EQUINE VETERINARY JOURNAL
Equine vet. J. (2007) **39** (3) 250-256
doi: 10.2746/042516407X171174

Scintigraphic examination of the cartilages of the foot

A. NAGY, S. J. DYSON* and R. M. MURRAY

Centre for Equine Studies, Animal Health Trust, Lanwades Park, Kentford, Newmarket, Suffolk CB8 7UU, UK.

Keywords: horse; sidebone; lameness; radiography; scintigraphy

Summary

Reasons for performing study: **Radiographic examination of the cartilages of the foot is well documented; however, there is limited information about their scintigraphic assessment.**

Objectives: **To evaluate the scintigraphic appearance of the cartilages of the foot using subjective and quantitative image analysis and to correlate radiographic and scintigraphic findings.**

Hypotheses: **An ossified cartilage would have similar radiopharmaceutical uptake (RU) to the ipsilateral aspect of the distal phalanx; RU would extend throughout the length of the ossified cartilage; a separate centre of ossification (SCO) would be identified on a scintigraphic image; and fracture or trauma to an ossified cartilage would manifest as increased RU (IRU).**

Methods: **Front feet (n = 223) of horses (n = 186) that had dorsopalmar radiographic views and dorsal scintigraphic images were included in the study. The cartilages of the foot were graded radiographically and scintigraphically. Quantitative evaluation of the scintigraphic images was carried out using region of interest (ROI) analysis. For statistical analysis RU ratios were used. Correlations between a radiographically detected SCO and focal RU and between IRU and radiographic abnormalities were assessed.**

Results: **There was a good correlation and an excellent agreement between radiographic and scintigraphic grades. ROI analysis showed a proximal to distal increase in RU ratios within each cartilage of the foot. A radiographically identified SCO could be detected scintigraphically in 12/17 feet (70.6%). Thirty-eight feet had IRU in the region of a cartilage, 25 of which (65.8%) had corresponding radiographic abnormalities. Fracture of an ossified cartilage was associated with IRU in all horses.**

Conclusions and potential relevance: **Scintigraphy may give information about the potential clinical significance of ossification of the cartilages of the foot and associated lesions, therefore prompting further investigation by use of a uniaxial ipsilateral palmar nerve block and imaging, using either magnetic resonance imaging and/or computed tomography.**

Introduction

Ossification of the cartilages of the foot is a common finding, but its aetiology and clinical significance are debated (Ruohoniemi *et al.* 1993; Verschooten *et al.* 1996, Stashak 2002; Dyson 2003), while radiographic examination is well documented (Colles 1983; Ruohoniemi *et al.* 1993; Verschooten *et al.* 1996; Butler *et al.* 2000; Down *et al.* 2007), for which a radiographic grading system has been proposed (Ruohoniemi *et al.* 1993). However, there is limited information about scintigraphic assessment of the cartilages of the foot (Ruohoniemi *et al.* 2004; Dakin *et al.* 2006).

Ruohoniemi *et al.* (2004) evaluated the clinical significance of ossification in Finnhorses, based on clinical, radiographic and scintigraphic examination. The study included 36 feet of 21 horses. A subjective grading system for scintigraphic assessment was used, based on dorsal, lateral and solar images. The scintigraphic grades did not allow direct comparison with the radiographic grades and quantitative image analysis was not used.

Dakin *et al.* (2006) reported a series of 10 horses with fractures of the ossified cartilages of the foot. Scintigraphic examination of the foot was performed in all horses and fracture was associated with increased radiopharmaceutical uptake (IRU).

The aims of the present study were to evaluate the scintigraphic appearance of the cartilages of the foot using subjective and quantitative image analysis, to develop a scintigraphic grading system based on dorsal scintigraphic images and to assess the correlation between scintigraphic and radiographic grades and between IRU and radiographic abnormalities.

It was hypothesised that an ossified cartilage would have similar radiopharmaceitical uptake (RU) to the ipsilateral aspect of the distal phalanx; RU would extend throughout the length of an ossified cartilage; a separate centre of ossification (SCO) would be identified on a scintigraphic image; and fracture or trauma to an ossified cartilage would manifest as IRU.

Materials and methods

Clinical records of skeletally mature horses with foot-related pain admitted to the Animal Health Trust between January 2003 and July 2005 were reviewed. Horses were selected that had weightbearing dorsopalmar radiographic views of one or both front feet and dorsal scintigraphic images of the distal forelimbs. Radiographic grades of degree of ossification of the cartilages of the foot of horses examined between January 2003 and December 2004 were obtained from a previous study (Down *et al.* 2007). Radiographs obtained between January and July 2005 and all scintigraphic images were evaluated by A.N.

