Controlling Anterior Tibial Translation: *In Vivo* Evidence For Anterior Closing-Wedge Osteotomy In Revision ACL Reconstruction

Kohei Kamada[1,2,3], Tom Gale[2], Koji Nukuto[1,2,3], Anja Wackerle[1,2], Mahmut Enes Kayaalp[1], William Anderst[2], Volker Musahl[1], Jonathan D. Hughes[1]
[1] Department of Orthopedic Surgery, University of Pittsburgh Medical Center, Pittsburgh, Pennsylvania, USA, [2] Biodynamics Laboratory, University of Pittsburgh, Pittsburgh, Pennsylvania, USA, [3] Department of Orthopaedic Surgery, Kobe University Graduate School of Medicine, Kobe, Japan
Presenting Author Contact Information: kok44@pitt.edu
Disclosures: Kamada (N), Gale (N), Nukuto (N), Wackerle (N), Kayaalp (N), Hughes (N), Musahl (N), Anderst (N)

INTRODUCTION: Emerging evidence suggests that a high posterior tibial slope (PTS) is associated with increased risk of anterior cruciate ligament (ACL) graft failure after primary or revision anterior cruciate ligament reconstruction (ACLR) [1,2]. Recent studies suggested an anterior closing-wedge slope reducing high tibial osteotomy (ACWHTO) could decrease the risk of ACL graft failure in patients with failed ACLR and high PTS [3,4]. Cadaveric studies suggested that ACWHTO reduced anterior tibial translation (ATT) and ACL graft force [5,6], and good clinical outcomes were reported in patients [3,4]. However, the effect of ACWHTO on *in vivo* joint kinematics remains unclear. The purpose of this study was to determine the changes in tibiofemoral kinematics in the operative knee following revision ACLR combined with ACWHTO at 6 months follow-up. Our hypothesis was that ACWHTO would decrease ATT but it would not affect other kinematics including knee flexion, internal/external rotation, or adduction/abduction during gait and running.
METHODS: This is an ongoing prospective single cohort study. Written informed consent was obtained from all participants. Inclusion criteria included patients with ACL graft failure and PTS greater than 12° who were scheduled for revision ACLR and ACWHTO. Exclusion criteria were age under 14 years, skeletal immaturity, previous HTO, or primary ACL injury. Both knees were imaged within a biplane radiography imaging system (150 images/second, 1ms exposure per image) for three trials per knee during walking (self-selected pace) and downhill running (10° slope at 3 m/s) on an instrumented treadmill. Tibiofemoral motion was tracked with an accuracy of better than 1mm and 1° using a previously validated volumetric model-based tracking process that matched computed tomography (CT)-based subject-specific three-dimensional (3D) bone models to the synchronized biplane radiographs. CT scans were collected preoperatively and postoperatively to create patient-specific bone models. Anatomic coordinate systems were created on the contralateral femur and tibia and mirrored onto the operative femur and tibia after co-registering corresponding 3D bone models [7] to ensure any observed differences were due to kinematics and not due to coordinate system orientation. The preoperative affected side anatomical coordinate system was copied to the postoperative model via rigid 3D model registration so no change in coordinate system orientation occurred from preoperative to postoperative. Tibiofemoral kinematics during stance were calculated following standard conventions [8] and interpolated to 1° increments of knee flexion to allow comparison among test dates and between knees [9]. Biplane radiography was collected preoperatively and at 6 months postoperative in the same laboratory under the same test conditions. Postoperative tibiofemoral kinematics in the operative knee were compared to tibiofemoral kinematics preoperatively as well as the contralateral knee. After averaging the values from the three trials for each subject on each test date, linear mixed model analysis was used to compare bilateral knee kinematics pre and postoperative. Fixed effects were test session (pre and postoperative) and side (operative or contralateral). When significant differences in test session, side, or their interaction were found, kinematics values were compared at every 10% increment in stance.
RESULTS: Thus far, 5 of 7 enrolled participants have completed preoperative and 6-month postoperative testing (2 men and 3 women, average age: 27.8 ± 2.4 years, mean BMI: 25.9 ± 2.4kg/m^2). A total of 60 walking and 60 downhill running trials were included in this analysis. Preoperative PTS ranged from 12 to 17°, and postoperative PTS was reduced to between 0 and 6°, resulting in PTS corrections of 5 to 12°. Contralateral PTS ranged from 7 to 17°. During walking, no significant differences in knee flexion were found between the affected and contralateral knees both pre and postoperatively. During running, the affected knee at 6 months postoperatively was less flexed than the contralateral side postoperatively at 40% and 50% of stance (mean difference 3.4°, p=0.03). During walking, the preoperative affected knee showed significantly greater ATT compared to the preoperative contralateral knee between 50 and 80% of stance (mean difference 3.3mm, p<0.01). The 6 months postoperative affected knee showed significantly less ATT compared to the preoperative knee throughout most of stance (mean difference 5.9mm, p<0.01), however, the 2.6mm difference between postoperative affected and postoperative contralateral knee was not significant (**Figure 1A**). During running, no difference in ATT was found between the preoperative affected knee and the preoperative contralateral knee (mean difference 1.1mm, p=0.09). However, the postoperative affected knee had an average of 5.8mm less ATT than the preoperative affected knee between 20 and 80% of running stance (p<0.01), and also an average of 4.4mm less ATT than the contralateral knee between 40 and 60% (p<0.01) (**Figure 1B**). In terms of internal/external rotation, during walking, the postoperative affected knee showed an average of 5.8° more tibial external rotation than the postoperative contralateral side at 10, 20, 30, 40, and 100% of stance (p<0.01) (**Figure 1C**). During running, the postoperative affected knee showed an average of 7.7° more tibial external rotation than the postoperative contralateral side from 0 to 90% of running stance (p<0.01) (**Figure 1D**). No statistically significant differences in adduction/abduction were found between the postoperative and the preoperative condition or the contralateral side.
DISCUSSION: The important findings of this interim analysis were that revision ACLR combined with ACWHTO effectively reduced ATT during gait and downhill running, however, the tibia remained more externally rotated compared to the contralateral side, both during walking and running. This persistent external rotation after ACLR+ACWHTO was similar to the residual external tibial rotation previously reported after primary ACLR [10]. One-year follow-up is ongoing to determine if the short-term effects of ACWHTO on ATT are maintained after 1 year postoperative and can thereby reduce the risk of ACL graft failure after return to sport.
CLINICAL RELEVANCE: This study provides *in vivo* evidence that revision ACLR combined with ACWHTO suppresses excessive ATT in high-PTS patients, supporting its use to reduce potential ACL graft failure risk.
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IMAGES AND TABLES:

