Eur. Radiol. 7, 1020–1024 (1997)

European
Radiology

Original article

MRI of normal anterior cruciate ligament (ACL) and reconstructed ACL: comparison of when the knee is extended with when the knee is flexed

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Received: 11 January 1996; Accepted: 27 December 1996

Abstract. The purpose of this study was to evaluate, using MRI, the morphology of normal anterior cruciate ligament (ACL) and ACL grafts when the knee was extended compared with when the knee was flexed. Eighteen normal controls and 22 ACL graft patients were studied. Spin-echo (SE) T1-weighted images (TR 330 ms/TE 15 ms, NEX 1) were obtained with a slice thickness of 3 mm. Oblique sagittal images parallel to the ACL were obtained at various flexed angles of the knee joint. In 12 of the 18 normal controls the ACL appeared convex toward the posterior side when the knee was extended and gradually became straight when the knee was flexed. In 15 of the 22 ACL graft patients the grafts appeared straight when the knee was extended and became convex toward the anterior side when the knee was flexed. It is concluded that the morphological changes seen on MR images of ACL grafts from when the knee is extended to when the knee is flexed are different from those in the normal ACL.

Key words: Anterior cruciate ligament (ACL) – ACL graft – Cine image – Knee joint – Magnetic resonance imaging (MRI)

Introduction

MRI has proved to be an excellent non-invasive modality for the evaluation of transplanted grafts for anterior cruciate ligament (ACL) reconstruction. There are many reports of evaluation of ACL grafts by MRI [1–6], and some reports of cine MRI of the knee joint [7–10]. However to date, to our knowledge, there have been no reports that have evaluated ACL grafts on MRI both when the knee was extended and when it was flexed and compared the findings with those for normal ACLs. This prospective study was performed to evaluate ACL grafts in this way about 6 months after operation and to compare the findings with those for volunteers with normal ACLs.

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Materials and methods

Eighteen normal controls (age range 22–32 years; nine males and nine females) and 22 ACL-reconstructed patients (age range 15–43 years; 17 males and five females) underwent MRI without the investigators having knowledge of the clinical information.

Eleven of the 22 graft patients had undergone arthroscopic ACL reconstruction with an allogenic tendon. Nine other patients received autogenous semitendinous tendons, and the remaining two received an autogenous patellar tendon and iliotibial band.

The patients were examined at postoperative intervals ranging from 5 to 7 months (mean 6 months). All studies were performed using a 1.0-T magnet (Siemens, Impact). The pulse sequence was T1-weighted 330/15 [TR (ms)/TE (ms), one acquisition). The determination of the slice directions was as follows. First, axial images of the femoral condyle in which ACL inserts into the femur were obtained; then the parasagittal direction 10° oblique from the mid-sagittal direction of the knee joint, which was considered to be parallel to the ACL or ACL graft, was determined. If the ACL was not depicted as a continuous low-intensity band, we changed the parasagittal angle to a maximum of 20° and tried again. The slice thickness was 3 mm with no gap, FOV was 180 mm and the imaging matrix was 256×256. Imaging time was 1.5 min for each image. We constructed a special knee brace for flexing and keeping the knee joint fixed (Fig. 1). A small FOV surface coil was placed on the lateral side of the knee joint.

First we examined the knee at the limit of its extension (15°–20°) allowed by the narrow space inside the magnet; we then had the subject flex the knee joint at various angles and examined it again. We examined be-

