Joint Residual Laxity and Increased Cartilage Contact Deformation in ACL Reconstructed Knees

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Introduction: Surgical reconstruction of the anterior cruciate ligament (ACL) is commonly accepted as a treatment to restore the stability of the ACL injured knees. However, previous investigations suggested that after ACL reconstruction and under functional activities, the knee kinematics are not fully restored, especially at low flexion angles [1]. The contact biomechanics of tibiofemoral joint such as articular cartilage deformations are not completely restored at lower flexion [2]. Abnormal knee kinematics have been thought to be a major biomechanical factor leading to long-term joint degeneration. We hypothesize that the residual joint laxity (changes in the kinematics) would be correlated with the changes of cartilage contact deformations. In this study, we analyzed the knee joint kinematics after ACL reconstruction and the corresponding cartilage contact deformation at the medial and lateral compartments.

Methods: With our institutional review board approval, eight patients with unilateral ACL rupture and healthy contralateral knees were recruited. Before ACL reconstruction surgery, both ACL deficient and intact contralateral knees of each subject were scanned using a 3T MR scanner. Those images were used to construct a 3D model of the knee. The kinematics of both knee were captured during weightbearing flexion (lunge) using a dual-orthogonal fluoroscopic system [4]. The knee kinematics were reproduced in a virtual fluoroscopic system and the 6DOF in vivo knee kinematics and corresponding joint contact biomechanics were determined.

Six months after ACL reconstruction, 6DOF kinematics of the knee during the same weightbearing flexion were collected, together with the cartilage contact biomechanics. During both pre- and post-operative study visits, the clinical stability test was performed using a KT-1000 arthrometer under maximum anterior load.

We examined the correlation of changes (postoperative relative to preoperative) of anterior-posterior translations (Δ AP), internal-external rotation (Δ IE) and the changes in IKDC results (Δ IKDC) with the changes of contact deformations (medial and lateral condyles) at full extension of the knee.

Results: In the anterior-posterior direction, the reconstructed knees showed a significant increase of Δ AP=2.5±1.5 mm relative to intact contralateral knees (Figure 1A). However the change in internal external rotation was not significantly different (Δ IE=0.5±6.3). A significant increase in cartilage deformation occurred at full extension, where a Δ Deformation of 7.3±3.0% was found in medial compartment, and 6.6±4.9% in lateral compartment (Figure 1B). The anterior laxity of the reconstructed knee as measured with the KT-1000 was similar to that of the intact contralateral (Δ IKDC=0.8±1.6).

Correlation of changes of anterior-posterior translations (Δ AP) and internal-external rotation (Δ IE) with changes of contact deformations is shown in Figure 2. Correlation coefficient (R) values are presented in Table 1. A very strong reverse correlation (R=-0.90) was detected between Δ deformation on medial side
and changes in internal rotation (Δ IE). Also, a moderate reverse correlation was detected between Δ IKDC and Δ deformation on lateral side; (R=-0.74).

**Discussion:** It was demonstrated that knee joint kinematics and its contact deformation after clinically successful ACL reconstruction were not restored to those measured in intact contralateral knees at lower flexion angles during a weightbearing single leg lunge. Many clinical studies have demonstrated that AP stability can be restored after ACL reconstruction. But, cadaveric studies showed that contemporary single bundle ACL reconstruction restores anterior tibial translation under anterior tibial load with different forces (both magnitude and orientation) in the graft compared to the intact ACL [3], as many having reported ACL graft failures that could be resulted from overloading the ACL grafts [5]. The elevated graft forces would change the loading on the cartilage surfaces and could contribute in long-term joint degeneration of ACL reconstructed knees. Therefore, a future anatomic ACL reconstruction should not only restore the normal stability of the ACL injured knee, but also restore the knee function using similar forces experienced by native ACLs.

**Significance:** Increases cartilage contact deformation is found negatively correlated with the residual laxity of the knee after ACL reconstruction. A future anatomic ACL reconstruction should not only restore the normal stability, but also restore the knee function using similar forces experienced by native ACLs.

![Figure 1: Changes of ACL-reconstructed knees relative to intact contralateral knees: (A) Changes in kinematics; (B) Changes in contact deformation in medial and lateral compartments.](image-url)
Figure 2: Correlation of changes (postoperative relative to preoperative states) of (A) anterior-posterior translations (Δ AP) and (B) internal-external rotation (Δ IE) with changes of contact deformations (medial and lateral condyles)
Table 1: Correlation of changes of kinematics, cartilage deformation and IKDC results after ACL reconstruction, ($\Delta$ indicates the change of ACL-reconstructed state relative to intact state).

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<th>Correlation Coefficient (R)</th>
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<tr>
<td></td>
<td>$\Delta$ (AP)</td>
</tr>
<tr>
<td>$\Delta$ (Deformation); Medial (Recon-Intact)</td>
<td>-0.54</td>
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<tr>
<td>$\Delta$ (Deformation); Lateral (Recon-Intact)</td>
<td>0.36</td>
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