Some aspects of rat femorotibial joint microanatomy as demonstrated by high-resolution magnetic resonance imaging

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Summary

High-resolution magnetic resonance images (MRI) of the right femorotibial joint of normal Han:Wistar rats were acquired using a 4.7 Tesla magnet and a single-turn solenoid radio frequency coil (built in-house). Some anatomical findings of the rat femorotibial joint, which have not been reported previously using MRI, are described. The separation of patellar ligament and crural fascia was feasible on MRI. This separation would not be seen on images of lower resolution and its presence on high-resolution images could be mistaken for artefact due to the magic angle effect. Band-like fibrous structures exist in the infra-patellar fat pad, which might be mistaken as ligaments within the femorotibial joint. On sagittal MRI a vessel was seen inserted on the central part of the caudal surface of the patellar ligament. Subcutaneous fascia/cutaneous muscles (panniculus carnosus) could also be demonstrated with MRI in the femorotibial joint area.

Keywords  Femorotibial joint; magnetic resonance imaging; rat

Animal models of joint diseases have been extensively used in biomedical research (Jorgensen et al. 2001, Henry 2004). Detailed images of joints demonstrating skin, muscle, synovial cavity, cartilage and bones would help to track disease, monitor its progress and see how it responds to potential treatment. High-resolution magnetic resonance imaging [MRI] is able to provide such information non-invasively (Carpenter et al. 1994, 1995, Loueille et al. 1997, Faure et al. 2003). Radiological examination of joints has long been used in veterinary diagnosis, both for the assessment of joint function and the diagnosis of joint pathologies. Sophisticated modern technologies such as MRI have also been used to facilitate earlier, more accurate diagnosis (Fitch et al. 1997, Snaps et al. 1998, Reichle & Snaps 1999, Banfield & Morrison 2000, Widmer et al. 2000).

Recently, we had the opportunity to assess the femorotibial joint of normal rats with high-field MRI. The scans were carried out to establish baseline anatomical information for future pharmacological studies on these rats. Here we report some microstructures in the rat femorotibial joint, which to our knowledge have not been previously described by using MRI.

Materials and methods

Twenty-five male Han:Wistar rats from Charles River UK, aged 11–12 weeks, were used in this study. Animals were group housed at three per cage in standard conditions. Water from the site drinking water supply and food (R&M No.1, SQC, Laboratory Animals Ltd, Laboratory Animals (2006) 40, 288–295 Accepted 26 August 2005

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pelleted diet, supplied by Special Diets Service Ltd, UK) were freely available. They were examined after arrival and underwent a thorough daily clinical examination, including body weight, physical condition and behaviour. No abnormality was found in any of the animals.

The MR scanner was a 4.7 Tesla Varian horizontal magnetic resonance system (Varian Inc, Palo Alto, California, USA). The coil was a single-turn solenoid radio frequency (RF) coil that was built in-house (for the principle of RF coils, see Fan et al. 1987), with a diameter of 30 mm and 12 mm in length.

Animals were lightly anaesthetized with 1.5–1.7% isofluorane (Abbott Laboratories, Kent, UK) vaporized in 95%O2/5%CO2, which was supplied in the magnet via a face mask. Respiration rate was monitored continuously during imaging using a signal transducer/amplifier linked to a water-filled balloon placed under the abdomen of the animals. The respiration rate was considered to be an indicator of the depth of anaesthesia. The temperature of the animals was monitored continuously by rectal probe and maintained at 38 ± 0.1°C by a continuous flow of heated air. All work was performed in full compliance with licenses issued under the UK Animals (Scientific Procedures) Act, 1986.

