PETSAVERS PAPER

A retrospective study of the MRI findings in 18 dogs with stifle injuries

OBJECTIVES: To make an objective assessment of the usefulness of magnetic resonance imaging in the diagnosis of meniscal damage and cranial cruciate ligament disease in the canine stifle by comparing magnetic resonance imaging findings with surgical findings.

METHODS: Magnetic resonance images of 18 stifles from 18 dogs which had undergone magnetic resonance imaging for the investigation of stifle disease were reviewed. For every stifle, the menisci and cranial cruciate ligaments were assessed according to predetermined criteria. The magnetic resonance imaging findings were compared with the reported surgical findings and the sensitivity, specificity, positive and negative predictive values (PPV and NPV) were calculated using the surgical findings as the gold standard. Kappa analysis was used as an objective measure of agreement between surgical and magnetic resonance imaging findings. For 11 stifles, meniscal evaluation by three different observers was used to measure interobserver agreement using Kappa analysis.

RESULTS: Magnetic resonance imaging was demonstrated to be an accurate technique in the detection of meniscal injury (k=0·86), with excellent interobserver agreement (k=0·89 to 1·0). Disruption of cranial cruciate ligament continuity and an increase in ligament intensity were found to be useful criteria in the diagnosis of cranial cruciate ligament rupture.

CLINICAL SIGNIFICANCE: Magnetic resonance imaging offers a non-invasive alternative to exploratory surgery in the evaluation of cranial cruciate ligament and meniscal disease.

E. BARRETT, F. BARR, M. OWEN* AND K. BRADLEY

Journal of Small Animal Practice (2009) **50**, 448–455
DOI: 10.1111/j.1748-5827.2009.00822.x

Accepted: 24 May 2009

Department of Clinical Veterinary Science, University of Bristol, Langford, North Somerset BS40 5DU

*The Veternary Hospital, Ferndene, Bradley Stoke, Bristol BS32 9DT

INTRODUCTION

The stifle is the most commonly diseased single joint in the dog (Anderson 1994). The commonest cause of canine stifle disease is cranial cruciate ligament injury (Brinker and others 1990, Moore and Read 1996), which is often associated with subsequent damage to the medial meniscus (Brinker and others 1990, Bennett and May 1991, Flo 1993). This can occur either soon after the initial cruciate injury, or as a "late" meniscal injury weeks to months later. While acute, complete cranial cruciate ligament rupture can be accurately diagnosed by experienced clinicians on physical examination, chronic tears and partial ruptures are less easy to detect (Scavelli and others 1990). Damage to the meniscus cannot reliably be confirmed on physical examination alone (Flo 1993). Subluxation of the tibia, together with distal dislocation of the popliteal sesamoid, identified on a medio-lateral radiograph of the stifle (with or without tibial compression) is reported as pathognomonic for cranial cruciate ligament rupture (De Rooster and others 1998). However, radiography is often non-specific in the diagnosis of cranial cruciate ligament and meniscal disease, showing only the secondary changes of joint effusion and osteoarthritis (Brinker and others 1990). The use of ultrasonography in the evaluation of the canine stifle has been described, but the clinical interpretation of any meniscal changes seen is reported to be difficult (Kramer and others 1999).

Historically, arthrotomy has been generally considered to be the gold standard for the definitive diagnosis of the cranial cruciate ligament tears (Scavelli and others 1990, Johnson and Johnson 1993) and meniscal damage (Hulse and Shires 1983, Dupuis and Harari 1993). Arthroscopy can provide information about the internal structures of the stifle (Kivumbi and Bennett 1981, Dupuis and Harari 1993) but has previously been considered technically demanding and inferior to arthrotomy. However, more recent advances in arthroscopic technique have made arthroscopy the investigation modality of choice for the internal evaluation of the canine stifle joint (Ralphs and Whitney 2002, Whitney 2003, Ridge 2006, Winkels and others 2008).

Magnetic resonance imaging (MRI) is a well-established technique for detecting internal derangements of the human knee with high diagnostic accuracy (Oei and others 2007). Although some studies demonstrate MRI findings to correlate well with arthroscopy (Naranje and others 2008), other published work suggests that arthroscopy is more accurate and should still be considered the gold standard for

definitive diagnosis of cruciate and meniscal damage in the human knee (Nikolaou and others 2008)

Magnetic resonance imaging is becoming increasingly available as a diagnostic tool in small animal practice (Pooya and others 2004) and offers a non-invasive alternative to exploratory surgery in the evaluation of canine cranial cruciate ligament and meniscal disease. In contrast to the wealth of information available in the medical literature about the accuracy of MRI findings in the human knee, limited material has been published in the veterinary literature objectively comparing the accuracy of MRI findings with surgical findings in dogs with naturally occurring stifle disease.

The use of MRI in the clinical investigation of canine stifle disease was first reported in a retrospective study of 11 military working dogs (Banfield and Morrison 2000) where MRI successfully identified cranial cruciate ligament, collateral ligament and meniscal abnormalities. The MRI appearance of a discoid lateral meniscus with partial cranial cruciate rupture, confirmed on arthroscopy, has been described (Ohlerth and others 2001). Three case series of 50, 4 and 80 dogs, respectively, with stifle disease have been published, describing the pathological changes seen with low-field MRI and correlating the MRI findings with surgical findings (Gonzalo-Orden and others 2001, Foltin and others 2004, Konar and others 2005). However, no attempt was made to determine the accuracy of MRI findings until Blond and others (2008) published work demonstrating that high-field MR imaging is a reliable technique for the pre-operative diagnosis of meniscal tears. The aim of our study was to make a similar objective assessment of the accuracy of MRI in the diagnosis of both meniscal and cranial cruciate ligament damage in 18 dogs with naturally occurring stifle disease.