*Author to whom correspondence should be addressed.
[Paper received for publication 17.08.06; Accepted 02.11.06]

Image acquisition

Weightbearing dorsopalmar radiographic views (Butler *et al.* 2000) were obtained as a part of comprehensive radiographic examination of one or both front feet of horses with foot pain. Scintigraphic images were obtained as previously described (Dyson *et al.* 2001; Dyson 2002). Images were transferred to a workstation and analysed using nuclear medicine software (Hermes)[1].

Image analysis

Grading the radiographs: Radiographic grading of the degree of ossification of the cartilages was carried out according to Ruohoniemi *et al.* (1993): *Grade 0* = no ossification; *Grade 1* = minimal ossification at the base of the cartilage, up to the level of the medial/lateral joint margins of the distal phalanx; *Grade 2* = mild ossification at the base of the cartilage up to the palmar level of the distal interphalangeal joint; *Grade 3* = moderate ossification up to the level of the proximal edge of the navicular bone; *Grade 4* = advanced ossification extending clearly above the navicular bone, but remaining in the distal half of the middle phalanx; *Grade 5* = extensive ossification up to the level of the proximal half of the middle phalanx. Presence and location of a SCO were recorded. Repeatability of the grading system was assessed by Down *et al.* (2007) and also independently by A.N. Ten pairs of bilateral radiographs were graded blindly 10 times.

Scintigraphic assessment: Bone phase scintigraphic images were assessed subjectively and objectively by the first author (A.N.) without knowledge of radiographic findings. Scintigraphic images were excluded from the study if there was poor RU in the distal forelimbs (total count <300,000 per pixel); if oblique positioning of the foot did not allow adequate subjective and objective assessment; or if there was a poor definition of the regions of the distal limb, even if the total count was considered adequate.

In order to determine anatomical landmarks on the scintigraphic images, magnified dorsal scintigraphic images and dorsopalmar radiographic views were registered using nuclear medicine software. Reference points were selected on the medial and lateral margins of the widest part of the RU in the distal phalanx and at another prominent point, distal or proximal to the widest part of the distal phalanx. The corresponding points were positioned on the radiograph and images registered. The registration was repeated 3 times on 5 feet to evaluate repeatability of the procedure.

Five horizontal lines were drawn on the scintigraphic images for the grading system (Fig 1) and for the determination of the proximal and distal borders of the regions of interest (ROIs). The anatomical positions of the lines were confirmed on the registered scintigraphic and radiographic images. Line 1 was drawn at the level of the most distal extremity of RU in the distal phalanx. The second line was drawn at the level of the proximal extremity of RU in the medial and lateral aspects of the distal phalanx. Line 3 was positioned at the level in the middle phalanx where the mediolateral extension of RU was narrowest. This level corresponded with the proximal border of the navicular bone on the radiograph. Line 5 was drawn at the level of the proximal extremity of RU in the middle phalanx. Line 4 was positioned midway between lines 3 and 5.

The proximodistal extent of RU in the region of the cartilages of the foot was scored 0–V for comparison with the radiographic grades (Ruohoniemi *et al.* 1993). *Grade 0* was no RU in the region of the cartilages of the foot. RU in a cartilage of the foot extending to lines 3, 4 and 5 were graded III, IV and V respectively. It was not possible to differentiate between RU of ossified cartilages graded 0–2 radiographically in a standard repeatable way, because of the variability in shape of the distal phalanx. Therefore, scintigraphic *Grades I* and *II* were not assigned and were categorised as *Grade 0.* Medial and lateral cartilages of the foot were graded separately.

Presence and location of focal RU medial or lateral to the middle phalanx, or a horizontal line within the cartilage of the foot with less RU than in other parts of the cartilage were recorded. IRU in regions A–D was described as focal or diffuse and mild, moderate or intense.

Objective assessment of RU was carried out using ROI analysis. Eight ROIs were drawn (Fig 2). The horizontal lines 1–5 gave the proximal and distal borders of the ROIs. Four vertical lines (the medial and lateral borders of each ROI) were positioned at the most medial and lateral margins of RU in the distal phalanx and the medial and lateral margins of RU in the middle phalanx. These lines defined the abaxial and axial borders within which each cartilage of the foot was situated. Each ROI was assigned a label (A–D, from proximal to distal, m = medial, l = lateral). Mean counts per pixel in each ROI was recorded.

