ANATOMY OF THE NORMAL KNEE AS SEEN BY MAGNETIC RESONANCE IMAGING

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Nuclear magnetic resonance imaging (MRI) was used to study the normal knee. As well as revealing bone quality, MRI provided useful information on intra-articular and extra-articular soft tissues. Mid-sagittal views gave clear images of the cruciate ligaments, and of the patellar and quadriceps tendons. Parasagittal views were the best for delineating the menisci which, like ligaments and tendons, are of low intensity; the semimembranosus tendon and its insertion to the proximal tibia were also seen clearly in these views. The cruciate ligaments and menisci, though visible in the coronal view also, were better seen in the sagittal view. Axial views provided information on the structure of the patella, its cartilage, the patellofemoral joint and posterior soft-tissue structures.

Nuclear magnetic resonance imaging (NMR or MRI) is becoming widely used in orthopaedic surgery. It has unique advantages over other imaging modalities. First, it is totally non-invasive and has no known adverse effects on the human body (Budinger 1981; Alifidi et al. 1982). Secondly, it can provide information not only on the density of tissues but also on their chemical structure. Thirdly, MRI can provide a direct three-dimensional view of the part examined. Different parts of the body have already been investigated. (Brady et al. 1983; Chafetz et al. 1983; Moon et al. 1983; Cohen et al. 1984), but until now the knee has not been explored in detail. For the diagnosis of knee disorders, an understanding of the normal knee is clearly essential and the aim of this present study was to learn the MRI appearance of a normal knee.

MATERIALS AND METHODS

The knees of 10 young healthy volunteers were examined by nuclear magnetic resonance imaging at the Elscint MRI Center, Herzlia. Informed consent was obtained in all cases before imaging. Conventional radiographs also were available in all cases.

The Elscint Gyrex S-5000 magnetic resonance imager has a cryogenic superconducting magnet operating at 0.5 tesla. Various radiofrequency pulse sequences were performed initially. They included saturation recovery, inversion recovery and spin-echo sequences. It appeared, however, that the best results for most orthopaedic conditions were obtained by applying spin-echo sequences with echo delay times ($T_2$ parameter) of 28 and 56 ms after application of the 90° pulse. Radiofrequency pulse sequence intervals ($T_R$ parameter) were varied between 450 and 2000 ms. Each patient underwent a total of four examinations: short (450 to 800 ms) and long (1200 to 1800 ms) $T_R$ series, in axial and coronal or sagittal planes. The slice thickness was 5 mm or 7 mm. A circular head coil with an aperture of 30 cm was used for all images.

RESULTS

The normal anatomy of the knee was displayed in three planes: sagittal, mid-coronal and axial. Sagittal views. Mid-sagittal view. Figure 1 shows that the femoral, tibial and patellar cortices give a low-intensity signal and therefore look dark. The soft-tissue structures closely applied to bone, namely the quadriceps tendon, the patellar tendon and the posterior cruciate ligament are conspicuous and also are of low intensity (Fig. 1). The bone marrow gives a high-intensity signal because of its high fat content and therefore looks bright. Other fatty tissues inside the knee, such as the subcutaneous tissues, the infrapatellar pad and the floor of the suprapatellar pouch also appear bright. In this particular instance (Fig. 1) the anterior cruciate ligament is not shown, though it can be seen in another volunteer in whom the sagittal slice was taken slightly lateral to the mid-line (Fig. 2).

In both Figures 1 and 2 the gastrocnemius muscle can be seen behind the posterior cruciate ligament. In Figure 2 the low-intensity image of the femoral artery is conspicuous behind the femur.
Parasagittal view (condylar view). In this view the shafts of the tibia and the femur are not seen and only the condyles are visible (Figs 3 and 4). The femoral articular cartilage is displayed as a white line on the black subchondral bone. The brightness of the articular cartilage is similar to that of the bone marrow. The medial meniscus shows quite well with conspicuously low intensity of the anterior and posterior horns. Behind the femoral condyle the semimembranosus is seen as a black line which inserts onto the tibia just beneath the posterior joint line. 

Mid-coronal view. The medial and lateral menisci can be distinguished at the edges of the joint space (Fig. 5) but their appearance in this view is less conspicuous than in the parasagittal view. The attachment of the posterior cruciate ligament to the medial condyle can be seen as an area of low intensity.