MATERIALS AND METHODS

Magnetic resonance (MR) images of 18 stifles from 18 dogs which had undergone MRI for the investigation of stifle disease were reviewed. Detailed clinical histories and the results of stifle arthrotomy or arthroscopy were available for all dogs. Imaging was performed with a 1·5 T whole-body scanner (Gyroscan ACS-NT, Philips Medical Systems) using a flexible surface coil (3C NT coil, Philips Medical Systems). All images were obtained with the dogs under general anaesthesia. The dogs were positioned in lateral recumbency, with the stifle being imaged positioned adjacent to the couch. In each case, images were obtained in sagittal, dorsal and transverse planes. As a minimum, proton-density-weighted (TR 1107 to 2066 ms, TE 17 to 20 ms, slice thickness 2·0 to 2·8 mm) and T2-weighted (TR 2066 to 2750 ms, TE 100 to 120 ms, slice thickness 2·0 to 2·8 mm) images were obtained in the sagittal plane, with a T2*-weighted sequence (TR 324 to 660 ms, TE 14 to 18 ms, flip angle 35°, slice thickness 2·5 to 3·0 mm) most commonly being obtained in the dorsal and transverse planes. For every stifle, each image plane and sequence was evaluated by one observer, blinded to all clinical information.

Evaluation of the menisci

From the MR images, the menisci were classified as entire or torn. The normal entire meniscus (Fig 1) is reported to be wedge shaped in both sagittal and dorsal planes (Baird and others 1998) and homogenously hypointense in all sequences (Banfield and Morrison 2000). In our study, menisci with a confined intra-meniscal area of high signal (Fig 2) were also classified as entire, in accordance with MRI studies of the human knee where such menisci are documented as normal on surgical exploration (Sproule and others 2005). Menisci with an area of high signal intersecting with at least one of the meniscal margins were classified as torn (Fig 3). The appearance and location of the area of high signal were recorded. Each meniscus was classified as entire or torn for each combination of plane and sequence used.

Evaluation of the cranial cruciate ligament

Following preliminary work which demonstrated that, compared with dorsal and

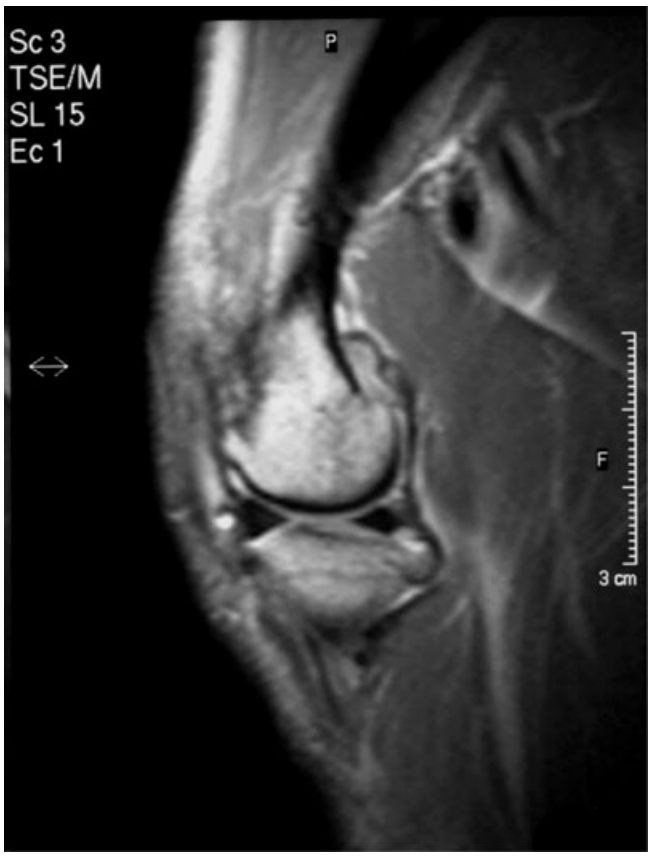

FIG 1. A normal homogenous hypointense medial meniscus (PD-weighted sagittal image)

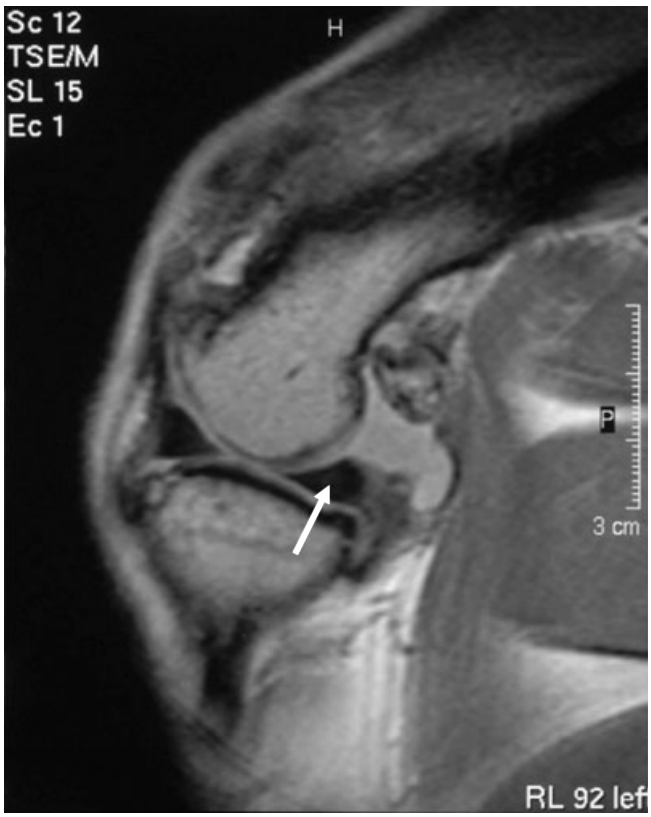

FIG 2. A confined ring of high intra-meniscal signal (arrowed) is seen in the caudal horn of the meniscus. Such menisci were classified as entire (PD-weighted sagittal image)

