The purpose of this study was to evaluate the effect of the AperFix device (Cayenne Medical, Inc, Scottsdale, Arizona), composed of polyetheretherketone (PEEK) polymer, on tunnel widening after hamstring anterior cruciate ligament (ACL) reconstruction as compared with 2 other fixation devices: the TransFix (Arthrex, Inc, Naples, Florida) and the EndoButton (Smith & Nephew Endoscopy, Mansfield, Massachusetts). Sixty-seven patients with isolated total ACL ruptures who underwent arthroscopically assisted reconstruction using hamstring autografts at the authors’ institution were included in the study. Patients were assigned into 1 of 3 groups in a nonrandomized fashion: AperFix (n=18), TransFix (n=29), and EndoButton (n=20). Mean follow-up was 30 months. Tunnel widening measurements were performed on anteroposterior and lateral digital plain radiographs taken in postoperative week 1 and at final follow-up. Laxity testing, Lysholm scoring, and arthrometric evaluation were performed.

All 3 graft fixation devices resulted in significant tunnel widening in both tibial and femoral tunnels at final follow-up when compared with the immediate postoperative period. Tunnel widening between groups was not significantly different in terms of coronal and sagittal femoral tunnel diameters. Tibial tunnel diameter increase in the sagittal plane in the EndoButton group was significantly smaller than that in the TransFix and AperFix groups. No correlation was found between the amount of tunnel enlargement and clinical outcomes of ACL surgery. This study’s findings suggest that tunnel enlargement after ACL reconstruction is influenced by the type of graft fixation on the tibial side irrespective of clinical outcome, and PEEK polymer does not have an effect on tunnel widening after hamstring ACL reconstruction.

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Drs Uzumcugil, Yalcinkaya, Ozturkmen, Dikmen, and Caniklioglu have no relevant financial relationships to disclose.

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Tunnel widening after anterior cruciate ligament (ACL) reconstruction is a common postoperative finding well documented in the literature.\textsuperscript{1,17} Tunnel widening is observed in single- and double-bundle fixation regardless of hamstring or patellar tendon preference.\textsuperscript{15,16} Many studies address the cause of this common phenomenon, including heat necrosis due to drilling, graft movement inside the tunnel, early aggressive rehabilitation, distance of fixation points to the articular surface, and nonspecific inflammatory response.\textsuperscript{1,2,9} