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Tibial Rotation is Not Restored after ACL Reconstruction with a Hamstring Graft

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Recent research suggests ACL reconstruction does not restore tibial rotation to normal levels during high demand activities when a bone-patellar tendon-bone graft is used. We asked if an alternative graft, the semitendinosus-gracilis (ST/G) tendon graft, could restore tibial rotation during a high demand activity. Owing to its anatomic similarity with the normal ACL we hypothesized the ST/G graft could restore excessive tibial rotation to normal healthy levels along with a successful reinstatement of the clinical stability of the knee. We assessed tibial rotation in vivo, using gait analysis. We compared the knees of ACL reconstructed patients with an ST/G graft to their intact contralateral and healthy controls during a pivoting task that followed a stair descent. We also evaluated knee stability after ACL reconstruction with standard clinical tests. ACL reconstruction with the ST/G graft and with current techniques did not restore tibial rotation to previous physiological levels during an activity with increased rotational loading at the knee, although abnormal anteroposterior (AP) tibial translation was restored.

Previous in vivo studies report increased rotation[2,12] in ACL-deficient patients. One study suggests ACL reconstruction using a bone-patellar tendon-bone graft can restore tibial rotation in low demand activities (eg, walking).[12] However, in higher demand activities (eg, landing and pivoting), this graft seems unable to restore pathological tibial rotation to normal values.[4,19,20] These findings could be attributed to BPTB graft morphologically having a more uniform anatomy, and therefore apparently unable to simulate correctly the oval shape of the natural ACL. During the last decade, many surgeons have used hamstrings as a graft source, mostly in the form of a four-strand semitendinosus/gracilis (ST/G) graft, as an alternative for the BPTB graft. The ST/G graft, compared with the BPTB, has some mechanical properties (superior strength, stiffness, and round-shape morphology) that fit better to the oval-shape morphology, strength, and stiffness of the natural ACL.[13,21] Due to these properties, it is possible that the ST/G graft can overcome the problems with the BPTB, and restore pathological tibial rotation to the previous healthy normal levels during high demand activities.

However, recent in vitro studies[15,16,27] suggest current ACL reconstruction procedures using an ST/G graft are successful in limiting AP tibial translation but fail to restore tibial rotation. We therefore expanded our past research[12,19,20] by investigating whether tibial rotation remains excessive in patients with an ST/G-graft reconstructed ACL. As in our past research, we evaluated the maximum range of motion (ROM) of tibial rotation after descending from a stairway and during subsequent pivoting. Consequently, we were able to evaluate the function of the replacement graft in response to combined anterior translational and rotational tibial loading. The application of such loads at the knee can provide us with additional insights into functional recovery after an ACL reconstruction.

We hypothesized the ST/G graft could restore excessive tibial rotation to normal healthy levels because of its anatomic similarity with the natural ACL. We also hypothesized the ST/G graft will successfully restore the clinical stability of the knee as measured with standard orthopaedic tests (Lachman, pivot-shift, IKDC).

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Each author certifies that his or her institution has approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research, and that informed consent was obtained.

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MATERIALS AND METHODS

We evaluated maximum range of tibial rotation during a pivoting activity, an ACL reconstructed group with an ST/G graft and a healthy control group, in order to see if tibial rotation is restored to normal healthy levels in the ACL reconstructed group during this high demand activity. With the aid of a six-camera opto-electronic system, we observed the movement patterns of the subjects while descending a stairway, subsequently pivoting on the landing leg at 90° and walking away from the stairway. The pivoting period was identified from initial foot contact with the ground of the ipsilateral leg until touchdown of the contralateral leg. All subjects were also clinically evaluated with standard orthopedic tests to assess the ability of the ST/G graft to restore the clinical stability of the knee after the reconstruction. Based on our hypotheses, we examined the clinical tests and the maximum ROM of tibial rotation during the pivoting evaluation period as our dependent variables.

The ACL group included 11 men (mean ± standard deviation; age 26 ± 9 [range 20–44 years]; mass 77 ± 12 [range 64–97 kg]; height 1.76 ± 0.1 [range 1.65–1.94 m]. The mean time from injury to surgery was 5 ± 3 months [range 1–12 months]; the mean time from surgery to testing 9 ± 0.3 [range 9–10 months]) with ST/G reconstructed knees. The control group included 11 age, height, and mass-matched men with no history of musculoskeletal or neurological conditions (mean ± standard deviation. The mean age was 29 ± 5 [range 20–36 years]; mean mass 76 ± 7 [range 64–88 kg]; mean height 1.76 ± 0.09 [range 1.65–1.92 m]). The ACL reconstructed patients were selected. We excluded patients with meniscal injuries in which a meniscectomy or a suture of the meniscus was performed, chondral lesions, posterior cruciate or collateral ligament injury, symptomatic anterior knee pain, or objective instability at the latest followup examination (positive pivot-shift test result, positive Lachman-test result and arthrometer KT-1000 side-to-side differences of more than 3 mm). All subjects agreed with the testing protocol and gave their consent in accordance with University policies.

