Magnetic resonance imaging for detection of late meniscal tears in dogs following tibial tuberosity advancement for treatment of cranial cruciate ligament injury

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Cranial cruciate ligament, dog, magnetic resonance imaging, meniscus, stifle

Summary
Objectives: To document the use of and to estimate the accuracy of magnetic resonance (MR) imaging for detection of late meniscal tears in dogs with cranial cruciate ligament injury treated with tibial tuberosity advancement (TTA).

Methods: Medical records of dogs that had TTA followed by stifle MR imaging for suspected meniscal tear and subsequent arthrotomy were reviewed retrospectively. Magnetic resonance images were reviewed independently by an observer blinded to clinical information who classified menisci as torn, abnormal but intact, or normal. Magnetic resonance and surgical findings were compared.

Results: Eight stifles from large breed dogs were included. Six stifles had a medial meniscal tear identified in MR images and later confirmed surgically. In the remaining two stifles, the menisci appeared intact in MR images and no tear was identified at subsequent arthrotomy. Lateral menisci in all stifles appeared intact in MR images and were considered normal at surgery. Susceptibility artefacts associated with TTA implants were present in all images but did not adversely affect interpretation of intra-articular structures.

Clinical significance: Magnetic resonance imaging appears to be accurate for diagnosis of late meniscal tears. Artefacts associated with TTA implants did not prevent evaluation of critical intra-articular structures. Further investigation with MR imaging should be considered when late meniscal tear is suspected following TTA.

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Introduction
Injury to the cranial cruciate ligament is one of the most common causes of canine pelvic limb lameness (1). Cranial cruciate ligament insufficiency renders the stifle joint unstable and predisposes to meniscal damage. The medial meniscus is more prone to damage than the lateral meniscus because it is compressed during cranial tibial translation in unstable stifles (2). It is estimated that 33–77% dogs with cranial cruciate ligament insufficiency have a concurrent meniscal tear at the time of diagnosis (3–4). Late meniscal tears can also occur weeks to months after surgical treatment of the cranial cruciate ligament insufficiency and have been estimated to affect three to 17% of dogs (5–8). Occurrence of late meniscal tears can explain why some dogs have a poor response or relapse following surgical treatment of cranial cruciate ligament insufficiency. A late meniscal tear must be differentiated from other possible causes of persistent clinical signs, including contralateral cranial cruciate ligament insufficiency, septic arthritis and implant failure (9). Diagnosis and treatment of meniscal tears is necessary for optimal clinical outcome and to limit joint degeneration (2). Meniscal tears cannot be reliably detected by physical examination and are usually identified at arthrotomy or arthroscopy, which enables diagnosis and treatment within the same procedure (2, 4, 8). However, these procedures are invasive and may not reveal meniscal lesions that do not reach the proximal surface of the meniscus.

Imaging techniques for non-invasive examination of the menisci have been investigated, including ultrasonography, computed tomographic arthrography, and magnetic resonance (MR) imaging (10–19). Magnetic resonance imaging has been used extensively for examination of the human knee and is considered the gold standard for diagnosis of meniscal tears (20, 21). The normal meniscus appears...
uniformly hypointense in MR images whilst meniscal tears appear as high signal linear foci that intersect either one (partial thickness tear) or both (full thickness tear) meniscal margins (20, 22). Magnetic resonance also appears to be an accurate method for diagnosis of meniscal tears in dogs but, to date, there have been no reports of the use of MR for the diagnosis of late meniscal tears following stifle stabilization (14–18).

One potential disadvantage of postoperative MR is the occurrence of susceptibility artefacts associated with metallic surgical implants or drill bit fragments, which may adversely affect the diagnostic quality of the image (23). In a recent canine cadaveric stifle study, it was found that tibial plateau levelling osteotomy implants, which contain ferromagnetic stainless steel, produced marked susceptibility artefacts that obscured or distorted most stifle anatomy (24). However, the stainless steel crimps used for extracapsular stabilization and the titanium alloy implants used for tibial tuberosity advancement (TTA) produced susceptibility artefacts that mainly affected the lateral aspect of the stifle, which allowed the cruciate ligaments and medial meniscus to be evaluated satisfactorily (24). Similarly, in a clinical study, susceptibility artefacts occurring in dogs following extracapsular stabilization and TTA did not prevent interpretation of meniscal and cruciate lesions (15). Susceptibility artefacts are significantly less marked in images obtained using turbo spin-echo sequences than in sequences employing spectral fat saturation (24). Effects of susceptibility artefacts can also be reduced by adjustments to frequency-encoding gradient direction and polarity, and stifle flexion or extension (25). Hence MR may be considered a suitable technique for non-invasive assessment of the stifle in dogs following surgery for cranial cruciate ligament insufficiency.