Axial view. Proximal to the femoral condyles (Fig. 6). At this level the vastus medialis has a muscular belly, while the vastus lateralis is already tendinous. The hamstring muscles and the popliteal neurovascular bundle are seen in the posterior half of the slice.

Through the distal femur (Fig. 7). This cross-section of a knee after ligament reconstruction shows the channels through which the ligaments pass, and also shows the
patellofemoral joint. The patella with its long and concave lateral facet (Wiberg Type II) is situated normally in the trochlear groove, and the hyaline cartilage of the patellofemoral joint looks normal. The medial and lateral heads of the gastrocnemius are inserted into the condyles and the three circular structures between them represent the popliteal artery, vein and nerve. The whole limb is encircled by the high-intensity signals of the subcutaneous fat.

Through the joint space (Fig. 8). It might be thought that this view would show both menisci but only one is seen, on the medial aspect of the left knee.

**Distal to the joint space** (Fig. 9). In the right knee the patellar tendon is seen inserting into the tibial tuberosity. In the left knee the patellar tendon (1) is seen before its insertion, with the white fat-pad (2) separating it from the tibia. The tibiofibular joint is seen in both knees, just beginning to appear on the left, and with the whole fibular head on the right. The muscle mass fills the posterior half of each slice.

**DISCUSSION**

Since its first application in medicine, NMR scanning has advanced greatly. Nowadays, the imaging equipment in clinical use focuses on the presence of the proton nucleus. Signal intensity is determined by such factors as proton density, proton relaxation times $T_1$ (longitudinal) and $T_2$ (transverse) and proton movement or flow. Hence, NMR imaging locates and increases the properties of naturally occurring substances within the body (Hinshaw et al. 1978). The whiteness of the image of fat and bone marrow is due to short $T_1$ and long $T_2$ relaxation times. Compact bone and air show as dark signals because their hydrogen concentration is very low.

Bone is poorly visualised. Soft tissues show more

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**Fig. 5**
Mid-coronal view ($T_\alpha = 550; \ T_\tau = 28 \text{ ms}$). PCL, posterior cruciate ligament; M, meniscus.

**Fig. 6**—Axial view and diagram proximal to the femoral condyles ($T_\alpha = 1200; \ T_\tau = 28 \text{ ms}$). 1, femur; 2, biceps femoris muscle; 3, semimembranosus muscle; 4, sartorius muscle; 5, vastus medialis muscle; 6, gracilis tendon; 7, semitendinosus tendon; 8, popliteal vein and artery. Figure 7—Axial view across distal femur ($T_\alpha = 700; \ T_\tau = 28 \text{ ms}$). 1, patellofemoral cartilage; 2, channel for ligamentous reconstruction; P, patella; F, fat.

**Fig. 7**

**Fig. 8**
Axial view across joint space ($T_\alpha = 1200; \ T_\tau = 28 \text{ ms}$). 1, medial meniscus.
clearly and present as different shades of grey. We found that the best visualisation of the quadriceps and patellar tendons and of the cruciate ligaments was provided by mid-sagittal and parasagittal views. The posterior cruciate ligament is more conspicuous than the anterior, partly because it is thicker and partly because of the enhancement effect of the posterior capsule. MRI is clearly useful in detecting acute or chronic ligament and tendon ruptures. The patellar tendon also is clearly visualised, and so the Insall–Salvati ratio can be measured directly and the level of the patella relative to the joint line accurately assessed.

The menisci were best seen in parasagittal views as dark wedges. Non-displaced meniscal tears can seldom be identified, but displaced peripheral or bucket-handle tears appear as interposed dark substance between the white articular cartilage of the femur and tibia. Meniscal tissue is not well detected in the axial view and this plane needs further refinement. Parasagittal views show the femoral condylar cartilage and the semimembranosus insertion into the tibia quite clearly.

As with CT scans, the patellar structure and the patellofemoral joint are well depicted in axial views. However, MRI also displays the patellar articular cartilage.

We believe that with further technological development, such as reduction in the thickness of each slice, visualisation—particularly of the menisci and articular cartilage—will be clearer, and that with improved resolution MRI should be invaluable, particularly in the early diagnosis of knee injuries.

REFERENCES