The ACL-reconstructed patients underwent an arthroscopically assisted ACL reconstruction using an ST/G graft. All patients with a reconstructed ACL underwent the same rehabilitation protocol, using a continuous passive motion device from the first postoperative day until they were discharged from the hospital. Active exercises also started during their hospital stay and were followed by a standardized accelerated rehabilitation protocol. Sport-related activities were permitted 24 weeks after reconstruction, provided the patients had regained full functional strength and stability.

Before any data collection, one clinician (AG) performed a clinical evaluation in all subjects. The clinician obtained Tegner and Lysholm[25] and International Knee Documentation Committee (IKDC)[14] scores during the evaluation. In addition, we evaluated anterior tibial translation using the KT-1000 knee arthrometer (MEDmetric Corp, San Diego, CA) for the patients with ACL reconstruction and the healthy controls.[7,24] The measurements were performed using 134 N posteroanterior external force at the tibia and maximum posteroanterior external force until heel clearance. Repeated anterior tractions were performed until a constant reading on the dial was registered.

All the subjects were operated on by the same orthopaedic surgeon (AG). The procedure was performed with the aid of an arthroscopic leg holder, which permitted full knee flexion-extension. After a 4 to 5 cm longitudinal skin incision over the pes anserinus, we harvested the semitendinosus and the gracilis tendon in all patients. While the graft was prepared by the assistant surgeon (VC), the senior surgeon (AG) proceeded with the endoscopic portion of the procedure. We created two portals, first the anterolateral (about 2 cm above the joint line immediately adjacent to the patellar tendon and his insertion at the patella) and then the anteromedial (at the same level above the joint line from 5 to 8 mm medial to the patellar tendon). We partially debrided the ACL stump, leaving a substantial portion to guide the tibial tunnel placement.

We drilled the tibial tunnel in the center of the ACL footprint. The tibial tunnel was drilled at an angle of 60º to the plateau, with a diameter of 8 to 10 mm for ST/G graft. Subsequently, we created the femoral tunnel through the anteromedial portal while flexing the knee 120°. A “bull’s eye” guide was used in order to preserve 1mm of posterior cortex. Then, we inserted the femoral guide pin at about 11 o’clock for the right knee and about 1 o’clock for the left knee, respectively. We used a 4.5 cannulated reamer (Smith & Nephew Endoscopy, Andover, MA) to drill the total femoral cortex and then measured the femoral tunnel. The length of the inserted graft was 2 to 2.5 cm in the femoral tunnel, and the drilling was 5 to 6 mm deeper than the graft insertion to allow for the turning radius of the EndoButton (Smith & Nephew Endoscopy, Andover, MA).

The final step was passing the graft through the tunnels and graft fixation. We secured the graft at the anterolateral cortex of the distal femur with the EndoButton and fixated it at the tibial tunnel with a bioabsorbable screw, which we secured with the knee flexed at 20° to 30°. We inspected the graft in full flexion and full extension to exclude graft impingement at the notch and at the posterior cruciate ligament. We did not perform a notch-plasty in any of our patients.

We used a six-camera optoelectronic system (Peak Performance Technologies, Inc., Englewood, CO) sampling at 50 Hz to capture the movements of 15 reflective markers placed on the selected bony landmarks of the lower limbs and the pelvis placed according the model described by Davis et al.[9] At the time of data collection, no clinical evidence of knee pain was found in the patients with reconstructed ACLs and all had resumed their daily living functions and their sports activities; pain was determined by the evaluating physician (VC), after a short clinical examination and questioning of the patients. All subjects were given enough time (10 minutes) to warm up and familiarize themselves with walking and ascending-descending on a stairway including three consecutive steps. We constructed the stairway according to guidelines for the dimensions and the number of the steps as provided by Andriacchi et al.[1] The subjects were asked to descend the three steps at their own pace. The descent period was concluded upon initial foot contact with the ground. After foot contact, the subjects were instructed to immediately pivot (externally rotate) on the landing (ipsilateral) leg 90° and walk away from the stairway. While pivoting, the contralateral leg was swinging around the body (as it was coming down from the stairway) and the trunk was oriented perpendicular to the stairway. None of the subjects reported pain or discomfort during the experiment.