The aim of this study was to document the use of and to estimate the accuracy of MR imaging for detection of late meniscal tears in dogs that had cranial cruciate ligament insufficiency. Hence MR may be considered a suitable technique for non-invasive assessment of the stifle in dogs following surgery for cranial cruciate ligament insufficiency.

Materials and methods

Medical records were searched for dogs that had TTA surgery at Chiltern Referral Services for the treatment of cranial cruciate ligament insufficiency between January 2007 and September 2012. Signalment, primary arthrotomy findings, time to re-injury, clinical findings, MR findings, and subsequent arthrotomy findings were recorded. Dogs were included in this study if they had intact menisci as determined visually and by meniscal probing via a medial parapatellar arthrotomy at the time of TTA, subsequent MR imaging and a second arthrotomy following the MR imaging during which the menisci were inspected. The TTA procedures were performed by a specialist surgeon (AL) according to standard technique using titanium alloy implants (7).

MR image acquisition

Imaging was performed using a 1.5T magnet. All images were obtained with dogs under general anaesthesia positioned in lateral recumbency with the limb being imaged adjacent to the couch using a multi-phase array coil. Stifles were neutrally positioned (neither flexed nor extended). Proton density spin-echo images were obtained using TR 1650ms and TE 16ms. T1-weighted spin-echo images were obtained using TR 25ms and TE 7.2ms. T2-weighted turbo spin-echo images were obtained using TR 2500ms and TE 100ms. T2-weighted gradient echo images (T2*) were obtained using TR 470ms and TE 23ms. Images were 2.5 mm thick with a 0.3 mm interslice gap. In all dogs, images were obtained in the sagittal plane. Frequency-encoding direction varied between the image series and exact position of the limb relative to the axis of the magnet. For proton-density and T2-weighted images, frequency-encoding direction was approximately parallel to the long axis of the tibia.

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Figure 1 Examples of a meniscal tear. A) Sagittal proton density magnetic resonance (MR) image of the stifle from dog 1 showing the medial meniscus. Hyperintense lines can be seen traversing the cranial horn (small arrow) and caudal horn (large arrow). Full thickness tears at the cranial and caudal horns of the medial meniscus were found at arthrotomy. Susceptibility artefact (A) associated with tibial tuberosity advancement implants is evident as a signal void superimposed on the tibial tuberosity. B) Sagittal proton density MR image of the stifle from dog 3 showing the medial meniscus. The cranial horn appears flattened (small arrow) and there is an oblique hyperintense line through the caudal horn (large arrow). Full thickness tears affecting the cranial and caudal horns of the medial meniscus were found at arthrotomy.
For T1-weighted images, the frequency-encoding direction was approximately perpendicular to the long axis of the tibia.

**MR image assessment**

A board certified radiologist (CRL) blinded to the surgical findings reviewed the MR images considered of diagnostic quality for all stifles. Criteria for normal appearance of the menisci and classification of suspected tears were based on existing reports (22). Menisci considered normal had homogenous hypointensity and a well-defined, regular wedge shape in sagittal images. Menisci were considered torn if there was an area of high signal extending through the meniscus and intersecting with one (partial thickness tear) or both meniscal margins (full thickness tear). Menisci containing hyperintense foci that did not reach their surface were considered abnormal but not torn, this detail was recorded, but was not used for estimation of accuracy, which refers only to meniscal tears. Areas of signal void, distortion of anatomic structures, or both together were considered to be susceptibility artefact. If susceptibility artefact affected interpretation of the intra-articular structures this was noted.

Magnetic resonance findings were compared with the post-imaging surgical findings in order to determine the diagnostic accuracy of MR imaging for the diagnosis of late meniscal tears following TTA surgery. Accuracy of MR imaging for diagnosing meniscal tear was calculated as true positives plus true negatives divided by total number of menisci.