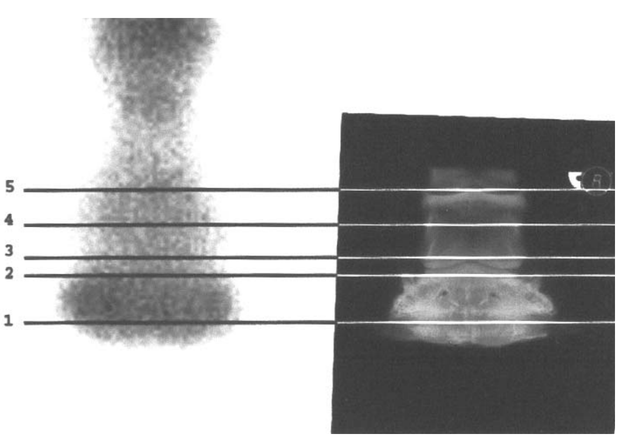

Fig 1: Registered magnified dorsal scintigraphic image and dorsopalmar radiographic view of a front foot. Scintigraphic grading of the ossification of the cartilage of the foot was performed based on lines 1–5.

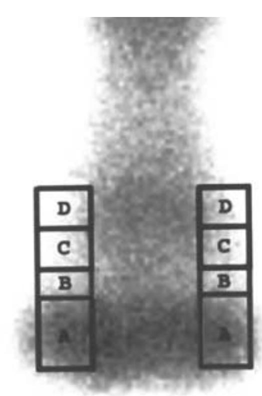

Fig 2: Dorsal scintigraphic image of a front foot with 8 regions of interest (ROIs) used for quantitative image analysis.

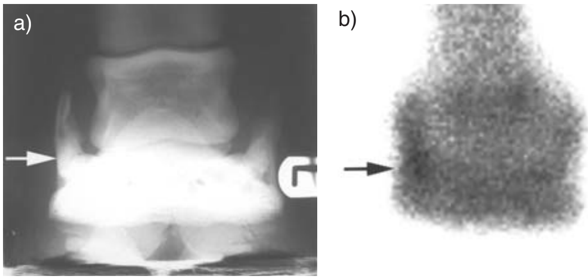

Fig 3: Dorsopalmar radiographic view (a) and magnified dorsal scintigraphic image (b) of the same left front foot. Lateral is to the right. Both cartilages were Grade 5 *radiographically and* Grade V *scintigraphically, supporting the good agreement between radiographic and scintigraphic grades for the extensively ossified cartilages. The proximal aspect of the lateral ossified cartilage is less radiopaque than medially, because it is either less mineralised or thinner. There is moderate focal IRU at the base of the medial cartilage (black arrow), corresponding to the radiolucent line identified on the radiograph (white arrow).*

In order to minimise error arising from uneven weightbearing or minor obliquity of the foot, mean counts in ROIs mB - mD and lB - lD were divided by the mean count in the corresponding ROI mA or lA. These ratios were used for statistical analysis.

Repeatability of scintigraphic grading of RU and objective assessment using ROI analysis was performed. Scintigraphic grading of 14 feet was repeated 5 times. Drawing of the 8 ROIs was repeated 6 times on 10 feet. The mean, s.d. and coefficient of variance was assessed for the RU in each ROI of each foot.

Additional radiographic analysis: The radiographs of all feet that had IRU in regions A–D in the dorsal scintigraphic image were assessed by S.J.D. without knowledge of the site of IRU. The dorsopalmar radiographic view was assessed first, and then all other available projections. Any abnormality of either an ossified cartilage or the distal phalanx was described.

Statistical analysis

Distribution of data was assessed using a Shapiro Wilks test. Weighted kappa agreement and a Spearman correlation test were used to assess agreement and correlation between radiographic and scintigraphic grades. A paired *t* test (for normally distributed data) and a Wilcoxon signed rank test (for non-normally distributed data) were used to compare ratios within either the medial or lateral cartilage of the foot and to compare the ratios of the medial and lateral sides at the same level. The difference between RU ratios for different degrees of ossification at each level was assessed using a Mann Whitney test. Statistical significance was set at P<0.05.

Results

Between January 2003 and July 2005, 492 dorsopalmar radiographs of front feet (343 horses) were obtained. Thirty-nine of these feet did not have a dorsal scintigraphic image. Two hundred and six feet were excluded because of the obliquity of the foot on the scintigraphic image. Thirteen feet were excluded because of inadequate counts and there was poor definition in 11 feet. Therefore, 223 front feet (126 left and 97 right) of 186 horses were included in the study.

Radiographic grading

In 186 feet of 155 horses, at least one of the cartilages of the foot was graded radiographically 0, 1 or 2. Altogether there were 341 *Grade 0–2* ossified cartilages (76.5% of all cartilages). One hundred and fifty-six feet of 132 horses had *Grade 0–2* ossification of both cartilages. Thirty-seven feet of 33 horses had at least one *Grade 3* ossified cartilage. There were 46 *Grade 3* ossified cartilages (10.8% of all cartilages). In 9 feet of 9 horses both cartilages were *Grade 3*. Nineteen feet of 22 horses had a *Grade 3* and a less ossified cartilage and 6 feet of 6 horses had a *Grade 3* and a higher grade ossified cartilage. Twenty-two horses (25 feet) had at least one *Grade 4* ossified cartilage. Altogether there were 38 *Grade 4* ossified cartilages (8.5% of all cartilages). In 13 feet (12 horses) both cartilages were *Grade 4*. Nine feet of 9 horses had a *Grade 4* and a less ossified cartilage, and 2 feet of 2 horses had a *Grade 5* ossified cartilage. In 15 feet of 12 horses there was at least one *Grade 5* ossified cartilage. Altogether there were 21 *Grade 5* ossified cartilages (4.7% of all cartilages). In 6 feet of 5 horses both cartilages were *Grade 5*.

