# Excellent Clinical Outcomes More Than 10 years After Quadriceps ACL Reconstruction Despite Persistent Individual Side-to-Side Differences in Patellofemoral Joint Kinematics

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**INTRODUCTION:** Altered patellofemoral (PF) joint kinematics have been reported in the early-term after anterior cruciate ligament (ACL) reconstruction (ACLR), and altered PF kinematics may contribute to the high prevalence of PF joint osteoarthritis (OA) in patients after ACLR [1, 2]. Although clinical manifestations of PF OA typically occur 5–15 years after ACLR [3, 4], previous evaluations of PF kinematics after ACLR have been limited to within 15 months postoperatively and found average side-to-side differences as large as 3 mm in translation and 7° in rotation [1, 2, 5]. The purpose of this study was to investigate PF joint motion during stair ascent more than 10 years after ACLR. It was hypothesized that PF joint motion would remain altered compared to the contralateral healthy side at a minimum of 10 years after ACLR.

**METHODS:** This study enrolled patients from a previous randomized controlled trial [6, 7] in which patients underwent primary anatomic ACLR using single- or double-bundle techniques with a quadriceps tendon autograft. Exclusion criteria for this follow-up study included ACL revision surgery or knee arthroplasty. Knee kinematics were assessed at a minimum of 10 years postoperatively. Synchronized biplane radiographs of both the ACL-reconstructed and the contralateral knees were obtained at 100 frames per second while participants walked up standard 19 cm (7.5 in) stairs. Among three trials conducted for each limb, the trial with the highest image quality was selected for this analysis. Volumetric and surface models of the femur, tibia, and patella were generated through segmentation of CT scans (Mimics, Materialize, Inc., Leuven, Belgium). Automated methods were used to establish coordinate systems in the femur, tibia, and patella [8, 9], and a validated model-based tracking system [10, 11] was employed to determine the 3D positions and orientations of each bone, enabling calculation of joint kinematics in accordance with established protocols [12]. The kinematic parameters analyzed included PF flexion, rotation, tilt, medial/lateral translation, proximal/distal translation, and anterior/posterior translation during stair ascent. Statistical parametric mapping (SPM) was employed to compare PF joint kinematics between the ACL-reconstructed and contralateral knees within subjects with significance was set at $P < 0.05$. Peak and average absolute side-to-side differences were calculated for each patient. The presence and severity of PF joint OA were evaluated on plain radiographs using a skyline view and graded according to the Kellgren-Lawrence (K-L) classification [13].Clinical outcomes at 10 or more years after ACLR were assessed using the Knee Injury and Osteoarthritis Outcome Score (KOOS) [14], the International Knee Documentation Committee (IKDC) subjective score [15], and the Marx activity scale [16]. Bilateral anterior tibial translation was measured with a KT-1000 arthrometer, and differences between the ACL-reconstructed and contralateral knees were evaluated using the Wilcoxon matched-pairs signed rank test. This study was approved by the university Institutional Review Board.

**RESULTS:** Ten subjects from the initial randomized control trial have been included (mean age at surgery, 26.3 ± 8.7 years; 2 (20%) females; 3 (30%) single-bundle ACLR). Clinical outcomes and stair ascent were evaluated at 12.0 ± 0.6 years after surgery, and no patients demonstrated PF joint OA of greater than K-L grade 2 **(Table 1)**. No significant kinematics differences were observed between the surgical and contralateral knees, with all mean differences in translation and rotation ≤ 2.7 ± 1.1mm and ≤ 3.2 ± 2.1°, respectively (**Figure 1**). However, at the individual level, peak side-to-side differences were as high as 5.8 mm and 6.2° (**Table 2**). The mean KOOS was 85.1 ± 11.1%, IKDC subjective score was 84.9 ± 14.4%, and participants scored an average of 7.7 ± 4.8 on the Marx activity scale. KT-1000 measurements showed no statistically significant differences between surgical and contralateral knee (2.1 ± 1.1 mm vs 2.1 ± 1.1 mm; $P > 0.99$).