transverse planes, the cranial cruciate ligament was best appreciated on sagittal plane images; it was decided to use the sagittal plane only in this study. The cranial cruciate ligament was assessed on sagittal plane images as being visible in its entirety, partly visible or not visible. A subjective evaluation was made of its intensity and margination. A normal cranial cruciate ligament was considered to be hypointense in all sequences (Banfield and Morrison 2000) with fairly uniform intensity and seen in its entirety within one or sequential sagittal slices. Ligaments of uniform hypointensity that could be seen in their entirety were classified as being normal (Fig 4). Ligaments that could not be seen at all, or which were only partially visible, were classified as abnormal (Fig 5). Ligaments which could be seen for all of their length but appeared to be irregularly marginated or of increased intensity were also considered to be abnormal. Each ligament was classified as normal or abnormal from each sagittal sequence used.

Once all 18 stifles had been assessed, the MRI findings were compared with the reported surgical findings and the PPV; NPV, sensitivity and specificity were calculated using the surgical findings as the gold standard. Kappa analysis was used to measure the agreement of MRI and surgical findings for each combination of plane and sequence in the assessment of the menisci and for each sequence in the assessment of the cranial cruciate ligament. The protocols giving the best agreement with surgical findings were then used to determine the accuracy of MRI in detecting meniscal and cranial cruciate ligament pathology.

Interobserver agreement

In order to measure interobserver repeatability in the MRI evaluation of the menisci, three observers were asked to assess the menisci in 11 stifles and classify them as entire or torn as previously described. Kappa analysis was used to calculate the interobserver agreement.

RESULTS

All dogs were of medium to large size with a mean bodyweight of 33·9 kg (22·2 to 53 kg) and a mean age of 63 months (24 to 108 months). Of the 18 dogs evaluated, 5 were Labrador retrievers, 4 were boxers, 3 were crossbreds and the others were represented by individual breeds. There were 10 males (3 neutered) and 8 females (7 neutered). Twelve left and 6 right stifles were imaged. All dogs were presented with pelvic limb lameness localising to the stifle joint. The average duration of lameness before MRI evaluation was 10 months (1 to 60 months). The most common clinical findings were quadriceps femoris muscle atrophy (13 dogs), soft tissue thickening around the stifle (11 dogs) and joint effusion (8 dogs). Cranial stifle instability was recorded in six dogs, decreased flexion in three dogs and pain on manipulation in three dogs. Eight dogs had a history of previous stifle surgery. The mean time interval between MRI and subsequent surgery was five weeks (0 to 18 weeks).

The menisci

Thirty-six menisci (18 medial and 18 lateral) were assessed on the MR images. The sagittal proton-density-weighted images demonstrated the best agreement with surgical findings (k=0·86, 95 per cent confidence interval 0·68 to 1·05), followed by the sagittal T2-weighted images (k=0·83, 95 per cent confidence interval 0·61 to 1·05). Dorsal and transverse plane images demonstrated poorer agreement.

From the sagittal PD-weighted images, 11 medial menisci were classified as entire, with a confined area of intra-meniscal high signal reported in 4, and 7 medial menisci were reported as torn (Table 1). Fifteen lateral menisci were classified as entire, with a confined area of intra-meniscal high signal reported in five, and three lateral menisci were reported as torn (Table 2). At surgery, eight torn medial menisci and two torn lateral menisci were identified. One medial meniscus was described as having a confined area of intra-meniscal signal and considered entire on MRI, but at surgery there was damage to the meniscal attachments and the axial part of the caudal horn was unstable. One lateral meniscus, identified as torn on MRI, appeared normal on surgical evaluation.

Using the surgical findings as the gold standard, MRI classification from the PD-weighted sagittal images had a specificity

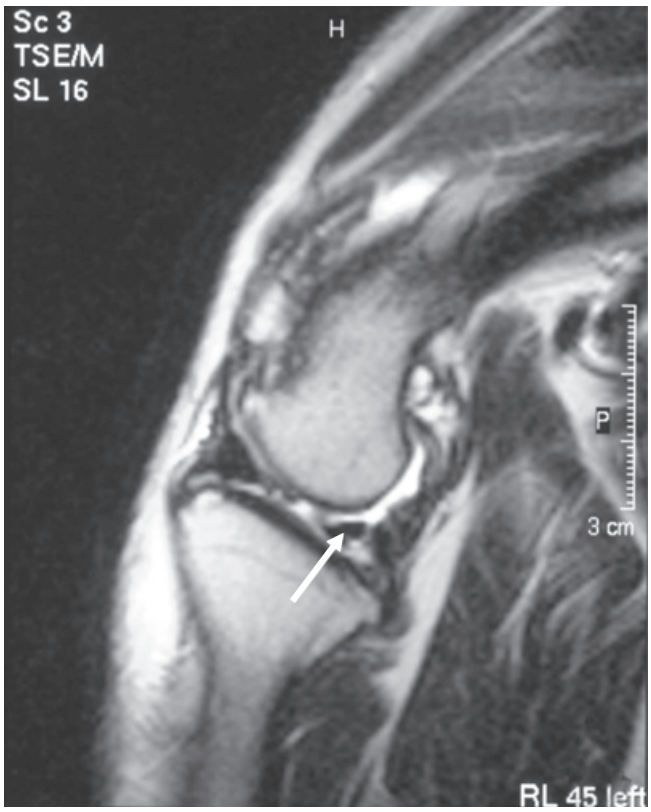

FIG 3. A linear area of hyperintensity (arrowed) is seen extending to the caudo-distal articular margin of the caudal meniscus. This was consistent with a mensical tear (PD-weighted sagittal image)