Comparison between radiographic and scintigraphic grades

Radiopharmaceutical uptake extended through the length of an ossified cartilage, but not beyond it. There was a moderate to good agreement (n = 446; weighted kappa statistic = 0.56) and a very strong correlation (n = 446; Spearman rank correlation: r = 0.70, P<0.0001) between the radiographic and scintigraphic grades of all cartilage sites. There was a stronger agreement for moderately or severely ossified cartilages (*Grades 3–5*) (n = 105, weighted kappa statistic = 0.43; Spearman rank correlation: r = 0.74, P<0.0001) (Fig 3) than for the non- or mildly ossified cartilages (*Grades 0–2*) (n = 341, weighted kappa statistic = 0.23; Spearman rank correlation: r = 0.42, P<0.0001). When assessing the scintigraphic and radiographic grades for each level of ossification, fewer cartilages were *Grade 3, 4* and *5* scintigraphically than radiographically. If cartilages were not given the same radiographic and scintigraphic grades, the scintigraphic grades tended to be lower.

Region of interest analysis

There was a low coefficient of variation (<3%) between repeated measurements of mean counts per pixel in the 8 ROIs. When all cartilages of the foot were assessed, the ratio of RU between each ROI in the cartilage of the foot and the ipsilateral aspect of the distal phalanx decreased from distally to proximally for all radiographic grades (B/A>C/A>D/A, P<0.001) (Table 1). The

TABLE 1: Mean values of radiopharmaceutical (RU) ratios B/A, C/A and D/A compared with radiographic grade of ossification of cartilages of the foot (n = 446)

	RU ratios			
Radiographic grade	B/A	C/A	D/A	n
0–2	0.644	0.559	0.49	341
3	0.695*	0.561	0.465	46
4	0.818*	0.644*	0.479	38
5	0.995*	0.917*	0.734*	21

*Significantly different values for the cartilages graded 1 degree lower radiographically within the same RU ratio.

difference between RU ratios varied depending on the degree of ossification determined radiographically. Radiopharmaceutical uptake ratios B/A and C/A were related positively to ossification grade, all ratios being greatest in ossification *Grade 5* and smallest in *Grades 0–2*. The mean value of RU ratios D/A for *Grade 0–2* ossified cartilages was greater than for *Grade 3* cartilages, but this difference was not significant.

In feet with ossification *Grade 0–2*, assessment of the medial and lateral RU ratios showed separately the same distal to proximal decrease ($P<0.0001$). However, there was a significant difference between RU ratios in medial and lateral ROIs at each level. At level B, lateral ratios were greater than medial, however, at levels C and D medial ratios were greater than lateral ($P<0.05$).

In feet with ossification *Grade 3* of one cartilage, there was no significant difference between RU ratios in the *Grade 3* and the less ossified side at any level. In feet with both cartilages *Grade 3* radiographically, there was no significant difference between the medial and lateral ratios at any level.

In feet with both cartilages *Grade 4* radiographically, there was no significant difference between medial and lateral RU ratios at any level. However, in feet where one cartilage was *Grade 4* and the other was less ossified, RU ratio B/A for the less ossified side was significantly lower than the *Grade 4* ossified side ($P = 0.0059$). Radiopharmaceutical uptake ratios of the *Grade 4* and the less ossified sides at levels C and D were not statistically different.

In feet with both cartilages *Grade 5* radiographically, the medial and lateral RU ratios at each level were not significantly different. Similarly in feet where one cartilage was *Grade 5* and the other was less ossified, RU ratios at each level were not significantly different between medial and lateral.

Separate centres of ossification

Fourteen feet of 12 horses had at least one SCO identified radiographically; in 3 feet there were SCOs in both cartilages. In 12 of 17 cartilages (70.6%) the SCO was identified on the scintigraphic image (Fig 4). In 11 cartilages there was a focal region of RU medial or lateral to the middle phalanx and, in one cartilage, there was a horizontal line within the RU of the cartilage, which had lower RU than in other regions of the cartilage. In 5 horses a nonfused SCO was not identified on the scintigraphic image.