The subjects continued to walk at least five consecutive strides. The pivoting period was identified from initial foot contact with the ground of the ipsilateral leg until touchdown of the contralateral leg. Each subject performed at least six trials for both legs. We initiated data collection at the top of the stairway and included the descending period, the subsequent pivoting, and the five walking strides. To validate our procedures and minimize errors reported in the literature[5,18] regarding video capture of external skin markers, we recorded an additional trial with the subjects in the anatomical position, which was used as the reference for the calculation of the anatomical angles. The subjects were instructed to stand in the anatomical position in a purpose-built mold with their feet parallel and 15 cm apart. This calibration procedure allowed for correction of subtle misalignment of the markers defining the local coordinate system. In addition, it provided a definition of zero degrees for all segmental movements in all planes.

Marker identification and angular displacement calculations were conducted using the Peak Performance software (Motus v.4.3.3; Peak Performance Technologies, Inc, Englewood, CO). Spot checking calibration assessment showed a maximum three-dimensional standard deviation error in marker reconstruction of 0.303 mm. All data were smoothed using the cross validated quintic spline.[26] Anthropometric measurements were combined with three-dimensional marker data from the anatomical position trial to provide positions of the joint centers and define anatomical axes of joint rotations.[9] The position of the reflective markers during the movement provided the three-dimensional segmental angles. The angular displacement of the tibial rotation was retained and the maximum and minimum points during the evaluation period were identified. These two points were subtracted to acquire the maximum range of motion for tibial rotation.

Based on our hypothesis maximum ROM of tibial rotation during the identified evaluation period as the primary dependent variable (Fig 1). A paired t test between the left and right sides within the control group revealed no differences ($p < 0.05$) for this variable, and therefore we selected the left side as the representative for the control group. Subsequently, independent t tests were used to examine differences between the healthy control knee and the intact knee of the reconstructed ACL group, and between the healthy control knee and the reconstructed knee of the reconstructed ACL group. Finally, a paired t test was used to examine differences between the reconstructed leg and the contralateral intact leg in the reconstructed ACL group (a 0.05).

RESULTS

All patients resumed their preinjury level of sports participation. The median Lysholm score was 92 (range, 87–95) and median Tegner score was 7 (range, 6–8) after surgery. For the healthy controls, the median Lysholm score was 98 (range, 96–100) and the Tegner score was 8 (range, 8–9).

The ACL reconstruction with an ST/G graft did not restore excessive tibial rotation to normal healthy levels. The reconstructed leg demonstrated a greater amount of tibial rotation compared with the intact leg (p 0.002), as well as compared with the control knee (p 0.011) (Figs 2, 3). In addition, we found no difference in the amount of tibial rotation between the healthy leg of the control group and the intact leg of the reconstructed ACL group (p 0.892) (Figs 2, 3).

Negative Lachman and pivot-shift tests indicated that clinical stability of the knee was regained. The results from the KT-1000 showed the mean difference between the anterior tibial translation of the reconstructed and intact sides in the reconstructed ACL group was 1.1 mm (range, 0.5–2 mm) for the 134 N test and 1.3 mm (range, 1–2 mm) for the maximum manual test, respectively. The IKDC score was scaled as normal (A) for all the patients.

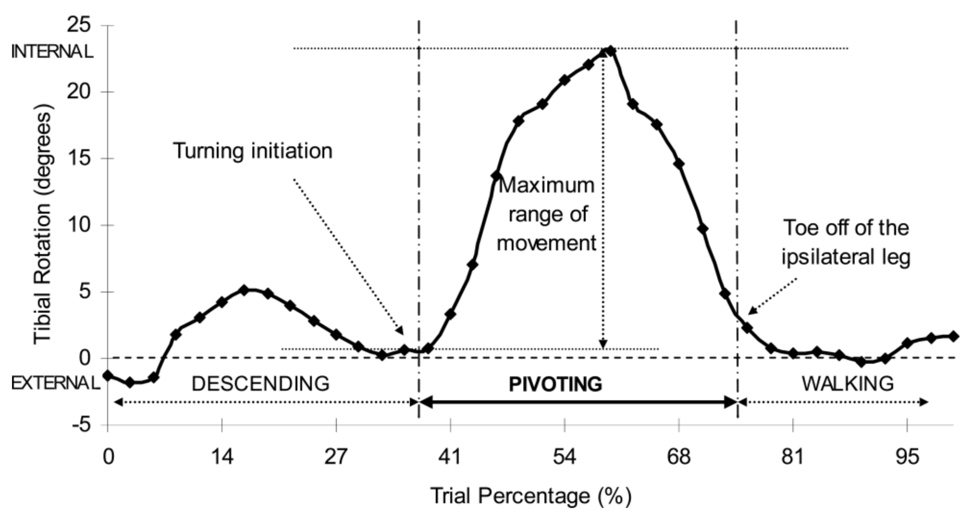

Fig 1. A typical tibial internal/external rotation curve during the study period is shown for an ACL-reconstructed patient with an ST/G graft. The difference between the maximum and minimum tibial rotation during the pivoting period is indicated. This difference was used as the dependent variable in this study. For this subject, the amount of tibial rotation during the pivoting period is 22°.