<table>
<thead>
<tr>
<th>Dog</th>
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<th>MRI diagnosis</th>
<th>Arthrotomy findings</th>
</tr>
</thead>
<tbody>
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<td>1</td>
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<td>Two hyperintense lines transecting both meniscal margins in the cranial and caudal horns</td>
<td>Tears in the cranial and caudal horns</td>
<td>Small full thickness tear at cranial horn: radial&lt;br&gt;Large full thickness tear of caudal horn: radial</td>
</tr>
<tr>
<td>2</td>
<td>Lateral</td>
<td>Hyperintense vertical line transecting both meniscal margins in the caudal horn; tip appears fissured</td>
<td>Tear at caudal horn</td>
<td>Full thickness tear at caudal horn: bucket handle</td>
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<td>3</td>
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<td>Meniscus small and flattened; hyperintensity affecting cranial horn; oblique hyperintense line through caudal horn</td>
<td>Abnormal cranial horn; tear at caudal horn</td>
<td>Minor full thickness cranial horn tear: longitudinal&lt;br&gt;Large full thickness caudal horn tear: longitudinal</td>
</tr>
<tr>
<td>4</td>
<td>Lateral</td>
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</tr>
<tr>
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<td>Appeared normal</td>
</tr>
<tr>
<td>6</td>
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<td>Cranial horn appears blunted, possibly a variant</td>
<td>Normal</td>
<td>Appeared normal</td>
</tr>
<tr>
<td>7</td>
<td>Lateral</td>
<td>Normal</td>
<td>Normal</td>
<td>Appeared normal; CCL remnants adjacent to meniscus</td>
</tr>
<tr>
<td>8</td>
<td>Lateral</td>
<td>Hyperintense zone in body of meniscus</td>
<td>Abnormal, no tear</td>
<td>Appeared normal</td>
</tr>
<tr>
<td></td>
<td>Medial</td>
<td>Hyperintense line transecting both meniscal margins in the caudal horn</td>
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<td>Large full thickness caudal horn tear: longitudinal</td>
</tr>
<tr>
<td></td>
<td>Medial</td>
<td>Hyperintense zone in body of meniscus</td>
<td>Abnormal, no tear</td>
<td>Appeared normal</td>
</tr>
<tr>
<td></td>
<td>Medial</td>
<td>Large full thickness caudal horn tear: bucket handle</td>
<td></td>
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</tr>
</tbody>
</table>

MRI = magnetic resonance imaging
Pre- and postoperative care

All dogs were treated with perioperative opioid medication (buprenorphine 0.02 mg/kg or methadone 0.01–0.2 mg/kg) and non-steroidal anti-inflammatory medication (carprofen 2–4 mg/kg or meloxicam 0.1–0.2 mg/kg). The specific drug, method of administration, and timing and frequency of administration was dog dependent and determined based on previous drug treatment, demeanour, and assessment of perceived severity of pain in each dog.

Results

Eight large breed dogs were included; three Labradors, two mixed breed dogs and a Rottweiler, a Boxer and a Golden Retriever (Appendix Table 1 – available online at www.vcot-online.com). There were four males and four females, all neutered. Dogs had a median body weight of 34.5 kg (range 32.4 – 44.5 kg) and a median age of 40 months (range 20 – 81 months) at the time of their TTA surgery. Each dog had one affected stifle (six right, two left). A medial parapatellar arthrotomy was performed in all dogs at the first surgery and both menisci were inspected visually and with a blunt curved probe. None of the dogs included in this study had any damage to the medial or lateral meniscus identified. A meniscal release was not performed in any of the dogs. All dogs had recurrent or persistent lameness following TTA surgery, hence a late meniscal tear was suspected. The median time between TTA and MR was 12 months (range 4 – 53 months). Following MR imaging a repeat medial parapatellar arthrotomy was performed and both the menisci were inspected as before. The median time between MR and subsequent arthrotomy was 17 days (range 0 – 48 days).

On the basis of MR images, six dogs were thought to have medial meniscal tears (Figure 1) and in each instance this was confirmed surgically (Table 1). The remaining two dogs had no signs of medial meniscal tear identified in MR images and none was found at surgery. Meniscal tears identified at surgery included longitudinal, bucket handle and radial tears (3). They affected the caudal horn of the medial meniscus in four dogs and affected both the cranial and caudal horns of the medial meniscus in two dogs. All lateral menisci appeared free of tears in MR images and this was confirmed at surgery. Hence the accuracy (true positives plus true negatives divided by total number of menisci) of MR for determining the presence or absence of meniscal tears in this series of dogs was (6 + 10)/16 = 100% (95% confidence interval, 76–100%).

Despite accurate determination of presence or absence of meniscal tears, there were instances in which MR findings did not agree perfectly with surgical findings. In one dog (case 4) a full thickness tear was suspected on the basis of MR images (Figure 2), whereas a partial thickness tear was found at surgery. In two dogs (cases 5 and 8) hyperintense foci within menisci were considered abnormal (Figure 3), but both affected menisci appeared normal at surgery.

Susceptibility artefacts associated with the TTA implants were evident in all of the MR images. There were no instances of T2-weighted or proton density images in which the artefact obscured or distorted the menisci or cruciate ligaments; however, in both series of T2* images, interpretation of the cranial horn of the lateral meniscus was not possible because of distortion associated with susceptibility artefact. In the single series of T1-weighted three-dimensional gradient echo images that were obtained, image contrast was considered insufficient for optimal examination of the menisci.