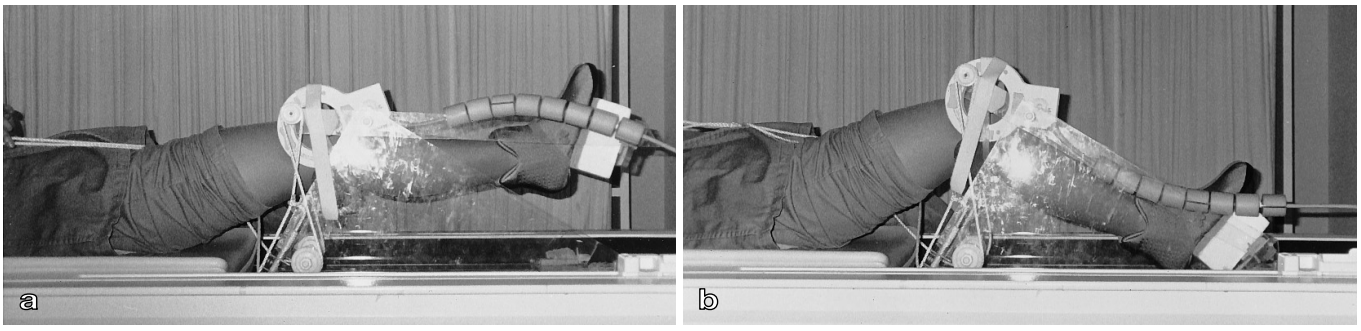

Fig. 1 a, b. A special knee brace was constructed. A round surface coil is attached to the lateral portion of the knee joint. **a** The knee joint can be fixed by the rope when the knee is at the limits of its extension of 15°–20° allowed by the narrow space inside the magnet. **b** The knee joint can be fixed when the knee is at maximally flexed angles in the knee brace

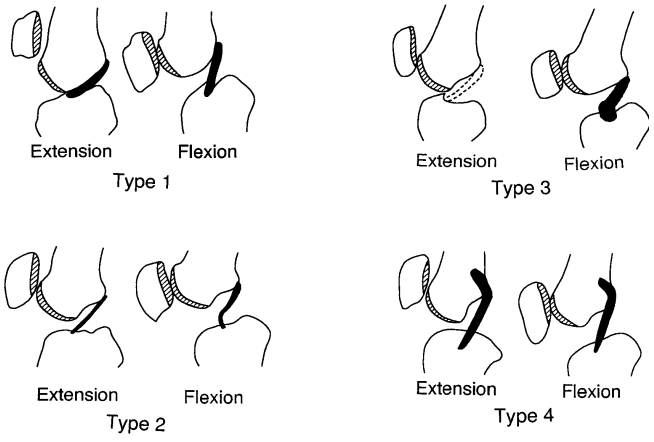

Fig. 2. Scheme of anterior cruciate ligament (ACL) movement. *Type 1:* The ACL appears convex toward the posterior side when the knee is extended. It becomes straight when the knee is flexed. *Type 2:* The ACL appears straight when the knee is extended. It becomes convex toward the anterior side when the knee is flexed. *Type 3:* The ACL does not appear as a clear low-intensity band when the knee is extended. It appears as a clear low-intensity band that is convex toward the anterior side when the knee is flexed. *Type 4:* The ACL appears straight both when the knee is extended and when it is flexed

Table 1. Cine MRI findings of the anterior cruciate ligament (ACL)

MRI findings	No. of ACLs	No. of ACL grafts
Type 1	12	0
Type 2	4	15
Type 3	2	0
Type 4	0	4
Re-injury	–	3
Total	18	22

tween four and seven partially flexed positions until the knee was fully flexed within the limitation of our special knee brace. The maximal flexed angles ranged from 35° to 45°. In the ACL graft patients, Gd-DTPA 0.1 mmol/kg was injected intravenously before the examination. The total examination time was about 40–50 min.

After the examination, three experienced radiologists analyzed all the images without knowledge of the subjects' clinical information. If necessary agreement among the three observers was obtained by consensus. We then selected the best images revealing the entire ACL in each flexed position, reconstructed dynamic images and repeated the analysis.

Results

We classified the patterns of morphological changes of normal ACL and ACL graft into four types (Fig. 2, Table 1).

Normal ACL

In 12 of the 18 normal volunteers, when the knee was extended the ACL appeared convex toward the posterior side and ran adjacent to Blumensaat's line. When the knee was flexed, the ACL gradually became straight, separated from Blumensaat's line, and appeared as a low-intensity band clearer than when the knee was extended (type 1, Fig. 3).

In the four other normal volunteers, the ACL appeared straight when the knee was extended and became convex toward the anterior side when the knee was flexed (type 2, Fig. 4). In the remaining two volunteers the ACL did not appear as a clear low-intensity band when the knee was extended. When the knee was flexed it appeared as a clear low-intensity band that was convex toward the anterior side (type 3, Fig. 5).

ACL graft

We found two types of ACL graft patterns and three cases of re-injury (Fig. 2, Table 1). In 15 of the 22 ACL graft patients the entire reconstructed ACL demonstrated a smooth, well-defined, low-intensity signal and appeared straight when the knee was extended, becoming obviously convex toward the anterior side when the knee was flexed (type 2, Fig. 6).