Scintigraphic and radiographic abnormalities

Thirty-eight feet of 36 horses had mild to moderate focal IRU or moderate diffuse IRU in the ROIs A–D (Table 2). Three horses had 2 areas of IRU within the same foot. A large proportion (26/38, 68.4%) of cartilages with IRU in regions A–D were moderately or severely ossified (radiographic *Grade 3–5*). Eighty-two percent (16/19) of cartilages with radiographic changes associated with IRU were moderately or severely ossified. In 21 feet the IRU was located within region A. In 13 feet IRU was present in regions A and B. In one foot, the IRU was located within region B and, in 2 feet, regions B and C were both involved. In one foot the IRU extended from region A to C, and in another foot from region B to D. In one foot a region of IRU was identified in region D.

Twenty-five feet had radiographic abnormalities associated with IRU (Table 2). In 9 feet there was an abnormality of the distal phalanx, all of which had IRU on the scintigraphic image

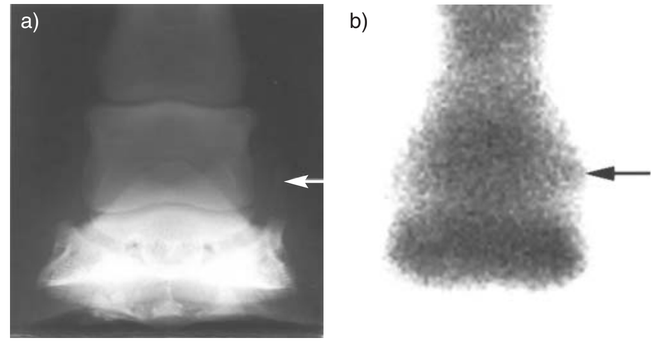

Fig 4: Dorsopalmar radiographic view (a) and magnified dorsal scintigraphic image (b) of the same left front foot. Lateral is to the right. There is an area of mild focal radiopharmaceutical uptake lateral to the middle phalanx (black arrow), corresponding to a separate centre of ossification (SCO) identified on the radiograph (white arrow).

in a corresponding location. Seventeen feet had radiographic lesions of the cartilages of the foot. In 14 of these 17 feet, radiographic abnormalities were identified on a dorsopalmar radiograph corresponding to the location of the IRU on the scintigraphic image. In 3 feet, a radiographic abnormality corresponding to the site of IRU was identified in other radiographic projections. In 9 feet, a fracture of an ossified cartilage was suspected or diagnosed radiographically, all of which had IRU in the corresponding location.

In 13 feet there were no detectable radiographic abnormalities in the cartilages of the foot or the distal phalanx, which could be related to the area of IRU. In 9 of these feet IRU was restricted to region A. The majority (6) of these feet had non- or mildly ossified cartilages of the foot. In 4 feet IRU was present in regions A and B, 3 of which had *Grade 4* ossification of the ipsilateral cartilage of the foot.

Discussion

The findings of this study indicate that an ossified cartilage of the foot can be identified on a scintigraphic image. There was a moderate to good agreement and an excellent correlation between radiographic and scintigraphic grades for all cartilages, supporting the hypothesis that RU would extend throughout the ossified cartilages of the foot. It was hypothesised that RU within the ossified cartilage would be similar to the RU in the corresponding area of the distal phalanx, however, ROI analysis showed a proximal to distal increase in RU ratios from regions D to B for all radiographic grades. A SCO identified radiographically was detected scintigraphically in 70.6% of feet. All fractures of the ossified cartilages had IRU. These results support the hypotheses that a SCO would be identified on the scintigraphic image and fracture or trauma to the ossified cartilages of the foot would manifest as IRU.

Comparison of scintigraphic and radiographic grades and ROI analysis

In the current study, a scintigraphic grading system for dorsal scintigraphic images of the foot enabled direct comparison with radiographic grades, whereas the method of Ruohoniemi *et al.* (2004) did not. That study was restricted to Finnhorses and there was no significant relationship between RU and radiographic

TABLE 2: Radiographic abnormalities of feet with increased radiopharmaceutical uptake (IRU) in 4 regions of interest (A–D) in the abaxial aspect of the distal phalanx and the medial or lateral cartilage of the foot

