Magnetic Resonance Imaging of 3-Dimensional In Vivo Tibiofemoral Kinematics in Anterior Cruciate Ligament–Reconstructed Knees

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Purpose: The purpose of this study was to use magnetic resonance imaging (MRI) to determine 3-dimensional knee kinematics after anterior cruciate ligament (ACL) reconstruction. **Methods:** Nine ACL-reconstructed and contralateral knees were tested 12 ± 8 months after surgery. MRI was performed at full extension and 40° of knee flexion under simulated weight-bearing conditions. Femoral condyle positions, tibial rotation, contact area, and contact location were analyzed by use of MRI-based 3-dimensional models. **Results:** When knees were fully extended, tibiae in ACL-reconstructed knees were externally rotated by 3.6° ± 4.2° compared with contralateral knees. The external rotation was due to anterior subluxation of the medial side of the tibia. At 40° of knee flexion, tibiae in ACL-reconstructed knees and contralateral knees were both internally rotated by 5.3°. There were no significant differences in contact area or contact location between ACL-reconstructed and contralateral knees. When moving from extension to flexion, ACL-reconstructed knees exhibited 3.5° ± 5.9° more internal tibial rotation than contralateral knees. **Conclusions:** Reconstruction of the ACL restored normal motion on the lateral side of the knee but not on the medial side, resulting in increased internal tibial rotation when moving from full extension to 40° of flexion. These results suggest that ACL reconstruction does not restore normal kinematics on the medial side of the knee, which may lead to early cartilage degeneration. **Level of Evidence:** Level IV, therapeutic case series. **Key Words:** Anterior cruciate ligament reconstruction—Magnetic resonance imaging—Kinematics—Biomechanics—Internal tibial rotation—Arthrosis.

Altered mechanical loading due to kinematic changes in the knee is thought to be an important factor in cartilage degeneration and progression of osteoarthritis (OA).[1,2] Rupture of the anterior cruciate ligament (ACL) causes changes in tibiofemoral kinematics that may affect the mechanical environment of the articular cartilage and subchondral bone, making ACL injury a potential risk factor for OA.[3-6]

Reconstruction of the ACL diminishes the severity of postreconstruction OA by decreasing the number of meniscal tears, which predispose patients for OA.[7,8] However, similar rates of OA have been observed in patients who undergo reconstruction and patients who decide not to undergo surgery. A long-term study of young, female soccer players 12 years after ACL injury showed that in those who underwent ACL reconstruction, symptomatic knee OA developed at a rate similar to that in those who chose not to have ACL reconstruction.[9] In another study 84% of patients after ACL reconstruction had slight to moderate changes equivalent to OA after 20 years.[10] Short-term changes have also been observed. Arthroscopic examination of 105 patients who had ACL reconstruction 15 months after surgery showed degeneration of all cartilage surfaces except the lateral femoral condyle.[11]

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Several different image-based techniques have been developed to measure in vivo kinematics of ACL-deficient and ACL-reconstructed knees. In vivo magnetic resonance imaging (MRI) during full or partial weight bearing has been used in a number of studies to measure tibiofemoral translation and contact location based on a pair of sagittal image slices bisecting the medial and lateral femoral condyles.[12-17] Logan et al.[13,14] used this technique to find that the position of the lateral tibial plateau in both ACL-deficient and ACL-reconstructed knees was anterior to that in normal contralateral knees. Anterior subluxation of the lateral tibia in ACL-reconstructed knees existed despite a return to normal anteroposterior laxity.

Previous studies have developed a 3-dimensional (3D) analysis of in vivo tibiofemoral kinematics, contact area, and contact location with an MRI-compatible loading device to simulate partial weight bearing during imaging in a clinical MRI system.[4,18] Using this technique, a study of 8 patients with unilateral ACL injury showed that the position of the lateral tibia in ACL-deficient knees in full extension was anterior to that in normal knees.[4] The results also showed that the cartilage-on-cartilage contact location on the tibial plateau in ACL-deficient knees was posterior to that in normal knees and that the contact centroid on the medial tibial plateau translated less than in normal knees during movement from full extension to 45° of flexion.

Knee kinematics and cartilage contact characteristics affect the mechanical environment in both cartilage and bone. Therefore the altered kinematics found in previous studies of ACL-deficient knees may have important effects on joint health. Measuring the 3D kinematics of ACL-reconstructed knees provides both a quantitative evaluation of knee performance after surgery and a means of understanding how the biomechanical environment in the knee changes after reconstruction. The goal of this study was to determine 3D flexion/extension knee kinematics in ACL-reconstructed knees. Our hypothesis was that ACL-reconstructed knees do not have normal knee kinematics when compared with contralateral normal knees.

METHODS

We recruited 9 patients (5 men and 4 women; mean age, 32 ± 9 years) with unilateral ACL reconstruction for the study. One patient received an Achilles tendon allograft, two received bone-to-bone autografts, and the rest received hamstring tendon autografts. A single-incision transtibial technique was used by the same surgeon to perform all ACL reconstructions. For the tibial tunnel position, all tibial tunnels were placed through the remaining tibial stump with the posterior edge of the anterior horn of the lateral meniscus as the landmark. The tibial stump was left behind to enable accurate placement of the graft. The femoral tunnel was positioned by use of the transtibial technique. A 6-mm offset guide was used in all cases, and the tunnels were placed at the 1:30 and 10:30 positions around the notch. Imaging was performed at a minimum of 6 months after surgery, with a mean time of 12 ± 8 months (range, 6 to 30 months) postoperatively. All patients had a clinically normal Lachman examination and instrumented examinations with anteroposterior translation of −1 to 2 mm when compared with the contralateral uninjured knees. None of the patients had meniscectomy, but 3 patients had all-inside lateral meniscus repairs. There were no patients in this study who had cartilage abnormalities that required further treatment. All patients gave informed consent to participate in the study, and all procedures were approved by the Committee on Human Research at our institution.

In vivo imaging under simulated partial weight-bearing conditions and 3D kinematic analysis were performed with methods previously used in a study of ACL-injured patients.[4] Patients were imaged in a General Electric 3.0-T Signa MRI system (GE Healthcare, Waukesha, WI). A dual-element, phased-array paddle coil (Nova Medical, Wilmington, MA) was attached to the medial and lateral sides of the knee, and an MRI-compatible loading device was used to apply a compressive force of 125 N to the bottom of the patient's foot while the patient lay in a supine position (Fig 1). Proton density–weighted images of the knee were acquired with a fast spin echo pulse sequence in the sagittal plane with a field of view of 16 cm, 512 × 256 matrix, in-plane resolution of 0.3 mm, slice thickness of 1.5 mm, repetition time of 3,500 milliseconds, and echo time of 9.7 milliseconds. Sixty-six slices were obtained with an imaging time of 7 minutes 40 seconds. Images of each knee were obtained in a position of full extension and in a position of approximately 40° of flexion. To help provide a consistent flexion position, patients were asked to flex the knee until the patella rested against a positioning plate attached to the scanning table (Fig 1).

For analysis of knee kinematics, the femur and tibia of each image were semiautomatically segmented by use of B-splines created with in-house software written and run in MATLAB (The MathWorks, Natick, MA). Medial and lateral tibiofemoral cartilage-on-