The following MRI sequences were used for the examination of the right femorotibial joint:

- **Sequence 1**: Multi-slice spin echo proton density weighted sagittal scan
  - Time of repetition (TR)/time of echo (TE) = 1.000/0.009 s
  - Slice thickness 1.5 mm, in-plane resolution 118 μm × 118 μm;

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**Figure 1** Rat right femorotibial joint spin echo proton density weighted sagittal MRI (lateral to medial). The MRIs clearly show epiphyses of femur (1) and tibia (2), their growth plates, patella (3), lateral and medial meniscuses (white arrow), patellar ligament (4), some band-like fibrous tissue in the infra-patellar fat pad (white arrow head, which correspond to the band-like fibrous tissue in Figure 6 indicated as dashed arrow), and a structure inserted on the central part of the caudal surface of the patellar ligament (black dashed long arrow). The subcutaneous fascia/cutaneous muscles can be seen as superficial dark signal (horizontal white arrow)
• **Sequence 2**: Multi-slice spin echo lightly T2 weighted sagittal scan
  TR/TE = 1.000/0.03 s
  Slice thickness 0.65 mm, in-plane resolution 118$\mu$m $\times$ 118$\mu$m;

• **Sequence 3**: Multi-slice spin echo T1 weighted transverse scan
  TR/TE = 0.3/0.009 s
  Slice thickness 1 mm, in-plane resolution 118$\mu$m $\times$ 160$\mu$m;

• **Sequence 4**: Three-dimensional (3D) gradient echo scan with chemical shift selective fat suppression
  TR/TE = 0.05/0.006 s
  Resolution 50$\mu$m $\times$ 313$\mu$m $\times$ 313$\mu$m with the maximum resolution at cranio-caudal direction of the joint;

• **Sequence 5**: 3D gradient echo scan with chemical shift selective fat suppression
  TR/TE = 0.075/0.0028,
  resolution 59$\mu$m $\times$ 117$\mu$m $\times$ 234$\mu$m.

Sequences 1–4 were used for 24 rats, while sequence 5 was used exclusively for one rat. For sequences 1–4, a 200 mT/m gradient (Oxford Instruments, Oxford, UK) was used.

![Figure 2](image-url)  
**Figure 2**  Rat right femorotibial joint spin echo lightly T2 weighted sagittal MRI for A, B and C, three-dimensional fat suppressed gradient echo MRI (sequence 4) for D. The patellar ligament (oblique white arrow) and crural fascia (oblique dashed arrow) are very close; however, a separation can be seen. The patellar ligament inserts into the tuberosity of the tibia and the crural fascia extends further down. The subcutaneous fascia/cutaneous muscles can be seen as superficial dark signal (horizontal white arrow in B and D).
For sequence 5, a 300 mT/m gradient (Oxford Instruments, Oxford, UK) was used.

The right femorotibial joint of rats was chosen for examination for convenience due to the set-up of the RF coil. The left femorotibial joint was not scanned due to consideration of the duration of anaesthesia.

To validate MRI findings, haematoxylin-eosin stained histology preparations of the femorotibial joint from a different group of Han:Wistar rats (also from Charles River UK) were assessed. The MRI-scanned animals went on to participate in pharmacological studies and were not available for histology comparison.

**Results**

**Magnetic resonance imaging**

High-resolution MRIs of the right femorotibial joint were obtained (Figures 1–3). The spin echo proton density sequence demonstrated the best signal-to-noise ratio with slice thickness of 1.5 mm. The 3D gradient echo sequences offered the best overall spatial resolution. Similar to experiences with human subjects at lower magnetic field strengths, the cortical bone, tendon/ligament and menisci were of low signal intensity on all images. Muscle showed low to intermediate signal intensity. Fat showed high signal intensity on all sequences except the fat-suppressed images. Joint cartilage showed bright signals on 3D gradient echo sequence. The MRIs allowed clear identification of the femur and tibia growth plates, lateral and medial menisci, patellar ligament, crural fascia, and lateral and medial patellar retinaculum.

In addition to the anatomical structures normally seen on MRIs of the femorotibial joint, the anatomical structures discussed...
below, which were seen on MRIs across all the studied animals, deserved particular attention.

The patellar ligament and crural fascia were very close to each other in the femorotibial joint, although upon close inspection the separation could be seen on MRIs (Figures 2 and 3). The patellar ligament inserts into the tuberosity of the tibia and the crural fascia extended further down (Figure 2).

Multiple band-like fibrous structures were seen in the infra-patellar fat pad (Figure 1). They tended to run in a longitudinal direction and to be consistent in location. They appeared as a low-intensity signal in the images of sequences without fat suppression and became invisible in fat-suppressed sequence images.

A structure inserted on the central part of the caudal surface of the patellar ligament was seen on sagittal spin echo MRIs (Figures 1 and 4). 3D gradient echo images indicated this structure was consistent with the vessel signal (Figure 5).