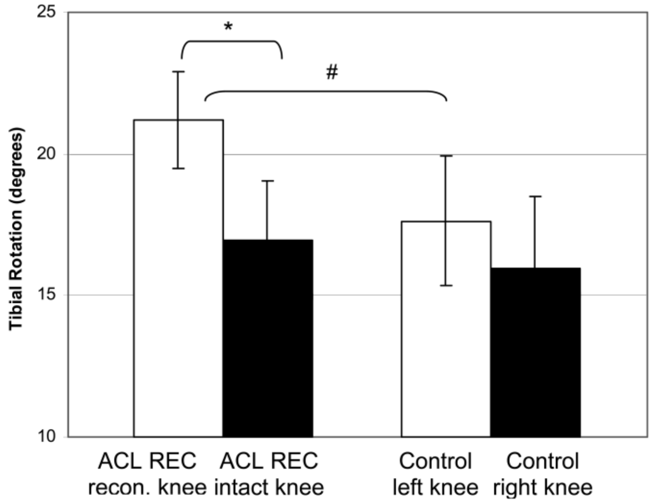

Fig 2. The reconstructed leg revealed a greater amount of tibial rotation compared with the intact contralateral leg, as well as compared with the healthy control. The bars demonstrated the group means and standard deviations for the maximum range of motion of the tibial rotation during the pivoting period. The asterisk (*) indicates the difference (p = 0.002) between the intact and reconstructed sides in the ACL-reconstructed group (ACL REC), while the pound sign (#) indicates the difference (p = 0.011) between the control knee and the ACL-reconstructed knee.

DISCUSSION

We investigated the effect of an ACL reconstruction with an ST/G graft on tibial rotation after descending a stairway and during subsequent pivoting. We hypothesized the ST/G graft could restore excessive tibial rotation to normal healthy levels because of its anatomic similarity with the normal ACL. We also hypothesized the ST/G graft will successfully restore the clinical stability of the knee as measured with standard orthopaedic tests (Lachman, pivot-shift, IKDC). The results refuted our first hypothesis but supported the second. Even though clinically the knee is stable using standard orthopaedic tests, our in vivo evaluation showed tibial rotation after an ACL reconstruction with an ST/G graft is not restored during high demand activities. These results are in agreement with previous in vitro studies[15,16,27] that have shown current ACL reconstructions using an ST/G graft are successful in limiting anterior tibial translation but fail to restore tibial rotation. Furthermore, the amount of excessive tibial rotation (4 to 5°) in our study is similar to that identified in our previous in vivo evaluations of BPTB grafts with a similar experimental protocol.[19,20]

The main limitations of this study are those related to gait analysis,[18,19] particularly with regard to movement of skin markers and their ability to predict bone locations. Perhaps more importantly, gait analysis reflects more or less stereotyped movements that likely are not reflected by the large range of movements characterizing participation in sports. However, gait analysis is widely accepted and is now considered a well-established and reliable if limited method.[6,11] Furthermore, we tried to address these limitations with more careful experimental procedures. We minimized operator error by having the same clinician place all the markers and collect all the anthropometric measurements. The absolute three-dimensional marker reconstruction error of the system was very low (maximum SD, 0.303 mm; calibration space, approximately 8 m^3). We incorporated a standing calibration procedure to correct for subtle misalignment of the markers defining the local coordinate system to provide a definition of zero

