Femoral Aperture Fixation Improves Anterior Cruciate Ligament Graft Function When Added to Cortical Suspensory Fixation

An In Vivo Computer Navigation Study

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Background: Recommendations for bone tunnel placement during anterior cruciate ligament (ACL) reconstruction have become more precise. However, these recommendations differ neither with the choice of graft nor with the method of fixation used. The influence of the method of femoral fixation used on the biomechanical function of a soft tissue ACL graft remains unknown.

Hypothesis: Our null hypothesis was that adding femoral aperture fixation to femoral cortical fixation, using the same bone tunnels, will not alter the control of anterior translation (AT) and internal rotation (IR) during ACL reconstruction using a hamstring graft.

Study Design: Controlled laboratory study.

Methods: A total of 22 patients with an acute isolated ACL rupture underwent reconstruction using a single-bundle autologous hamstring graft. Computer navigation was used intraoperatively to plot the AT and IR during the pivot-shift test before reconstruction, after ACL reconstruction using cortical suspensory fixation, and after the addition of femoral aperture fixation. Statistical analysis (analysis of variance) was used to compare the AT and IR during the pivot shift at each stage in the procedure.

Results: Before ACL reconstruction, the mean (±SD) AT was 14.2 ± 7.3 mm and mean IR was 17.2° ± 5.5°. After reconstruction using femoral cortical suspension, these figures were significantly reduced to 6.2 ± 3.5 mm and 12.5° ± 3.20°, respectively ($P < .001$). The addition of the aperture fixation was associated with a further significant reduction to 4.6 ± 3.2 mm and 10.4° ± 2.7°, respectively ($P < .001$).

Conclusion: The addition of femoral aperture fixation to suspensory fixation results in a significant reduction in both the AT and IR that occurs during the pivot-shift assessment immediately after ACL reconstruction using autologous hamstring graft.

Clinical Relevance: The most precise positioning of bone tunnels during soft tissue ACL reconstruction needs to take into consideration the type of fixation being used.

Keywords: ACL; femoral fixation; computer navigation; pivot shift

The outcomes after anterior cruciate ligament (ACL) reconstruction continue to improve, but the rate of recurrence after ACL reconstruction remains higher than the rate of ACL rupture in the contralateral knee.[24] Revision rates vary from 10% to 40%, and although some of these failures are not attributable to surgical technique, technical error is either the predominant or a contributing factor in at least 50% of cases. Of these technical errors, at least 80% are attributed to malpositioning of the femoral and/or tibial tunnels.[24]

Anatomic studies have described the ACL attachments to both the tibia and femur in detail.[2,5-9,39] The term *anatomic* is commonly used to refer to the positioning of the bone tunnels within these footprints. However, the footprints have a larger cross-sectional area than both the midsubstance of the native ACL and the autologous graft.[8] Therefore, there are potentially an infinite number of anatomic locations for the graft. Authors have recommended precise positioning of the bone tunnels based on the center of these footprints relative to various reference points, sometimes to the order of the nearest millimeter.[4,28,29,36,37,42,43] There may be an assumption

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that the center of the aperture will represent the location of the central and most functionally important fibers in the ACL graft. However, when a soft tissue ACL graft is used with femoral cortical fixation, the graft becomes concentrated eccentrically within the bone aperture in the direction in which the graft is pulled.[18] If the graft is fixed with an interference screw, this results in the graft being secured at the articular aperture of the tunnel and it is pushed eccentrically away from the center of the aperture. The direction in which the graft moves will depend on where the screw is positioned relative to the graft. The effect that this movement of the graft within the tunnel has on the function of the graft remains unknown.

The best accepted clinical measure of functional instability is the pivot-shift test, and its execution has been well described.[22,26,38] Unlike instrumented testing of knee laxity and the Lachman test, the severity of the pivot-shift test has been correlated with functional instability, patient dissatisfaction, activity limitation, poor knee function, limited sports participation, and lower functional knee scores.[16] Previously, the pivot shift lacked objective measurement. Computerized navigation has now enabled objective measurement of the pivot shift. Correction of the pivot shift has also been shown to correlate with improved functional outcome.[16] Using computer navigation, therefore, it is now possible to compare the effect of various types of graft fixation on the pivot-shift test and thus functional outcome.

The goal of the current study was to determine whether the addition of femoral aperture fixation to femoral cortical fixation influences the ability of the ACL reconstruction to reduce the anterior translation (AT) and/or internal rotation (IR) that occurs due the pivot-shift test. Our null hypothesis was that the addition of aperture fixation would not make a significant difference.