**DISCUSSION:** The primary finding of this study was that, for the overall group, no side-to-side differences in PF kinematics were detected during stair ascent at more than 10 years after ACLR, however, on an individual level, peak side-to-side differences averaged up to 5.8mm and 6.2°. These results are consistent with a recent report showing no differences in PF kinematics during gait between ACLR and contralateral intact knees at 6-15 months post-surgery [5]. The average peak side-to-side differences we found were slightly larger than previously reported early-term differences in PF kinematics of 2–3 mm in lateral translation and 3–5° in rotation during functional tasks [1, 2]. The absence of persistent group-level deviations, but substantial within-patient differences, suggests that long-term side-to-side differences in PF kinematics after ACLR are patient-specific in terms of size, direction, and timing within the movement cycle. Nevertheless, in this dataset, despite the presence of kinematic asymmetries, patients achieved excellent long-term clinical outcomes.

**SIGNIFICANCE/CLINICAL RELEVANCE:** At more than 10 years after ACLR, PF kinematics appear to be restored at the group level, however, substantial patient-specific asymmetries exist. Nonetheless, these kinematics asymmetries do not appear to compromise long-term clinical outcomes.

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**Table 1.** Patient demographics and baseline characteristics[a]

| Characteristics | Values |
|---|---|
| Body mass index (kg/m$^2$) | 28.5 ± 3.2 (range, 22.3–35.5) |
| PF pain (y/n) | 0 / 10 |
| PF crepitus (Grade 0/1/2/3) [b] | 3 / 7 / 0 / 0 |
| K-L grade of PF joint (0/1/2/3/4) | 4 / 4 / 2 / 0 / 0 |

[a]Data are expressed as mean ± SD unless otherwise noted. PF, patellofemoral; K-L, Kellgren-Lawrence.

[b]Grading system of crepitus (grades 0–3): grade 0, absent; grade 1, mild (palpable); grade 2, moderate (palpable and soft audible); grade 3, severe (palpable and loud audible).

**Table 2.** Peak and mean individual absolute side-to-side differences in PF kinematics[a]

| PF kinematics | Peak $SSD_A$ | Mean $SSD_A$ |
|---|---|---|
| Flexion (°) | 5.6 ± 1.4 | 2.9 ± 0.8 |
| Rotation (°) | 5.7 ± 3.5 | 2.7 ± 2.1 |
| Tilt (°) | 6.2 ± 2.1 | 3.3 ± 2.1 |
| Medial/lateral translation (mm) | 5.8 ± 1.9 | 2.7 ± 1.1 |
| Proximal/distal translation (mm) | 4.0 ± 1.0 | 1.9 ± 0.8 |
| Anterior/posterior translation (mm) | 2.3 ± 1.2 | 1.1 ± 0.8 |

[a]Data are expressed as mean ± SD. PF, patellofemoral; $SSD_A$, absolute side-to-side difference.

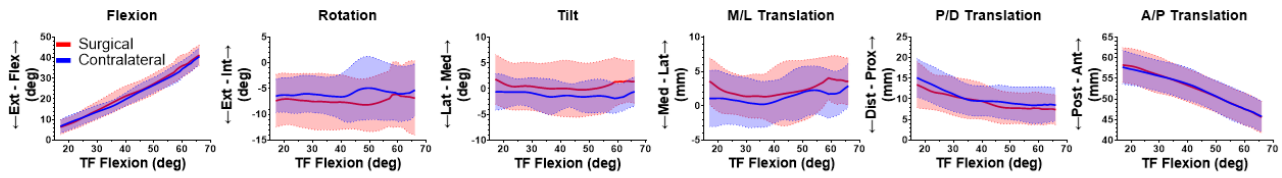


**Figure 1.** Average PF kinematics of the surgical and contralateral knees during stair ascent. Shaded regions indicate one standard deviation. No significant side-to-side differences were observed more than 10 years after surgery. PF, patellofemoral; TF, tibiofemoral; M/L, medial/lateral; P/D, proximal/distal; A/P, anterior/posterior.