Horse	Grade of ossification*	Scintigraphic finding	Radiographic abnormalities of the cartilages of the foot		Radiographic abnormalities of the distal phalanx
			Dorsopalmar view	Other views	
1	5	Moderate focal IRU in med A and B	Lucent line with remodelled bone and sclerosis at the base of med cartilage; lucent line and sclerosis at base of lat cartilage	Fracture at the base of med cartilage; sclerosis at base of lat cartilage	NAD
2	5	Moderate focal IRU in med A and B	Ill defined lucent line at the base of med cartilage	Lucent line traversing base of ossified cartilage and sclerosis; second lucent line proximally with smoothly outlined new bone: old fracture or fused SCO	NAD
3	4	Moderate diffuse IRU in med A	Subtle ill defined lucent line at the lat base	NAD	NAD
4	2	Mild focal IRU in lat A	Ill defined lucent line and modelling at base of lat cartilage - old fracture?	NAD	NAD
5	5	Moderate diffuse IRU in lat A and B, line in C	Possible fracture at base lat cartilage, border discontinuous	Slight sclerosis at base of medial cartilage, possible fracture at the base of lateral cartilage	NAD
6	4	Moderate focal IRU in lat A and B	Fracture at base of lat cartilage	NAD	NAD
7	5	Mild focal IRU in med A	Possible fracture at the base of med cartilage	Fracture at base med cartilage	NAD
8	4	Moderate focal IRU in lat A and B	NAD	Fracture at base lat cartilage	NAD
9	5	Mild diffuse IRU in med A and B	Odd heterogeneous opacity of med cartilage	Old fracture/partially fused SCO in proximal med cartilage	NAD
10	5	Moderate focal IRU in lat B and C	SCO in lat cartilage and small SCO in med cartilage	NAD	NAD
11	1	Mild focal IRU in lat A	New bone proximal to base of lat cartilage	NAD	Incomplete fracture through lat palmar process?
12	5	Moderate focal IRU in lat D	SCO in med and lat cartilage	NAD	NAD
13	2,3	Moderate focal IRU in lat A, moderate focal IRU in med B and C	Slightly irregular margin of lat ossified cartilage axially	NAD	NAD
14	4	Moderate focal IRU in med A and B	Bifid proximal aspect of med ossified cartilage, mild sclerosis abaxially at the med base	NAD	NAD
15	4	Mild focal IRU in lat A	NAD	NAD	NAD
16	4	Mild focal IRU in med A	NAD	NAD	Lucent area in region of insertion of med CL DIP J; lat SCO
17	0	Mild focal IRU lat A	NAD	NAD	NAD
18	2	Moderate focal IRU in med A	NAD	NAD	Fracture medial palmar process
19	1	Mild focal IRU in lat A	NAD	NAD	NAD
20	5	Moderate focal IRU in med A and B	NAD	NAD	NAD
21	2	Mild focal IRU in lat A and B	NAD	NAD	NAD
22	4	Mild linear diffuse IRU in med A and B	NAD	NAD	NAD
23	5	Moderate focal IRU in lat B	Partially fused SCO in lat cartilage; lat cartilage thicker than med	NAD	NAD
24	3	Moderate focal IRU in lat A	NAD	NAD	Very irregular abaxial margin of lat palmar process
25	5,5	Moderate focal IRU in med A; moderate diffuse IRU in lat B-D	NAD	Fracture at the med base; fracture at lat base	NAD
26	1	Moderate focal IRU in med A	NAD	NAD	NAD
27	1	Moderate diffuse IRU in med A	NAD	NAD	NAD
28	1,1	Moderate focal IRU in med<lat A	NAD	NAD	Lucent area in the region of insertion of lat CL DIP J
29	5	Moderate diffuse in lat A	NAD	Sclerosis at junction of med SCO	NAD
30	1	Mild focal IRU in med A	NAD	NAD	NAD
31	2	Mild focal IRU in med A	NAD	NAD	NAD
32	1	Moderate focal IRU in lat A	NAD	NAD	NAD
33	1	Mild focal IRU in lat A	NAD	NAD	NAD
34	4	Mild diffuse IRU in lat A and B	NAD	NAD	NAD
35	4	Moderate focal IRU in med A and B	NAD	NAD	NAD
36	4	Moderate diffuse IRU in lat A–C	NAD	NAD	Sclerosis around region of insertion of med and lateral CL DIP J
37	1	Moderate focal IRU in med A	NAD	NAD	Fracture med palmar process
38	3	Moderate focal IRU in lat A and B	Pointed elongation abaxially of the lat cartilage	NAD	Fracture lat palmar process

* of the cartilage of the foot with IRU; NAD = no abnormalities detected; med = medial; lat = lateral; SCO = separate centre of ossification; CL = collateral ligament; DIPJ = distal interphalangeal joint.

ossification grades of the cartilage. In the current much larger study, encompassing horses from a broad range of breeds and athletic disciplines, the radiographic and scintigraphic grades showed excellent correlation. If scintigraphic and radiographic grades were not equal, the scintigraphic grades were lower, correlating with the results of ROI analysis.