METHODS

During the period from March 1, 2015 to May 30, 2015, patients presenting to the main author (M.P.) with a ruptured ACL and who satisfied the inclusion and exclusion criteria were invited to take part in the study. The inclusion criteria were an isolated ACL rupture in a patient aged 18 to 65 years presenting within 4 weeks of the injury who was willing to take part in the study. The exclusion criteria were a history of previous ACL rupture, the presence of other injuries requiring the use of a splint or surgical intervention (other ligament injury, meniscal damage, chondral or osteochondral injury), patients unfit for general anesthesia, and those in whom ACL reconstruction was not indicated. Ethics approval was granted from an institutional quality, safety, and ethics committee. We recorded which knee was injured, patient sex, and age at presentation.

Surgical Technique

All reconstructions were performed within 6 weeks of injury. The procedure was performed under general anesthesia, and a tourniquet was used. A diagnostic arthroscopy was performed to confirm the diagnosis of isolated ACL rupture, and the stumps of the ACL were debrided. If there was an osteochondral lesion, meniscal lesion requiring repair or partial meniscectomy, or additional ligament rupture requiring surgery or the use of a brace, the patient was excluded from the study. The ipsilateral gracilis and semitendinosus tendons were harvested and used to make a quadrupled soft tissue graft. A navigated pivot-shift test was then performed on the ACL-deficient knee, as described previously.[31] The primary outcome measure was the amount of AT and IR that occurred.

Femoral and tibial bone tunnels were then drilled using reproducible arthroscopic anatomic landmarks.[31,33] The tibial tunnel was drilled using an Acufex Director Drill Guide (Smith & Nephew) set at 50°, and the articular aperture was centered on a point one-third of the way along a line joining the medial tibial spine to the anterior horn of the lateral meniscus. The femoral tunnel was drilled via the anteromedial portal. The aperture was positioned in the most posterior portion of the femoral footprint without violating the posterior wall of the femoral condyle. The center of the tunnel was adjusted to ensure that there was 1 mm of intact bone remaining posterior to the femoral tunnel aperture. The bone tunnels were drilled to the same size as the hamstring graft. An adjustable-loop suspensory device (ACL button; Arthrex) was used for cortical suspensory fixation. The hamstring graft was then hand-tensioned and the graft secured at the tibial end using a poly-L-lactic acid–hydroxyapatite (PLLA-HA) screw (BioRCI-HA; Smith & Nephew Endoscopy) with the knee in full extension and the screw positioned posterior to the graft. The tibial screw used was 30 mm in length, and its diameter was 1 mm larger than that of the tibial tunnel. We then repeated the navigated pivot-shift test, recording the amount of anterior translation (ATb) and internal rotation (IRb) that occurred after the cortical fixation.

Next, a 7 × 25–mm BioRCI-HA interference screw with an 8-mm head was placed in the femoral tunnel anterior to the ACL graft (standard thread for left knees, reverse thread for right knees). We then repeated the navigated pivot-shift test, this time recording the amount of anterior translation (ATs) and internal rotation (IRs) that occurred after the aperture fixation.

Navigation System

An infrared computerized navigation system was used (Braun Orthopilot; Braun Melsungen AG). The intraosseous pins used for fixation of the optical arrays were placed percutaneously into the distal medial femur and proximal medial tibia. The pivot-shift test was performed by applying an axial load with valgus and internal rotation force on the tibia and passively flexing the knee from full extension to 90° of flexion. This was repeated 5 times, and the mean AT and IR values were recorded. Martelli et al[25] demonstrated intrasurgeon repeatability to be less than 1 mm for AT and less than 1.6° for rotation in ACL-deficient and -reconstructed knees using optoelectronic navigation. The use of a similar navigation system has been described previously[31] and validated.[15,30]

TABLE 1
Anterior Translation (AT) and Internal Rotation (IR) Values for the Operated Knee Before Reconstruction, After Reconstruction With Femoral Suspensory Fixation, and After the Addition of Femoral Aperture Fixation[a]

Anterior Translation, mm, Mean ± SD			Internal Rotation, deg, Mean ± SD		
AT1	ATb	ATs	IR1	IRb	IRs
14.2 ± 7.3	6.2 ± 3.5[b]	4.6 ± 3.2[b]	17.2 ± 5.5	12.5 ± 3.2[b]	10.4 ± 2.7[b]

[a]AT1 and IR1, values before reconstruction; ATb and IRb, values after reconstruction with femoral suspensory fixation; ATs and IRs, values after femoral aperture fixation.
[b]Statistically significant difference compared with before reconstruction ($P < .05$).

Statistical Analysis

Statistical analysis was performed using SSPS (v22; IBM Corp). Analysis of variance (ANOVA) with paired-samples tests was used to compare AT before reconstruction (AT1) with that after reconstruction using the button (ATb) and with that after the addition of the interference screw (ATs). We also compared IR before reconstruction (IR1) with that after reconstruction with the button (IRb) and after the addition of the screw (IRs). The cut off for statistical significance was set at $P < .05$. A power analysis using generalized linear models was performed for each comparison and found that at least 17 patients were required for a power of 80% and alpha value of 5%.