of 0·96, a sensitivity of 0·9, a PPV of 0·9 and NPV of 0·96.

The location of meniscal damage as seen at surgery was reported for 6 out of the 10 damaged menisci. In four medial menisci with damage to the caudal horn, the location of the abnormal high signal correlated exactly with the surgical findings. In two lateral menisci with "mid-body" tears, the location of the high signal did not correlate exactly with the surgical findings.

The cranial cruciate ligament

Eighteen cranial cruciate ligaments were assessed and classified as being normal or abnormal. Proton-density-weighted sagittal images again demonstrated the best agreement with the surgical findings (k=0·77, 95 per cent confidence interval 0·34 to 1·2).

From the sagittal PD-weighted images, 4 ligaments were considered to be normal and 14 ligaments abnormal. One of the normal appearing ligaments was excluded from analysis as it was thought likely that further injury had occurred during the prolonged time (18 weeks) between MRI and surgical exploration. Fifteen ruptured and two entire cranial cruciate ligaments were identified at surgery (Table 3). Of the 15 dogs with damaged cranial cruciate ligaments identified on surgical exploration, 8 dogs had a history of previous surgery to stabilise a cranial cruciate ligament deficient stifle. In seven dogs the repair had failed, but in one case an entire intra-articular graft was found, which was incorrectly identified as a normal cranial cruciate ligament on MRI. The remaining seven dogs had evidence of cranial cruciate ligament rupture without previous surgical intervention.

Using the surgical findings as the gold standard, specificity and PPV were perfect. Sensitivity was 0·93 and NPV 0·67. Agreement between MRI and surgical findings was good (k=0·77, 95 per cent confidence interval 0·34 to 1·2).

Interobserver repeatability

Interobserver repeatability was demonstrated to be very good with complete agreement evident between two observers and the surgical findings. Agreement with the third observer was very good (k=0·89, 95 per cent confidence interval 0·68 to 1·10).

DISCUSSION

The 18 stifles evaluated in this study were from medium to large breeds of dog, representative of those typically affected by cranial cruciate ligament injuries. The majority of cases were characterised by chronic hindlimb lameness, with only one case presented for MRI within one month of the onset of lameness. Almost half the dogs had a history of previous cruciate surgery. These cases are of particular clinical relevance in the evaluation of late meniscal injuries, which may occur some weeks or months after surgery.

Using our simple predetermined criteria for the classification of the menisci as entire or torn, MRI was demonstrated to be useful and accurate in detecting surgically evident damage to the canine meniscus, with very good interobserver repeatability demonstrated. There is no universally accepted system for classification of meniscal injury in people (Chang and others 2004). However, the most reliable criterion for the MRI diagnosis of a meniscal tear is reported to be the presence of a high signal extending through the meniscus to intersect with one (PPV 85 per cent) or two (PPV 98 per cent) meniscal margins (Manaster and Tyson 1995). A study documenting the appearance of meniscal lesions with low-field MRI (Martig and others 2006) was unable to reliably detect intra-meniscal lesions but demonstrated a good correlation between menisci with high signal extending to the meniscal margins and the surgical documentation of a meniscal tear. Blond and others (2008) compared the high-field MRI appearance of meniscal lesions with surgical findings, reporting one medial meniscus with an area of increased intra-meniscal signal which was found to be normal at surgery. In human beings, menisci with increased intra-meniscal signal are similarly reported to be normal at surgery (Sproule and others 2005) but histologically demonstrate mucoid degeneration of the meniscus. Although it has been suggested that such changes eventually culminate in a full thickness tear (Stoller

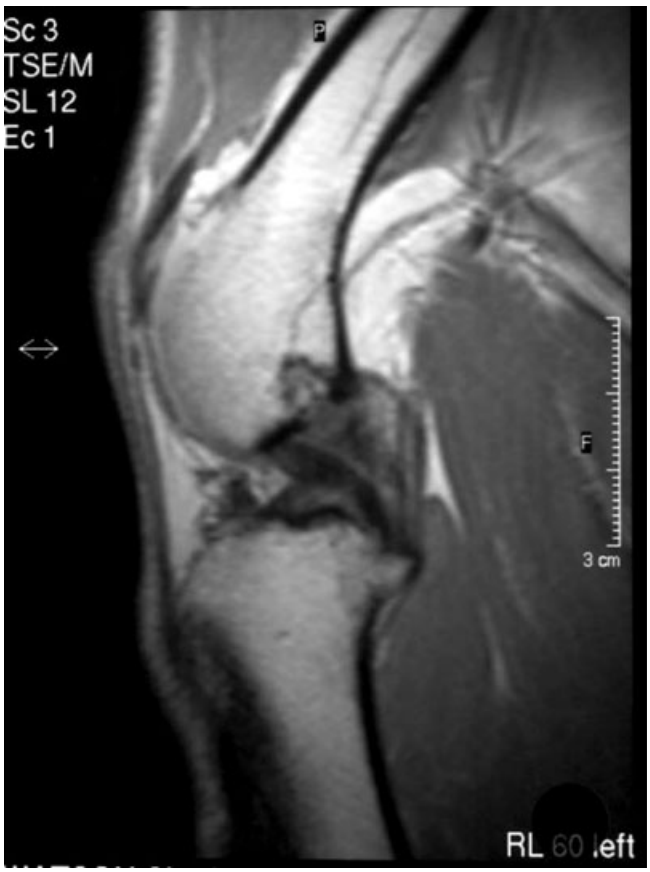

FIG 4. A normal, intact cranial cruciate ligament (PD-weighted sagittal image)

