In-vivo Kinematics of the Knee 3 Years after ACL Reconstruction

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Introduction: Anterior cruciate ligament (ACL) is the most commonly injured ligament of the knee joint. More than 125,000 ACL reconstructions are performed each year in the US alone [1]. However, a majority of those patients will suffer post-operative osteoarthritis in the reconstructed knee [2]. Abnormal knee kinematics after the surgery has been assumed to be a major biomechanical factor causing joint degeneration. This study was designed to investigate the in-vivo 6DOF kinematics of the ACL injured knees pre-operatively and 3-years post-operatively, and compared the kinematics data with those of intact contralateral knee.

Methods: Ten unilateral ACL-injured patients (gender: 5M, 5F; age: 36.7 ± 9.3 yrs; body weight: 74.9 ± 8.6kg; body height: 171.3 ± 5.9cm; BMI: 25.5 ± 2.8) were recruited in this study with IRB approval. Prior to surgery, both injured and contralateral healthy knees were MRI-scanned using a 3-Tesla MR scanner (MAGNETOM Trio, Siemens, Malvern, PA) and the MR images were used to construct 3D knee joint models. All subjects then performed a step-up motion (14 cm high) and the knee motion was imaged using a dual-fluoroscopic imaging system (Fig. 1). The 3D knee joint poses along the step-up path were reproduced using a 2D-to-3D registration procedure [3]. The patient then underwent an ACL reconstruction surgery normal performed in our clinic. Each patient performed the step-up motion again 3 years after the operation (follow-up time: 3.4 ± 0.2 yrs). We analyzed the 6DOF kinematics of the contralateral healthy knee, the injured knee, and the knee 3 years after operation. All motion patterns were described as femur with respect to tibia. A repeated ANOVA was used to analyze the kinematic data at every 20% of the motion path and the significance level was set as p<0.05.
Results: At beginning of the step up, the knee flexion angles were 57.2±5.2°, 53.6±3.7°, and 56.6±4.9° for the healthy, injured, and reconstructed knees, respectively, and were 4.1 ± 5.4°, 6.9 ± 6.0°, and -2.0 ± 3.8° at the end of the step up activity, respectively (Fig. 2a). The reconstructed knees extended significantly more than the pre-operative knees at 100% of the step-up. There were no significant differences in axial and varus-valgus rotations among the 3 knee conditions (Figs. 2b and 2c).

At the end of the step-up activity, the femur was at -2.8 ± -3.5, -3.9 ± 3.0, and -4.0 ± 3.9 mm positions in anterior-posterior direction for the healthy, injured, and reconstructed knees, respectively without statistical differences among these knees (Fig. 2d). In medial-lateral direction, the reconstructed knees showed larger medial femoral translation along the motion path than the healthy and injured knees (Fig. 2e). In superior-inferior direction, the reconstructed knees had lower femoral superior (more inferior) translation than other knees throughout the step-up, especially at the end of the activity (Fig. 2f).
Discussion: This study measured the 6DOF in-vivo kinematics of the knee after ACL reconstruction for at least 3 years. Comparing the data with those of the contralateral healthy knee and pre-operative injured conditions, the reconstruction restored the AP and rotational stabilities. However, the femur of the reconstructed knees had the trend to move more medially and more distally, especially at the end stage.
of the step-up activity. These kinematics variations after ACL reconstruction might imply a change in articular contact biomechanics. As indicated previously, the changes in medial-lateral translation may cause shifts of the tibiofemoral contact locations and cause impingement of the tibiofemoral contact at the tibial spine [4]. The increased inferior femoral translation implied an increase in cartilage contact deformation at the tibiofemoral joint. Future study is warranted to investigate the post-operative cartilage deformation and the development of cartilage degeneration of these patients using advanced T1ρ/T2 relaxation mapping techniques.

Significance: The data indicated that the ACL reconstruction restored the stability of the knee, but may not restore the cartilage contact biomechanics which is a biomechanical factor for joint degeneration. Future ACL reconstruction surgery should not only restore the joint stability, but also the cartilage contact deformation.

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