RESULTS

Fifty-nine patients presented with an ACL rupture during the study period. A total of 22 patients satisfied the inclusion criteria and consented to take part in the study. The 37 patients excluded from the study were done so on the basis of previous ACL rupture (n = 8), meniscal injury (n = 16), other ligament injury (n = 6), chondral injury (n = 4), and osteochondral injury (n = 3).

Patient Demographics

There were 9 male and 13 female patients in the study. The mean age (±SD) was 25.1 ± 6.2 years. Ten of the injured knees were dominant and 12 nondominant.

Computer Navigation Results

The primary outcome measures were AT and IR during the performance of the navigated pivot-shift test. These are summarized in Table 1.

In the ACL-deficient knee prior to reconstruction, the mean (±SD) anterior translation (AT1) was 14.2 ± 7.3 mm. This value was significantly reduced after ACL reconstruction with both cortical fixation (ATb, 6.2 ± 3.5 mm) ($P < .001$) and aperture fixation (ATs, 4.6 ± 3.2 mm) ($P < .001$). ATs was significantly smaller than ATb ($P < .001$).

With regard to IR, the mean value was 17.2° ± 5.5° before reconstruction. This was reduced after both cortical fixation (IRb, 12.5° ± 3.2°) and aperture fixation (IRs, 10.4° ± 2.7°) ($P < .001$). IRs was significantly smaller than IRb ($P < .001$) (Table 1).

DISCUSSION

Our study demonstrates that when aperture fixation is added to suspensory fixation on the femoral side of an ACL reconstruction using autologous hamstring graft, there is a significant reduction in both AT and IR during the pivot-shift test. We therefore reject our null hypothesis on the basis that the addition of the femoral screw does alter the function of the soft tissue ACL graft. Although both methods of femoral fixation (suspensory and combined suspensory and cortical) resulted in significant reduction in the outcomes measures, the latter achieved a significantly greater reduction in both AT and IR.

The ideal study design would have enabled a comparison of cortical fixation with aperture fixation alone, using the same bone tunnels in the same patient. However, this would have resulted in an unacceptable prolongation of the operative time and potential damage to the autograft. In such an ideal design it would still have been impossible to ensure that the tension in the final construct was the same in both cases. The design used was an ethically acceptable compromise. Although the end result of the study used was a comparison of double- or "hybrid" fixation with suspensory fixation, the addition of the femoral screw moves the fixation point to the femoral tunnel aperture. Unless the construct is being tested to failure of the femoral screw fixation, the biomechanical performance of the hybrid fixation may be equivalent to that of the femoral aperture fixation. It would have been possible to perform the ideal study design on cadaveric knees but it cannot be assumed that the outcome in live patients will be the same as that seen in cadavers.

There are proponents for both methods of femoral fixation but a paucity of high-level research to support either method. To the best of our knowledge, there are no in vivo studies comparing femoral cortical fixation with femoral interference screw fixation using the same bone tunnels. Ibrahim et al[12] compared intratunnel femoral fixation with extratunnel fixation (or suspensory fixation) for soft tissue ACL reconstruction in a clinical trial in which patients were randomized to either group. At a mean follow-up of 30 months, they found less instrumented laxity with intratunnel fixation, which they attributed to more rigid fixation closer to the joint.[12]

Other reported benefits of aperture fixation relative to suspensory fixation include less movement of the graft within the bone tunnel, less tunnel widening, enhanced tendon-bone healing with more normal-appearing Sharpey fibers, less synovial fluid migration between the graft and the tunnel wall, and the potential for bone tunnel reossification.[§] Concerns with regard to the strength of the interference screw fixation include potential graft elongation, lower fixation strength, and reduced stiffness.[27] Hybrid fixation has been shown in laboratory studies to be stronger, in terms of ultimate tensile strength, stiffness, and slippage, than either device on its own.[29] The combination of suspensory fixation with aperture fixation may combine the favorable attributes of both fixation methods.

Lee et al[18] demonstrated that the soft tissue ACL graft becomes concentrated eccentrically with the femoral tunnels when suspensory fixation is used, and close to 50% of the tunnel aperture remains empty as the graft concentrates toward the anterior extreme of the tunnel. This shift in the graft not only provides a conduit for synovial fluid to enter the bone tunnel but also resulted in a shift in the graft angle. The authors felt that the latter may result in increased pressure exerted by the graft against the anterior wall of the femoral tunnel and possibly a biomechanical factor contributing to tunnel widening seen with suspensory fixation.[18]

Previous research has demonstrated the importance of the "obliquity of the graft" in terms of its ability to control IR during the pivot-shift test.[33,41] When suspensory femoral fixation is used, the graft will concentrate in the direction in which it is pulled and will have a functional attachment at the circumference of the articular aperture of the bone tunnel.[18] The head of the femoral interference screw used was 8 mm, and therefore, this functional attachment could potentially shift up to 8 mm, thus altering the graft angle and function. If the graft angle in the sagittal plane is altered, this will also influence the ability of the graft to control anterior laxity (Figure 1). This may explain the alteration in graft function after the insertion of the screw but warrants further research.