In four other cases the ACL grafts consistently appeared straight (type 4, Fig. 7). In the remaining three cases the ACL grafts were not consistently depicted. In

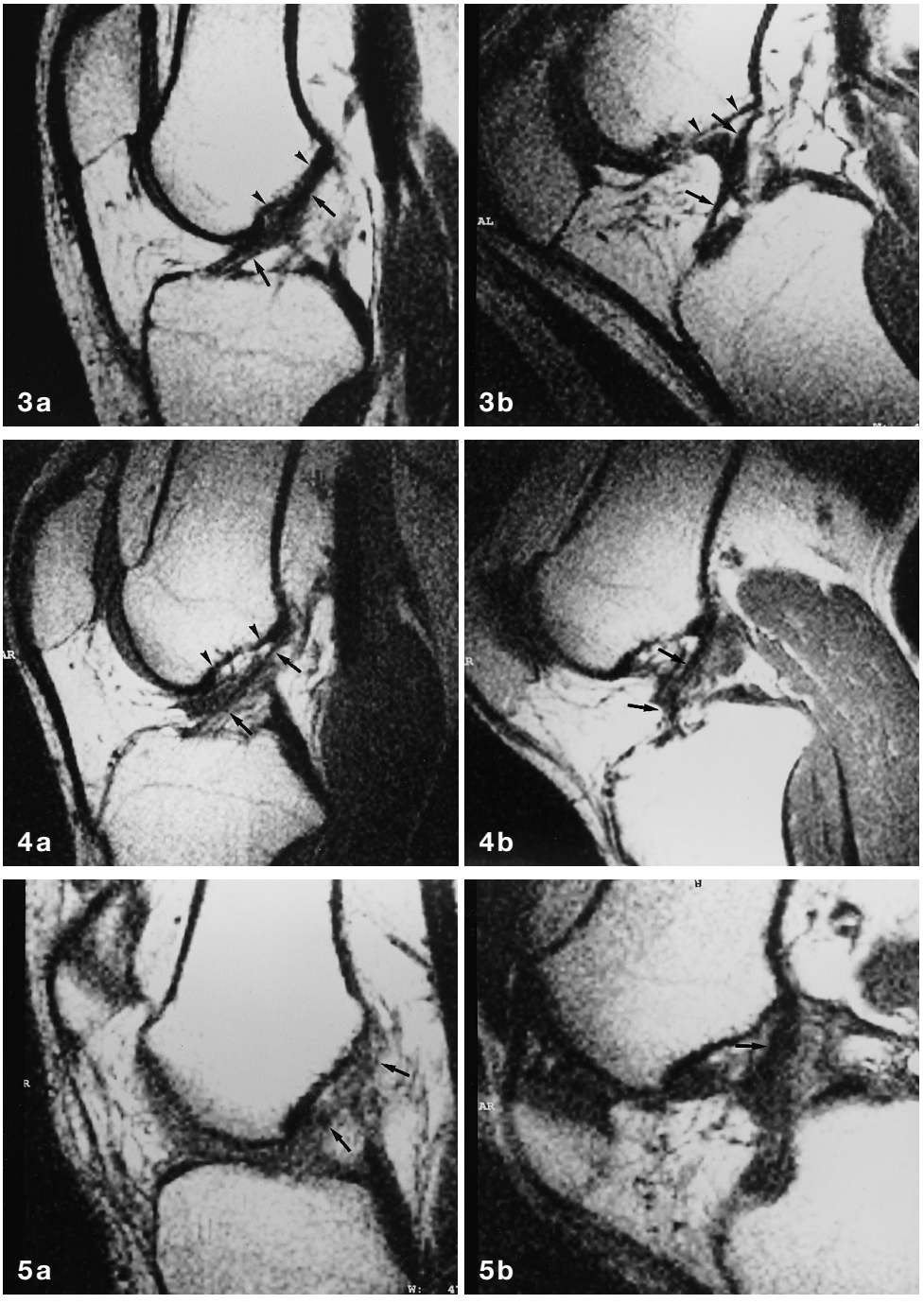

Fig. 3 a, b. A 30-year-old normal male volunteer (type 1). **a** The ACL appears convex toward the posterior side when the knee is extended *(arrows)* and runs adjacent to Blumensaat's line *(arrowheads)*. **b** The ACL becomes straight when the knee is flexed *(arrows)* and is separated from Blumensaat's line *(arrowheads)*