and others 1987), some studies report no increased risk of a subsequent tear (Manaster and Tyson 1995). It is not known for certain whether mucoid degeneration occurs in the canine meniscus (Martig and others 2006). However, Libicher and others (2005) documented increased signal in the caudal horn of the medial meniscus in dogs 12 weeks after experimental transection of the cranial cruciate ligament. No signal change was evident in the control dogs, and it was concluded that this change was likely to be due to meniscal degeneration. In our study, of the nine menisci (five medial and four lateral) described as having increased intra-meniscal signal, only one was found to be abnormal at surgery: as our study was based on live, clinical patients, histological examination of these menisci was not possible.

The surgical reports used for this study described three types of meniscal damage: unstable meniscal horns, meniscal tears and the absence of part of the meniscus due to partial meniscectomy. In all cases with a damaged medial meniscus, the injury was located in the caudal horn, previously found to be the most frequently affected area. Although folding of the caudal horn of the medial meniscus with displacement between the medial femoral and tibial condyles is reported to be more common than meniscal tears (Bennett and May 1991), this was not identified in any of the dogs in this study. However, an "unstable" caudal horn, potentially a precursor to a folded horn, was reported in the single case where a surgically abnormal meniscus was not identified on MRI.

Discrete caudal medial meniscal tears were identified at surgery in four dogs: these were accurately identified and localised on MRI as hyperintense streaks in the caudal horn. Mid-body tears of the lateral meniscus were identified in two dogs. These were less clearly defined and less clearly located on the MR images than the medial meniscal tears. Previous studies have demonstrated damage to the lateral meniscus to be rare (Bennett and May 1991). It is interesting to note that in both cases where the lateral meniscus was damaged, the cranial cruciate ligament was found to be entire.

Two dogs had a history of partial medial meniscectomy. In both cases, MR images revealed more diffuse hyperintense changes involving both proximal and distal meniscal margins. This is consistent with reports in the medical literature which document the presence of high signal within the residual meniscus which abuts the articular margins and can mimic the appearance of a meniscal tear (Toms and others 2005). An accurate surgical history is therefore important to avoid overdiagnosis of damage to the residual meniscus.

In the analysis of MRI findings in this study, surgical findings (arthroscopy or arthrotomy) have been taken as the gold standard. Although widely used as a gold standard in similar studies, limitations of surgical evaluation include the inability to assess the internal architecture of the meniscus and the difficulty of evaluating the tibial surface of the menisci with arthroscopy.

Magnetic resonance imaging assessment of the cranial cruciate ligament was less easy to characterise, with a less clearly defined distinction between normal and abnormal findings. The MRI findings were highly specific with all 14 cranial cruciate ligaments identified as abnormal on MRI being confirmed as abnormal at surgery. Six ligaments were not seen at all, while four were only partially seen. The remaining four ligaments were seen in their entirety within the same or sequential slices but demonstrated relatively increased intensity (4 cases) and irregular margination (1 case). Of these four ligaments, surgical reports indicated partial ruptures of the cranial cruciate ligament in two cases but did not record the degree of damage in the other two cases. In a further case, an entire over-the-top fascia lata intra-articular graft appeared as a straight hypointense band and was wrongly identified as an entire ligament. Intra-articular grafts in the human knee are differentiated from the native anterior cranial cruciate ligament by their different course and the fact that from three months after surgery, the graft demonstrates gradually increasing signal intensity, mainly due to revascularisation, before reverting back to a hypointense appearance on T1 and T2-weighted images,

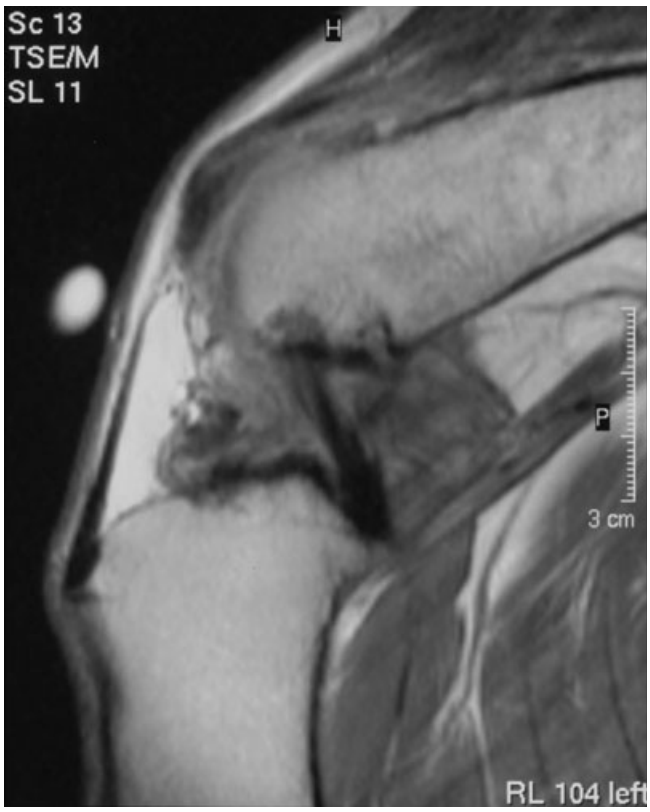

FIG 5. Complete rupture of the cranial cruciate ligament (PD-weighted sagittal image)

usually within a year (Ilaslan and others 2005). In this case, the graft had been present for 10 months.

