness after IA analgesia of the MCP joint and MR evidence of abnormal mineralization of the distal dorsal aspect of the third metacarpal bone. However, it was considered likely that the foot injuries were the principle cause of pain causing lameness. It is a common observation that if palmar nerve blocks do not abolish lameness, then lameness may deteriorate, possibly because of altered foot placement associated with a change in proprioceptive function of the foot.

There were notable differences in the response to IA analgesia of the DIP joint in horses in Group 4, with 47.4% improved or sound compared with ≤18% improved only in Groups 1, 2, and 3. It is considered likely that, in these horses, injuries of the DDFT, navicular bone, and DSIL were of greater clinical significance than the presence of ossification of one or both of the cartilages of the foot.

Radiography, Radiology, and Nuclear Scintigraphy

There is value in comparing DPa, DPr-PaDiO, and flexed oblique radiographic views of the ossified cartilages to identify the extent of ossification (Fig. 13), radiolucent lines, and associated modeling (Fig. 6). However, there are difficulties in differentiation between trauma at the junction between SCsO and a fracture using either radiography or MRI. The presence of focal IRU helps to verify that these sites have active modeling (Figs. 6, 8, and 11), and because such injuries have been seen as the sole identifiable cause of lameness, it seems reasonable to assume that they may be a source of pain and lameness in some horses. However occasionally, IRU is seen at the junction between SCsO in the non-lame limb of a bilaterally lame horse, indicating that this may be a point of stress concentration. In such horses, there is usually less reactive change seen around the junction on MR images compared with the horses described in the current study. Modeling at the origin of ligaments between the distal abaxial aspect of the proximal phalanx and the proximal aspect of the cartilages of the foot was seen in a small number of horses in the current study but

Fig. 13. (A) Dorsolateral-palmaromedial oblique radiographic view of the right front foot of a horse from Group 4, which also had an extensive core lesion of the lateral lobe of the deep digital flexor tendon. Note the very extensive ossification of the lateral cartilage of the foot (arrows). (B) Dorsal short tau inversion recovery low-field MR image of the same foot as in A. Lateral is to the left. There is increased signal intensity in the axial aspect of the lateral ossified cartilage, especially at the origin of chondroesamoidean ligament (arrows).
was never associated with IRU and probably reflects entheseseous stress.

Scintigraphic results were generally well-correlated with the presence of osseous abnormalities of the distal phalanx detected using MRI, including either regions of increased signal intensity in STIR images or areas of abnormal mineralization.

Predilection Sites for Injury

This study confirms the result of previous observations that the base of an ossified cartilage or the junction between SCsO are predilection sites for injury. The force of impact with the ground compresses the digital cushion, forcing the cartilages of the foot abaxially at their connection with the distal phalanx. The force is transferred and thus, dissipated through the venovenous anastomoses running through the cartilages. The base of the cartilages of the foot had greater radiopharmaceutical uptake than more proximally, indicating that it is a site of continued modeling throughout life, a reflection of the focal concentration of force. Extensive ossification reduces the flexibility and capacity for energy dissipation of the cartilages. The predilection for fractures of ossified cartilages at their base may be explained by maximum stress/or strain concentration at this point. The junction between SCsO is a potential weak link. It has been suggested that the reduced energy-dissipation capacity and associated redistribution of energy caused by extensive ossification of one or both cartilages of the foot may predispose to injury of a CL of the DIP joint.

In the current study, abnormalities of the cartilages of the foot included focal or diffuse mineralization. Whether such mineralization reflects a response to chronic trauma or is a physiological response is not known. It may further stiffen an ossified cartilage and alter force transmission through the ossified cartilage, and possibly, it may further predispose the horse to injuries of the cartilages themselves or closely related osseous and soft-tissue structures, such as the distal phalanx and chondrocoronal and chondrosesamoidean ligaments or the CLs of the DIP joint. In the current study, there was frequently an association between trauma of an ossified cartilage and abnormalities of the ipsilateral aspect of the distal phalanx.

Injuries of the lateral cartilage of the foot and the ipsilateral aspect of the distal phalanx were more common than medial injuries in Groups 1 and 2. This coincides with the observation that the lateral cartilage of the foot was usually more extensively ossified than the medial cartilage of the foot.

Relationship Between Ossification of the Cartilages and Injuries of the Chondrocoronal and Chondrosesamoidean Ligaments

Injuries of the chondrocoronal or chondrosesamoidean ligaments were not seen in the control limbs, although occasionally there was mild focal increased signal intensity in STIR images at their origins on the cartilages of the foot. In the current study, evidence of injury of these ligaments was seen in some horses in Groups 2 and 3 and was characterized by increased signal intensity in fat-suppressed images in the ligaments and/or their osseous attachments, increased thickness of the ligaments.
aments, and lack of definition from adjacent anatomical structures, probably reflecting ligament fiber disruption and entheseal reaction. Alteration in the shape of the cartilage, with axial irregularity, was also seen at sites of ligamentous attachments.

Limitations of the Study
This study has some limitations. Horses in Group 1 did not undergo MRI, and it is possible that there may have been other injuries contributing to pain and lameness. However, many of these horses had similarities to those in Group 2. In Groups 3 and 4, it was not possible to determine accurately to what extent abnormalities of the ossified cartilages of the foot contributed to pain and lameness, although correlating the results of local analgesic techniques, nuclear scintigraphy, and MRI was helpful. A group of horses free from lameness with ≥ grade 3 ossification of the cartilages of the foot that had undergone MRI was not available for comparison.

5. Conclusions
Moderate or extensive ossification of one or both cartilages of the foot may be of clinical significance, being associated with primary injury of the ossified cartilage, injury of the ipsilateral aspect of the distal phalanx, or injury of ligaments attached to the cartilages of the foot or the CLs of the DIP joint.

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References and Footnote

*Dyson S, Murray R. Unpublished data.