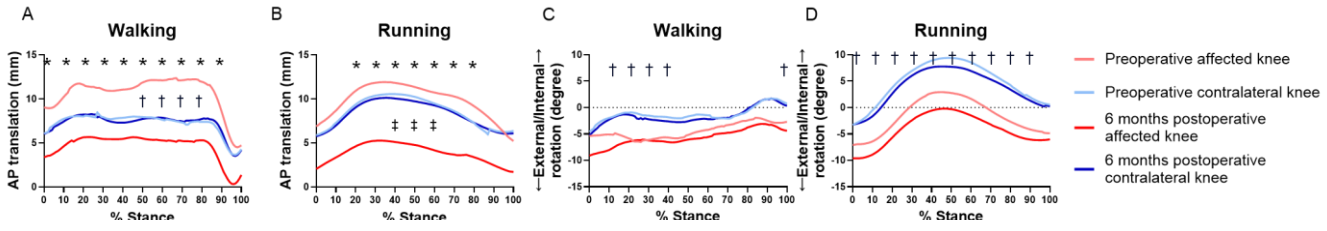

Figure 1A,B. Anterior tibial translation during walking (A) and running (B). **Figure 1C,D.** Internal/external rotation during walking (C) and running (D). Asterisks (*) indicate a significant difference between the preoperative and 6-month postoperative affected knees. Daggers (†) indicate a significant difference between the preoperative affected and contralateral knees. Double daggers (‡) indicate a significant difference between the 6-month postoperative affected and contralateral knees.