Primary signs of anterior cruciate ligament rupture in the human knee include discontinuity of the ligament, abnormal signal and abnormal location (Hodler and others 1992, Brandser and others 1996). While discontinuity is a reasonably objective criterion, changes in signal and position are more subjective and therefore harder to define. Comparison with the caudal cruciate ligament, generally seen within the same or medially adjacent sagittal slice, is likely to be the most useful reference for the assessment of signal intensity. In this study, we did not attempt to objectively document changes in ligament position.

All except one dog in this study had a history of chronic (greater than two months) lameness. Both chronic and partial cranial cruciate ligament tears are difficult to diagnose on clinical examination, and it is therefore reasonable to assume that such cases are more likely to be presented for advanced imaging. However, the MRI diagnosis of such cases is also more challenging, with the accuracy of detecting partial anterior cruciate ligament tears in the human knee being considerably less than for complete tears (Tsai and others 2004). Magnetic resonance imaging studies of the anterior cruciate ligament in people have demonstrated a difference in the appearance of acute and chronic ligament tears (Vahey and others 1991, Tsai and others 2004, Mandalia and others 2005). While acute tears can be accurately diagnosed by the presence of focal or diffuse disruption of the ligament, together with soft tissue oedema, chronic tears have a more variable appearance. In one study, 30 per cent of chronic tears (greater than six weeks duration) appeared as entire bands, mimicking the appearance of an entire ligament, due to the presence of bridging scar tissue (Vahey and others 1991). This was considered as a possible explanation for those cases with apparently entire ligaments of increased signal. Alternative explanations for the increased signal included a decrease in the number of entire fibres present and partial

Table 1.

Medial meniscus		MRI classification		
		Torn	Entire	
Surgical findings	Torn	7	1	8
	Entire	0	10	10
		7	11	18

Table 2.

Lateral meniscus		MRI classification		
		Torn	Entire	
Surgical findings	Torn	2	0	2
	Entire	1	15	16
		3	15	18

Table 3.

Cranial cruciate ligament		MRI classification		
		Normal	Abnormal	
Surgical findings	Normal	14	1	15
	Abnormal	0	2	2
	Not included	0	1	1
		14	4	18

averaging of the signal from the ligament with adjacent structures.

Comparison of MRI findings from the different planes and sequences used in this study demonstrated that, for the menisci, sagittal proton density-weighted images provided the best correlation with the surgical findings. This is in agreement with Blond and others (2008) who reported that proton density images were considered to have the highest likelihood of detecting a meniscal lesion. Proton density-weighted images also demonstrated the best agreement with surgical findings in the evaluation of the cranial cruciate ligament. Proton density-weighted images are widely used in the evaluation of the human knee due to their high signal-to-noise ratio and ability to yield high resolution images (McRobbie and others 2003) and have been reported in the veterinary literature to be well suited to the assessment of the cranial cruciate ligament and menisci (Konar and others 2005). In addition, MRI protocols used in the investigation of joint disease usually include at least one fat saturated or fat suppressed sequence (such as STIR) to evaluate any associated bone injuries. Although not addressed in this study, the inclusion of such sequences is likely to be useful in the assessment of naturally occurring stifle disease, where high-signal STIR lesions are reported to be a common finding (Winegardner and others 2007).

This study did not attempt to analyse the usefulness of dorsal and transverse plane images in the evaluation of the cranial cruciate ligament. While the ligament could usually be identified in these planes, they were not found to be useful in the evaluation of ligament integrity. Although the sagittal plane was subjectively considered to be most useful, the oblique course of the cranial cruciate ligament meant that even the normal ligament was not consistently seen in its entirety within one sagittal slice, making the objective assessment of ligament disruption more difficult.

Two further useful observations were made during the course of the study. A blunted infra-patellar fat pad identified on stifle radiographs is often considered to be a consequence of stifle joint effusion (Owens 1982). However, in this study it was found that distortion of the fat pad was most frequently due not to fluid but to a heterogenous accumulation of tissue within the cranial femoro-tibial joint space, with a joint effusion more often identified within the caudal joint space. It seems likely that this tissue represents localised synovial hyperplasia, fibrous tissue and inflammatory cell infiltration which are reported as having a similar appearance in the human knee (Ilaslan and others 2005), although direct correlation with surgical and histological findings would be needed to confirm this. This abnormal tissue appeared to be a non-specific finding and was identified in dogs with and without cranial cruciate ligament rupture both before and after surgical intervention.

In five of the eight stifles which had undergone previous surgical intervention, one or more metallic implants were present in the peri-articular tissues. Although the presence of such implants is widely believed to cause significant image distortion due to metallic artefacts, in the five cases evaluated there was only a localised loss of information which did not interfere with the visualisation of the menisci or cranial cruciate ligament. The location of an implant will obviously determine which part of the image is affected, but it has been reported that the presence of a non-ferrous implant in the human knee rarely precludes useful MRI assessment (Ilaslan and others 2005). It is therefore suggested that the presence of metallic (non-ferrous) implants in the vicinity of the stifle should not be considered to be a contra-indication to MR imaging.