There are variable patterns of ossification of the cartilages of the foot, with ossification extending further palmad distally (Bowker *et al*. 1998). Although such ossification can be identified in lateromedial and oblique radiographic views of the foot, RU in the more palmar aspects of the bone is not generally viewed in lateral scintigraphic images. Moreover RU is not proportional to bone thickness. Therefore, greater RU at the base of the cartilages presumably is not related to increased thickness. The proximal to distal increase in RU ratios indicates greater osteoblastic activity in the distal part of the cartilage of the foot. The cartilages of the foot have an important role in energy dissipation during locomotion (Bowker *et al*. 1998), and move abaxially at ground contact. The impact energy is transmitted to the cartilages of the foot and to the blood in their vascular network via venovenous anastomoses. Forces at impact distribute proximally, therefore the distal part of the cartilage is exposed to greater forces, possibly resulting in more bone modelling at the base of the cartilage than further proximally.

Generally, when cartilages of a foot were given the same radiographic grade, there was no significant difference between medial and lateral RU ratios at any level. However, in feet with both cartilages *Grade 0–2* radiographically, at level B lateral RU ratios were greater than medial, and at levels C and D medial RU ratios were greater than lateral. Uneven loading could cause differences between medial and lateral RU, although by using RU ratios instead of mean counts per pixel values, any differences should be minimal. This observation does not appear to have a biological explanation.

In feet where one cartilage was *Grade 4* and the other was less ossified, RU ratio B/A for the less ossified side was significantly lower than for the *Grade 4* ossified side, indicating increased modelling at the base of the more severely ossified cartilage. This observation was not noted for feet with a *Grade 5* and a less ossified cartilage, but this result should be interpreted with care because of the low number (9) of feet in this group. If one cartilage of the foot is extensively ossified and the other one is not, forces mediated by ligamentous attachments to the cartilages may be transmitted differently through a rigid osseous structure compared with an unossified cartilage. This may result in increased stress, modelling and risk for bone trauma or fracture at the base of the unilaterally extensively ossified cartilage, compared with 2 symmetrically ossified cartilages. We have previously demonstrated that there is usually a correlation between the radiographic grade of the medial and lateral cartilages of the foot and left right symmetry (Down *et al*. 2007). Marked asymmetry between cartilages may be a risk factor for injury.

Separate centres of ossification

In this study, 70.6% (12/17) of the SCOs diagnosed radiographically were identified scintigraphically. In one foot the SCO was small in size and it was less radiopaque than the middle or distal phalanges and in 4 feet a SCO was very close to or partially fused with the base of the ossified cartilage, providing a possible explanation for not being identifiable on a scintigraphic image. In Ruohoniemi *et al*. (2004), it was not described whether a SCO could be identified on the scintigraphic image. In the current study, 2 feet had IRU in the region of a fusion line of SCO with the ossified cartilage, one with irregular new bone on the axial aspect of the fused SCO, and the other with a vertical radiolucent line within the SCO proximally. This is suggestive of response to trauma at the fusion site. This has subsequently been verified using magnetic resonance imaging (MRI) in one horse with lameness abolished by a uniaxial, ipsilateral palmar nerve block (S.J. Dyson and R.M. Murray, unpublished data). In one foot, there was IRU just distal to the fusion line between the SCO and the base of the cartilage associated with area of reduced radiopacity, possibly indicating that the ossification was incomplete.

Scintigraphic and radiographic abnormalities

Fracture of an ossified cartilage has been associated with IRU (Ruohoniemi *et al*. 2004; Dakin *et al*. 2006) and this is supported by the results of the current study. In 9 feet, fracture of the base of an ossified cartilage was diagnosed or suspected on 'blind' radiographic examination, and all feet had IRU at a corresponding location. Fracture of the ossified cartilage predominantly occurred at the base, as previously documented (Ruohoniemi *et al*. 2004; Dakin *et al*. 2006).

Presence of IRU within a cartilage of the foot on a dorsal scintigraphic image corresponding to other radiographic changes other than fracture has not been described previously. Irregular margins, heterogeneous opacity and sclerosis may be the result of trauma. In the majority of feet where IRU, in regions A–D, was associated with radiographic changes of the cartilages of the foot, the cartilages were also moderately to severely ossified. Most feet with IRU in region A had a primary lesion of the distal phalanx (Table 2), but, in a small proportion (3/21, 14.3%), a lesion of the base of the ossified cartilage was present. Careful radiographic assessment, including use of oblique views (Butler *et al*. 2000) was necessary for accurate diagnosis.

In 4 feet with IRU, in regions A and B, there was no detectable radiographic abnormality. Three of these feet had an ipsilateral *Grade 4* ossified cartilage. Three of 9 feet that had IRU in region A but no detectable radiographic abnormality, had *Grade 4* or *5* ossified cartilages. Experience with MRI has subsequently shown in similar horses, that such IRU may be associated with increased signal intensity in fat suppressed images consistent with bone trauma (S.J. Dyson, unpublished data). It is speculated that severe ossification results in abnormal biomechanical forces at the base of the cartilage predisposing to bone trauma or fracture.