Subcutaneous fascia/cutaneous muscles (panniculus carnosus) could also be demonstrated using MRI (Figures 2 and 3).

Histology

Histology (Figure 6) showed the band-like fibrous structures in the infra-patellar fat pad. This correlated with the band-like fibrous structures as demonstrated on the MRI in Figure 1.

Histology (Figure 7) showed patellar ligament and crural fascia. This correlated with the patellar ligament and crural fascia as demonstrated on the MRI in Figure 2.

Where the MRI demonstrated vasculature inserted on the caudal surface of the patellar ligament, histology preparations consistently showed vascular structures with associated connective tissue (Figure 8), though actual insertion site of these vessels was not obtained.

Histology (Figures 7 and 9) showed the subcutaneous fascia/cutaneous muscles. This correlated with subcutaneous fascia/cutaneous muscles.

Figure 5  Three-dimensional fat suppressed gradient echo MRI (sequence 5), multiple slices arrayed from medial to lateral side. Due to the nature of the 3D gradient echo sequence, vasculature with slow flowing blood shows bright angiographic signal. Vertical arrow indicates the patellar ligament; horizontal arrow indicates the vasculature behind the patellar ligament; arrow-head indicates a small vessel connected with the larger vessel (horizontal arrow) and inserted on the patellar ligament. L=lateral; M=medial.
cutaneous muscles (panniculus carnosus), as demonstrated on the MRI in Figures 2 and 3.

**Discussion**

To date, MRI tomographic knowledge of rodent joint anatomy and pathology is limited (Tessier *et al.* 2003, Wang & Westwood 2006). Indeed, knowledge accumulated for human clinical MRI has been translated into understanding of MRI of animal joints (Banfield & Morrison 2000). However, rodent joints are not just a smaller version of human joints. Unique aspects of rodent joint anatomy should be appreciated, especially for researchers from a medical science background.

To our knowledge the separation of patellar ligament and crucial fascia, band-like fibrous structures in the infra-patellar fat pad, and vascular structures inserted on the caudal surface of the patellar ligament have not been reported previously with MRI. The fibrous structures in the infra-patellar fat pad might be mistaken for joint ligaments within the femorotibial joint if not correctly recognized. The vascular signal seen on the 3D gradient echo MRIs may present as venous structure, as this tends to be bigger than the accompanying artery, and slower blood flow speed renders itself as a
bright signal on 3D gradient echo MRIs. The accompanying artery may have a dark signal and therefore be invisible on 3D gradient echo MRIs due to the ‘flow void phenomenon’. Unfortunately, for histology, no single histological section cut through the exact insertion site of this vessel into the tendon on step sectioning through whole joints.

It is worthwhile noting that if the spatial resolution (in-plane resolution or slice thickness) is not high enough, the patellar ligament and crural fascia could be regarded as a single structure. When the spatial resolution is sufficient and this anatomic phenomenon is not recognized, the patellar ligament and crural fascia could be regarded together as patellar ligament on sagittal images, but with a confusing longitudinal bright signal in the middle, as shown in Figure 2D, which could be regarded as due to a ‘magic angle’ effect (Karantanas et al. 2001).

MRI in the femorotibial joint area could also demonstrate subcutaneous fascia/

Figure 8  Haematoxylin-eosin stained rat sagittal histology section of a femorotibial joint. The tibia (Ti) and patellar ligament (black arrow) are shown. In the infra-patellar fat pad caudal to the patellar ligament vascular structures are seen (dashed arrow)

Figure 9  Haematoxylin-eosin stained rat sagittal histology section of a femorotibial joint. The patellar ligament (oblique arrow), cutaneous muscles (horizontal arrow), skin (Sk), tibia (Ti) and meniscus (Me) are shown
cutaneous muscles (panniculus carnosus). It is noteworthy that some rodent anatomy textbooks suggest that cutaneous muscles are present only in the head, neck and trunk of rodents (Greene 1963).

A comprehensive understanding of the imaging anatomy of animal joints is important for both biomedical research and veterinary care. Our results showed the power of high-field strength MRI and an optimized RF coil in demonstrating the microanatomy of small animal joints.

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**References**