CONCLUSIONS

Using the criterion of high signal extending to the surface of the meniscus, this study objectively demonstrates MRI to be useful and accurate in the diagnosis of canine meniscal injury in 18 dogs with naturally occurring stifle disease. Using this criterion, the interobserver repeatability is very good. Magnetic resonance imaging is also shown to provide useful information in the evaluation of cranial cruciate ligament injury. While the most reliable diagnostic criterion for the detection of such injury is the incompleteness or non-visualisation of the ligament, increased signal was also correlated with ligament damage. In this study, sagittal proton density-weighted sequences are demonstrated to provide the best agreement with surgical findings in the identification of meniscal and cranial cruciate injury.

Acknowledgements

This study was supported by a Petsavers grant. The authors would like to thank Burgess Diagnostics for the acquisition of the MR images and John Conibear of the University of Bristol for his assistance in digitising the images for publication.

References

Anderson, J. (1994) The stifle. In: Manual of Small Animal Arthrology. Eds J. Houlton and R.W. Collinson. BSAVA, Cheltenham, UK. pp 267-300

Baird, D. K., Hathcock, J. T., Rumph, P. F., Kincaid, S. A. & Visco, D. M. (1998) Low-field magnetic resonance imaging of the canine stifle joint: normal anatomy. *Veterinary Radiology and Ultrasound* **39,** 87-97

Banfield, C. M. & Morrison W. B. (2000) Magnetic resonance arthrography of the canine stifle joint: technique and applications in eleven military dogs. *Veterinary Radiology and Ultrasound* **41,** 200-213

Bennett, D. & May, C. (1991) Meniscal damage associated with cruciate disease in the dog. *Journal of Small Animal Practice* **32,** 111-117

Blond, L., Thrall, D. E., Roe, S. C., Chailleux, N. & Robertson, I. D. (2008) Diagnostic accuracy of magnetic resonance imaging for meniscal tears in dogs affected with naturally occurring cranial cruciate ligament rupture. *Veterinary Radiology and Ultrasound* **49,** 425-431

Brandser, E., Riley, M., Berbaum, K. S., Elkhoury, G. Y. & Bennett, D. L. (1996) MR imaging of anterior cruciate ligament injury: independent value of primary and secondary signs. *American Journal of Roentgenology* **167,** 121-126

Brinker, W., Piermatti, D. L. & Flo, G. L. (1990) Diagnosis and treatment of injuries of the hindlimbs. In: Handbook of Small Animal Orthopaedics and Fracture Treatment. Eds W. Brinker, D. L. Piermatti & G. L. Flo. W. B. Saunders, Philadelphia, PA, USA. pp 341-470

Chang, C. Y., Wu, H. T. H, Huang, T. F., Ma H. L. & Hung, S. C. (2004) Imaging evaluation of meniscal injury of the knee joint – a comparative MR imaging and arthroscopic study. *Clinical Imaging* **28,** 372-376

De Rooster, H., Van Ryssen, B. & van Bree, H. (1998) Diagnosis of cranial cruciate ligament injury in dogs by tibial compression radiography. *Veterinary Record* **142,** 366-368

Dupuis, J. & Harari, J. (1993) Cruciate ligament and meniscal injuries in dogs. *Compendium on Continuing Education for the Practicing Veterinarian* **15,** 215

Flo, G. (1993) Meniscal injuries. *Veterinary Clinics of North America – Small Animal Practice* **23,** 831-843

Foltin, I., Rieden, K. & Matis, U. (2004) MRI visualisation and evaluation of diseases of the canine stifle joint. *Tierarztliche Praxis Ausgabe Kleintiere Heimtiere* **32,** 1-8

Gonzalo-Orden, J., Altonaga, J. R., Gonzalo, J. M., Millan, L. & Orden, M. A. (2001) Magnetic resonance imaging in 50 dogs with stifle lameness. The *European Journal of Companion Animal Practice* **11,** 115-118

Hodler, J., Haghighi, P, Trudell, D. & Resnick, D. (1992) The cruciate ligaments of the knee – correlation between MR appearance and gross and histologic findings in cadaveric specimens. *American Journal of Roentgenology* **159,** 357-360

Hulse, D. & Shires, P. (1983) The meniscus – anatomy, function and treatment. *Compendium on Continuing Education for the Practicing Veterinarian* **5,** 765-774

Ilaslan, H., Sundaram, M. & Miniaci, A. (2005) Imaging evaluation of the post-operative knee ligaments. *European Journal of Radiology* **54,** 178-188

Johnson, J. & Johnson A. L. (1993) Cranial cruciate rupture: pathogenesis, diagnosis and post-operative rehabilitation. *Veterinary Clinics of North America – Small Animal Practice* **23,** 717-733

Kivumbi, C. & Bennett, D. (1981) Arthroscopy of the Canine Stifle. *Veterinary Record* **109,** 241-249

Konar, M., Vidoni, B., Kneissl, S., Doherr, M., Mayrhofer, E. & Lang, J. (2005) Low-field MRI of the canine stifle joint. Part 2: distribution of pathologic findings and correlation with surgical results *Tierarztliche Praxis Ausgabe Kleintiere Heimtiere* **33,** 73-82

Kramer, M., Stengel, H., Gerwing, W., Schimke, E. & Sheppard, C. (1999) Sonography of the canine stifle. *Veterinary Radiology and Ultrasound* **40,** 282-293