Fig. 4 a, b. A 32-year-old normal male volunteer (type 2). **a** The ACL appears straight when the knee is extended *(arrows)* and is separated from Blumensaat's line *(arrowheads)*. **b** The ACL becomes convex toward the anterior side when the knee is flexed (*arrows*)

Fig. 5 a, b. A 25-year-old normal female volunteer (type 3). **a** The ACL is not clearly seen when the knee is extended *(arrows)*. **b** The ACL becomes clear and is convex toward the anterior side *(arrow)* when the knee is flexed

these three cases second-look operations were performed, and re-injuries were proven.

Discussion

There have been some reports of the use of cine MRI of the knee joint to inspect the motion of the ACL [7–10]. In our study we made a special knee brace for use in the narrow gantry of the supermagnet machine. However, we had no flexible surface coil to wind around the whole knee and therefore a planar surface coil had to be used. Our special knee brace was designed to fix the patient's femur and patella and make the patient move the lower leg. The problem of our method was that the maximal angle of extension and flexion in our MR gantry was limited and varied according to the size of the patient, and the exact angle of flexion could not be measured. We tried to obtain a slice direction parallel to the normal ACL or ACL graft from the axial images of the femoral condyle in which the ACL inserts into the femur. If ACL was not depicted as a continuous low-intensity band, we changed the parasagittal angle from a minimum of 10° to a maximum of 20° and tried again. We did not use a real cine MR pulse sequence but obtained spin-echo T1-weighted images with a 3 mm slice

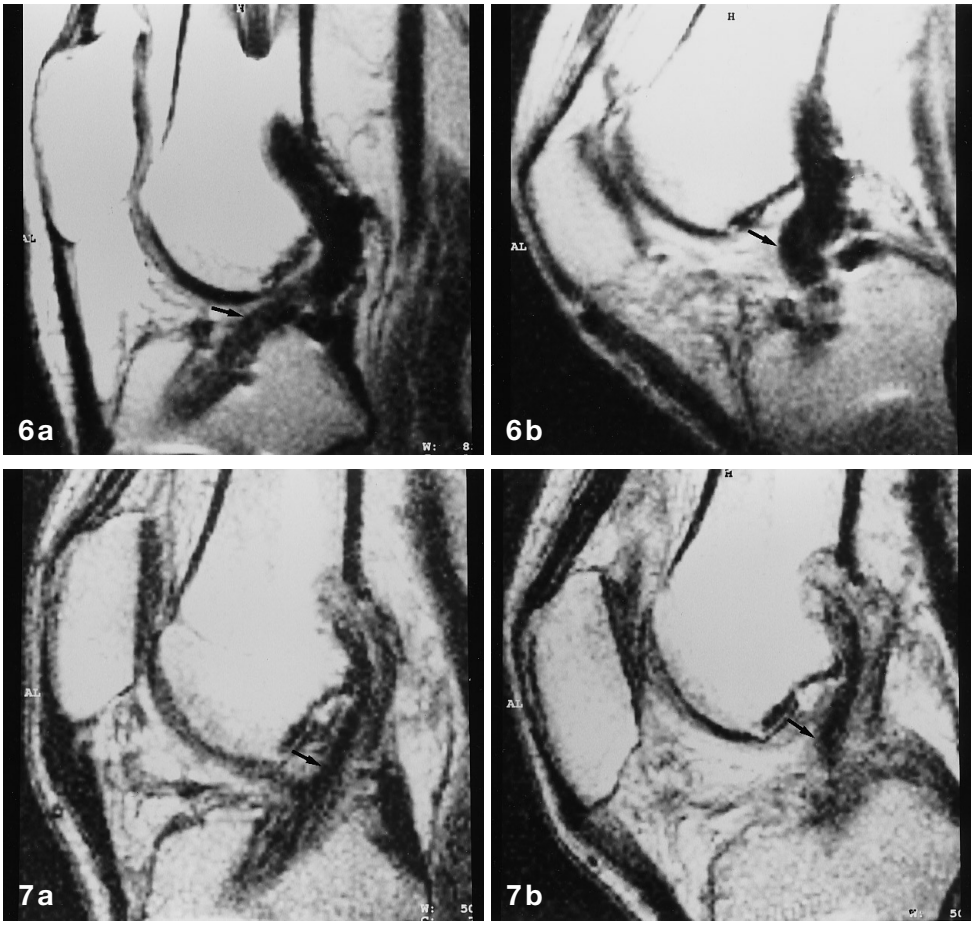

Fig. 6 a, b. A 20-year-old man with an ACL graft from an allogenic tendon (type 2). **a** The ACL appears straight when the knee is extended *(arrow)*. **b** The ACL becomes convex toward the anterior side *(arrow)* when the knee is flexed. On the tibial insertion, the flex is quite obvious