Discussion

The current study demonstrates that MR is a feasible and potentially accurate method for imaging the canine stifle following surgical stabilization despite the presence of titanium implants. Therefore, MR imaging is a useful technique for the investigation of dogs that have poor clinical response to TTA suspected to be associated with a late meniscal tear. As previously reported, it is possible to detect the presence of meniscal tears and determine their location within the meniscus (14–19). If MR imaging is a sensitive method for the detection of meniscal tears, it could be used to avoid the need for unnecessary arthrotomy or arth-
roscopy and therefore eliminate additional morbidity for dogs undergoing these procedures for purely diagnostic purposes. Early use of MR imaging has been advocated for knee injuries in humans in order to reduce overall costs by avoiding unnecessary surgery (26, 27).

Late meniscal tears most commonly occur in the caudal horn of the medial meniscus (8). All dogs in the present study with meniscal injury had either a tear within the caudal horn or a tear in both the caudal and cranial horns of the medial meniscus. When examining the stifle joint by arthrotomy and arthroscopy it can be difficult to assess the caudal most aspect of the stifle joint and, therefore, it is possible that some caudal tears could be missed. Magnetic resonance imaging could potentially provide clinicians with important information that would help them decide if surgery is indicated.

This small series also serves to illustrate some of the difficulties of interpreting MR images of the menisci, including the problem of resolving small, but critical, stifle structures in dogs. In an experimental study of low-field strength (0.3T) MR in dogs with transected cranial cruciate ligament, it was found that MR images had insufficient resolution for examination of the menisci in small Beagle dogs (up to 10 kg body weight), but that meniscal tears were consistently well visualized in large (from 32 kg) dogs (18). Use of high-field MR imaging and relatively large dogs, as in the present study, will tend to minimize this problem, but will not eliminate it. For example, in dog 4 in our series, it was not possible to determine the completeness of the meniscal tear. The MR images produced in the present study were 2.5 mm thick with an interslice gap of 0.3 mm, which allows the possibility of small lesions being missed because they occupy only a small proportion of the slice thickness (partial volume artefact) or because they fall in the interslice gap.

In addition there were suspected abnormalities in the MR images that were not explained by surgical findings. In two dogs, hyperintensity was evident affecting the substance of a meniscus but no abnormality was identified at arthroscopy. It is unclear if this finding represents a false positive finding arising because of sub-optimal MR image quality or a genuine lesion, such as cartilage degeneration beneath the proximal surface of the meniscus. Hyperintense or heterogeneous meniscal signal intensity that does not reach the surface of the meniscus is consistent with subclinical degenerative changes (18, 19, 28). Degenerate changes observed on MR images are consistently not detected at the time of arthrotomy or arthroscopy (18). The clinical significance of meniscal hyperintensity in dogs is not established; hence the optimal treatment is unclear. Future studies would be required to establish the significance of these lesions, their impact on clinical signs, and their prognostic value.

Ferromagnetic material within the body is potentially unsafe for MR imaging because it is liable to be moved or heated by interactions with the magnetic field (29). Even Implanted microchips or surgical implants that are relatively safe because they are made of nonferrous metal (e.g. titanium alloy) can cause susceptibility artefacts on MR images that significantly reduce their diagnostic usefulness (24, 30). Due to the need for general anaesthesia for MR imaging concerns about patient safety, image quality as a result of metal artefact, or both may tend to inhibit use of MR in the postoperative canine stifle. However, previous studies have demonstrated that the artefacts associated with extracapsular stabilization and TTA implants do not prevent observers interpreting either the cruciate ligaments or the menisci (15, 24). Susceptibility artefacts may also occur with coloured (but not uncoloured) polydioxanone suture (18). All dogs in the present study had wounds closed using polydioxanone. The absorption time of polydioxanone is reported to be 180 days, but at least three of these dogs may have had residual suture material in a position liable to cause image distortion; however, no artefacts attributable to suture material were identified in any dog (31).

When managing a dog with suspected late meniscal tear, a variety of diagnostic techniques may be considered. Arthrotomy and arthroscopy are direct, potentially definitive techniques, but arthroscopy is associated with significant morbidity and arthroscopy requires specialist equipment and training. A non-invasive, accurate method for diagnosis of late meniscal tears could be valuable. This study shows MR imaging appears to address this need with successful diagnosis of late meniscal tears in dogs following TTA.

Conflict of interest
The authors declare no conflict of interest.

References