Libicher, M., Ivancic, M., Hoffman, V. & Wenz, W. (2005) Early changes in experimental osteoarthritis using the Pond-Nuki dog model: technical procedure and initial results of in vivo MR imaging. *European Radiology* **15,** 390-394

Manaster, B. & Tyson, L. (1995) Magnetic resonance imaging of the knee menisci and cartilage. *Operative Techniques is Sports Medicine* **3,** 35-46

Mandalia, V., Fogg, A. J., Chari, R., Murray, J., Beale, A. & Henson, J. H. L. (2005) Bone bruising of the knee. *Clinical Radiology* **60,** 627-636

Martig, S., Konar, M., Schmökel, H. G., Ryatz, U., Spreng, D. Scheidegger, J., Höhl, B., Kircher, P. R., Boisclair, J. & Lang, J. (2006) Low-field MRI and arthroscopy of meniscal lesion in ten dogs with experimentally induced cranial cruciate ligament insufficiency. *Veterinary Radiology and Ultrasound* **47,** 515-522

McRobbie, D. W., Moore, E. A., Graves, M. J. & Prince, M. R. (2003) Basic clinical protocols. In: MRI from Picture to Proton. Eds D. W. McRobbie, E. A. Moore, M. J. Graves & M. R. Prince. Cambridge University Press, Cambridge, UK. p 20

Moore, K. & Read, R. (1996) Rupture of the cranial cruciate ligament in dogs. I. *Compendium on Continuing Education for the Practicing Veterinarian* **18,** 223

Naranje, S., Mittal, R., Nag, H. & Sharma, R. (2008) Arthroscopic and magnetic resonance imaging evaluation of meniscus lesions in the chronic anterior cruciate ligament-deficient knee. *Arthroscopy* **24,** 1045-1051

Nikolaou, V. S., Chronopoulos, E., Savvidou, C., Plessas, S., Giannoudis, P., Efstathopoulos, N. & Papachristou, G. (2008) MRI efficacy in diagnosing internal lesions of the knee: a retrospective analysis. *Journal of Trauma Management and Outcomes* **2**, 4

Oei, E. H., Ginai, A. Z. & Hunink, M. G. (2007) MRI for traumatic knee injury: a review. *Seminars in Ultrasound, CT, and MR* **28,** 141-157

Ohlerth, S., Lang, J., Scheidegger, J., Nötzli, H. & Rytz, U. (2001) Magnetic resonance imaging and arthroscopy of a discoid lateral meniscus in a dog. *Veterinary and Comparative Orthopaedics and Traumatology* **14,** 90-94

Owens, J. M. (1982) The joints. In: Radiographic Interpretation for the Small Animal Clinician. Ed. D. N. Biery. Ralston Purina Company, Saint Louis, MO, USA. pp 26 & 46

Pooya, H. A., Gavin, P. R., Séguin, B., Tobias, K. M. & Tucker, R. L. (2004) Magnetic resonance imaging in small animal medicine: clinical applications. *Compendium on Continuing Education for the Practicing Veterinarian* **26,** 292-301

Ralphs, S. C. & Whitney, W. O. (2002) Arthroscopic evaluation of menisci in dogs with cranial cruciate ligament injuries: 100 cases (1999-2000). *Journal of the American Veterinary Medical Association* **221,** 1601-1604

Ridge, P. A. (2006) Isolated medial meniscal tear in a Border Collie. *Veterinary and Comparative Orthopaedics and Traumatology* **19,** 110-112

Scavelli, T. D., Schrader, S. C., Matthieson, D. T. & Skorup, D. E. (1990) Partial rupture of the cranial cruciate ligament of the stifle in dogs: 25 cases (1982-1988) *Journal of the American Veterinary Medical Association* **196,** 1135-1138

Sproule, J. A., Khan, F., Rice, J. J., Nicholson, P. & McElwain, J. P. (2005) Altered signal intensity in the meniscus: an MR finding of questionable significance. *Archives of Orthopaedic and Trauma Surgery* **125,** 267-271

Stoller, D. W., Martin, C., Crues, J. V. III, Kaplan, L. & Mink, J. H. (1987) Meniscal tears: pathologic correlation with MR imaging. *Radiology* **163,** 731-735

Toms, A. P., White, L. M., Marshall, T. J. & Donald, S. T. (2005) Imaging the post-operative meniscus. *European Journal of Radiology* **54,** 189-198

Tsai, K. J., Chiang, H. & Jiang, C. C. (2004) Magnetic resonance imaging of anterior cruciate ligament rupture. *BMC Musculoskeletal disorders* **5**, 21

Vahey, T. N., Broome, D. R., Kayes, K. J. & Shelbourne, K. D. (1991) Acute and chronic tears of the anterior cruciate ligament: differential features at MR imaging. *Radiology* **181,** 251-253

Whitney, W. O. (2003) Arthroscopically assisted surgery of the stifle joint. In: Small Animal Arthroscopy. Eds B. S. Beale, D. A. Hulse, K. S. Schulz & W. O. Whitney. W. B. Saunders, Philadelphia, PA, USA. pp 117-157

Winegardner, K. R., Scrivani, P. V., Krotscheck, U. & Todhunter, R. J. (2007) Magnetic resonance imaging of subarticular bone marrow lesions in dogs with stifle lameness. *Veterinary Radiology and Ultrasound* **48,** 312-317

Winkels P., Bottcher P. & Oechterling G. (2008) Distraction of medial compartment of canine stifle for precise evaluation of meniscal integrity. Proceedings of ESVOT. Munich, Germany, September 2008. p 356