In 6 feet with non- or mildly ossified cartilages there was IRU in region A with no detectable radiographic abnormality. This could be associated with enthesopathy of the collateral ligament of the distal interphalangeal joint, or an osseous cyst-like lesion not detectable radiographically (Dyson *et al*. 2005). Further information could have been obtained by evaluation of the lateral and solar scintigraphic images.

Limitations of the study

Accurate radiographic and scintigraphic grading for *Grades 0–2* ossified cartilages was difficult and subjective because of their various shapes. Additional scintigraphic views could have provided additional information about the precise location of IRU, but the principle aim of this study was a direct comparison between dorsal scintigraphic images and dorsopalmar radiographic views.

Conclusions and potential relevance

Scintigraphy may give information about the potential clinical significance of ossification of the cartilages of the foot and prompt further scrutiny of radiographic images and acquisition of additional views. Moderate or severe ossification of one or both cartilages of the foot may be a risk factor for injury. Radiographic examination may be inconclusive in the assessment of a fracture or trauma to a fusion site of a SCO, or trauma to the base of an ossified cartilage or the adjacent distal phalanx. Scintigraphy may highlight the need for further investigation by use of a uniaxial, ipsilateral palmar nerve block and imaging using MRI or computed tomography. Further correlation between IRU and the results of MRI is yielding additional information about the pathological processes involving the cartilages of the foot and the distal phalanx that may occur associated with lameness.

Acknowledgements

We thank Shelley Down for providing radiographic data, Jo Weekes for technical assistance and the yard staff of the Animal Health Trust for assisting during image acquisition.

Manufacturer's address

[1]Nuclear Diagnostics, Gravesend, Kent, UK.

References

Bowker, R.M, Van Wulfen, K.K., Springer, S.E. and Linder, K.E. (1998) Functional anatomy of the cartilage of the distal phalanx and digital cushion in the equine foot and hemodynamic flow hypothesis of energy dissipation. *Am. J. vet. Res.* **58**, 961-968.

Butler, J., Colles, C., Dyson, S. and Poulos, P. (2000) Foot, pastern and fetlock. In: *Clinical Radiology of the Horse*, 2nd edn., Blackwell Sciences, Oxford. pp 27-68.

Colles, C.M. (1983) Interpreting radiographs 1: the foot. *Equine vet. J.* **15**, 297-303.

Dakin, S.G., Robson, K.E. and Dyson, S.J. (2006) Fractures of the ossified cartilages of the foot: 10 cases. *Equine vet. Educ.* **18**, 130-136.

Down, S.S., Dyson, S.J. and Murray, R.C. (2007) Ossification of the cartilages of the foot. *Equine vet. Educ.* **19**, 51-56.

Dyson, S.J. (2002) Subjective and quantitative scintigraphic assessment of the equine foot and its relationship with foot pain. *Equine vet. J.* **34**, 164-170

Dyson, S.J. (2003) Diseases of the cartilages of the foot. In: *Diagnosis and Management of Lameness in the Horse*, Eds: M.W. Ross and S.J. Dyson, Saunders Publication, St. Louis. pp 323-325.

Dyson, S.J., Lakhani, K. and Wood, J. (2001) Factors influencing blood flow in the equine digit and their effect on uptake of 99m technetium methylene diphosphonate into bone. *Equine vet. J.* **33**, 591-598.

Dyson, S.J., Murray, C.M. and Schramme, M.C. (2005) Lameness associated with foot pain: results of magnetic resonance imaging in 199 horses (January 2001 - December 2003) and response to treatment. *Equine vet. J.* **37**, 113-121.

Ruohoniemi, M., Makela, O. and Eskonen, T. (2004) Clinical significance of the ossification of the cartilages of the front feet based on nuclear bone scintigraphy, radiography and lameness examination in 21 Finnhorses. *Equine vet. J.* **36**, 143-148.

Ruohoniemi, M., Tulamo, R-M. and Hackzell, M. (1993) Radiographic evaluation of ossification of the collateral cartilages of the third phalanx in Finnhorses. *Equine vet. J.* **25**, 453-455.

Stashak, T.S. (2002) Ossification of the collateral cartilages of the distal phalanx (sidebones). In: *Adams' Lameness in Horses,* 5th edn., Lippincott Williams & Wilkins Publications, Philadelphia. pp 715-717.

Verschooten, F., Van Waerebeek, B. and Verbeeck, J. (1996) The ossification of cartilages of the distal phalanx in the horse: an anatomical, experimental, radiographic and clinical study. *J. equine vet. Sci.* **16**, 291-305.

Author contributions All authors contributed to the initiation, conception and planning of this study. Its execution and writing were by S.J.D. and A.N., and A.N. and R.M. compiled the statistics.