Fig. 7 a, b. A 32-year-old man with a reconstructed ACL using an allograft tendon (type 4). **a** The ACL appears straight when the knee is extended *(arrow)*. **b** The ACL also appears straight when the knee is flexed *(arrow)*

thickness, even though it took a considerable time to evaluate the ACL's exact anatomical structure.

As has been reported, the ACL is attached to a fossa on the posterior aspect of the medial surface of the lateral femoral condyle and to a fossa in front of and lateral to the anterior tibial spine [12, 13]. The tibial attachment of the ACL is somewhat wider and stronger than the femoral attachment [12, 13]. The ACL is attached to the femur and tibia not as a single cord but as a collection of individual fascicles that fan over a broad, flattened area [12, 13]. The normal ACL is 30 mm wide from anterior to posterior [12, 13], including the anteromedial band (AMB) and posterolateral bulk (PLB). When the knee is extended, the PLB is tight whereas the AMB is moderately lax. However, as the knee is flexed, the femoral attachment of the ACL assumes a more horizontal orientation, causing the AMB to tighten and the PLB to loosen [12, 13].

In 66% (12/18) of the normal volunteers in our present study, when the knee was extended the ACL appeared convex toward the posterior side and ran adjacent to Blumensaat's line. When the knee was flexed, the ACL gradually became straight, separated from Blumensaat's line, and appeared as a low-intensity band clearer than when the knee was extended. As has been reported, the tension to the AMB of the ACL increases as the knee flexes, becoming maximal at full flexion of the knee [12, 13]. The tightened bundle seems to be straight, which makes its margin appear more distinctly within the imaging section [12, 13].

In four other normal volunteers the ACL appeared straight when the knee was extended and became convex toward the anterior side when the knee was flexed. This motion seems to correspond to the motion of the PLB of the ACL [12, 13]. In the remaining two normal volunteers the ACL did not appear as a clear low-intensity band except when the knee was flexed, even though we changed the parasagittal angle repeatedly. In these cases, the ACL seemed to be tight only when the knee was fully flexed. In all the normal volunteers, with tibial insertions, the width of the low-intensity area was less than 30 mm. Our results suggest that the low-intensity band which is recognized as the ACL does not represent the entire ACL. Rather, only either the AMB or the PLB is depicted, and if the direction of the ligament's fibers is not parallel to the direction of slicing, it does not appear as a clear low-intensity band [5].

There are many reports of the evaluation of ACL grafts with MRI [1–6], but they have all described the case when the knee is extended. Howell et al. [1] described that when the knee was extended the unimpinged ACL graft is placed in tibial tunnels posterior and parallel to the slope of the intercondylar roof. Moreover, they pointed out that unimpinged grafts do not angle around the distal edge of the intercondylar roof. In 15 of our present 22 ACL graft cases the graft

appeared straight when the knee was extended, becoming convex toward the anterior side when the knee was flexed (type 2). We suggest that this type of motion is normal for ACL graft patients. The ACL graft consists of only one bundle, unlike the normal ACL, and the whole bundle thus extends and flexes together [1]. In four other grafted cases the reconstructed ACL appeared straight in all positions (type 4). These patients did not show obvious clinical symptoms of re-injury.

We consider that MR examination using our device is a temporary method; in future, with a flexible surface coil, routine examination of the knee joint will be able to be performed when the knee is flexed 35°–45° to depict the ACL or reconstructed ACL and also the posterior cruciate ligament clearly.

Conclusion: (1) about two-thirds of normal ACLs appear convex toward the posterior side when the knee is extended and gradually become straight when the knee is flexed; (2) about 17% of normal ACLs appear straight when the knee is extended and become convex toward the anterior side when the knee is flexed; (3) the most common findings for reconstructed ACLs are a straight appearance when the knee is extended and a convex appearance toward the anterior side when the knee is flexed.

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