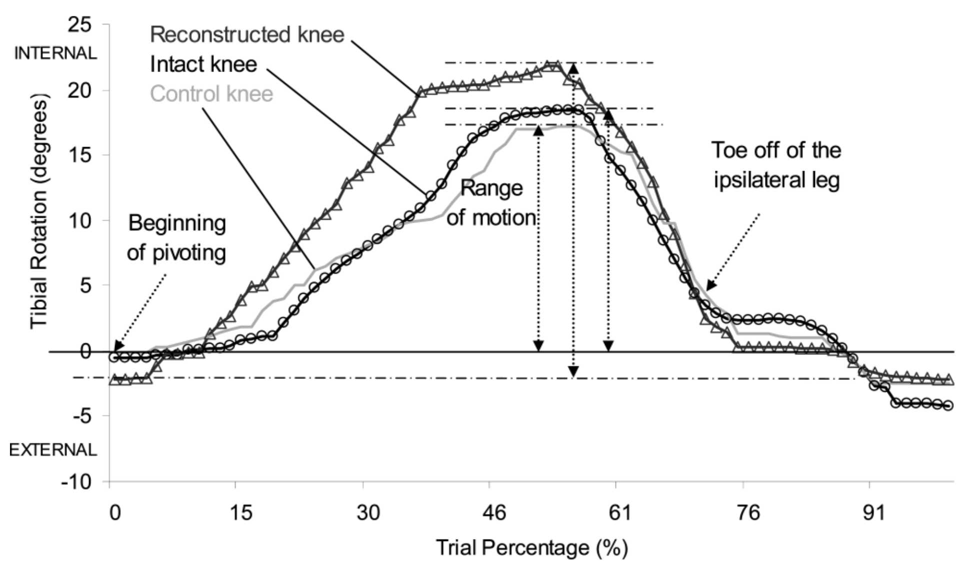

Fig 3. Time series curves for the intact and reconstructed knee from an ACL reconstructed subject and from a healthy control subject. The blue and red line curves represent respectively the intact and reconstructed knee from the ACL REC subject, while the green line curve represents the control subject. The maximum ROM of tibial rotation is 24° for the reconstructed knee, 19° for the intact contralateral knee and 18° for the healthy control knee.

degrees for all segmental movements in all planes. We incorporated a double control group since we used as controls both the intact leg of the reconstructed ACL group and a completely healthy group of subjects. Since the same instrumentation was used for all subjects, we can assume the level of measurement noise consistent for all subjects and any differences attributable to changes within the system itself.

A possible explanation for the results in our study may be the positioning of the graft placement. Woo et al[27] indicated in vitro tibial rotation is not restored after an ACL reconstruction with an ST/G graft when the graft is placed in the 11 o'clock position of the femur, because it primarily replicates the anteromedial bundle, not the posterolateral, resulting in inadequate resistive ability to rotational forces. Scopp et al[22] and Loh et al[16] have also shown in vitro a more oblique tunnel placement in the femur is more appropriate than the standard femoral tunnel placement regarding rotation. In these studies, the more oblique femoral tunnel placement (at 10 o'clock) resulted in less internal tibial rotation in comparison with the standard femoral tunnel placement. We placed the femoral tunnel at the 11 o'clock position. However, we are now performing ACL reconstructions with an ST/G graft and placing the femoral tunnel in a more oblique position, at about 10 o'clock. We have already initiated a study to examine if this technique will improve the in vivo kinematics of the ACL reconstructed knee.

Another possible explanation of the inability to restore tibial rotation to normal levels using the ST/G graft is the absence of complete reinstatement of the actual two-bundle morphologic anatomy of the ACL. With our current techniques, we imitate mostly the anteromedial bundle. The role of this bundle has been widely demonstrated to resist anterior translational loads. The posterolateral bundle, however, has not received sufficient attention. Gabriel et al[10] have shown the posterolateral bundle plays an important role in the stabilization of the knee against a combined rotatory load, which suggests the need for a more anatomical reconstruction designed to replicate both ACL bundles. This combined 2-bundle function does not seem to be restored with current single-bundle reconstruction techniques, affecting tibial rotation. However, further investigation of our in vivo methodology is warranted to clearly establish this conclusion.

Our results may also provide an intriguing explanation regarding the development of future pathology and deterioration of the ACL reconstructed knee observed not only longitudinally[8,23] but also shortly after the reconstruction.[3] It is possible that over time the abnormal rotational movement pattern of the articulating bones at the ACL reconstructed knee could result in deterioration of the articular cartilage of the joint. This may be due to the application of these rotational loads at areas of the cartilage not commonly loaded in a healthy knee.[28] These areas, because of insufficient cartilage strength, may not be able to withstand the newly introduced loading and, over time, the end result could be knee osteoarthritis. However, this theoretical proposition should be explored via both in vivo and in vitro studies.

We found the current ACL reconstruction technique using ST/G graft succeeds in limiting anterior tibial translation but cannot restore excessive tibial rotation during a high-demand activity. Alhough this graft has a superior mechanical profile compared to other grafts, it could not replicate the normal ACL in its actual anatomy and functional rotational abilities. The improvement and development of new surgical procedures and grafts seems the only way to address the problem of excessive tibial rotation.

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