The addition of the femoral interference screw may alter the biomechanical performance of the graft simply by reducing the overall length of the construct and/or the movement of the graft within the femoral tunnel. This may explain the results at time zero.

In a previous study, we demonstrated that it is possible to control both AT and IT that occurs during the pivot-shift test using a single-bundle reconstruction and interference screws in both bone tunnels, relative to the uninjured contralateral knee.[31] The current study found that the addition of aperture fixation to suspensory fixation resulted in better control of AT and IR during the pivot-shift test. This would suggest that the addition of the interference screw significantly altered the function of the soft tissue graft within the same bone tunnel. The addition of the interference screw reduced AT and IR, and thus, the grade of the pivot-shift test. Previous research has correlated a reduction in the pivot-shift test with improved functional outcome.[16]

Imhauser et al[13] found that positioning the femoral and bone tunnels such that the centers of the tunnel apertures were at the center of the ligament footprint did not restore normal knee kinematics. They found that ACL deficiency resulted in increased mean contact stress in the posterior sections of both the medial and lateral compartments under anterior and rotational loads, respectively, in 11 cadaveric knees. After ACL reconstruction using autologous hamstring graft, femoral suspensory, and tibial interference screw fixation with "center-center" positioning of the bone tunnels, contact stress was reduced but abnormalities persisted within the knee.

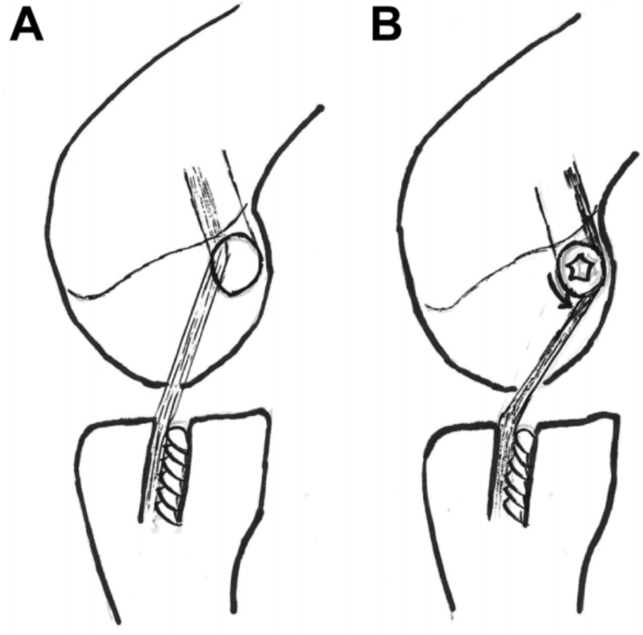

Figure 1. Ways in which the method of femoral fixation used may alter the obliquity of the graft in the sagittal plane. (A) Concentration of the graft to the anterior aspect of the femoral tunnel with cortical fixation. (B) An interference screw positioned anterior to the graft can displace the graft toward the posterior aspect of the tunnel, thus increasing the obliquity in the sagittal plane.

When an ACL reconstruction is performed using a soft tissue graft, the bone footprints become filled with the soft tissue graft and are not reconstituted. The ACL insertion site can never be restored, and the aperture comes to form a permanent defect in the footprint, with no prospect of any direct fiber attachment. Until real footprint restoration is possible, genuinely anatomic reconstruction will remain impossible. Nonetheless, the current study shows that it may be possible to improve the function of the soft tissue ACL graft with the use of aperture fixation, although this warrants further research.

There are a number of weaknesses in this in vivo study. There were no means of standardizing the graft tension or the loads applied during the pivot-shift test, and the examiner was not blinded. This is a study of surgical technique at time zero and it is not known how the biomechanical performance of the graft will change with time as the graft becomes incorporated. Areas of potential future research

[§]References 1, 3, 10, 11, 14, 17, 19-23, 32, 34, 35, 40.

include longer term functional outcome and incidence of osteoarthrosis in knees relative to the type of fixation used, the influence of graft fixation on knee kinetics, and the correlation between graft position (rather than tunnel position) and function.

Our in vivo study has shown that the addition of a femoral interference screw to an ACL reconstruction performed with femoral suspensory fixation and a tibial interference screw results in an increased reduction of both anterior translation and internal rotation during the pivot-shift test.

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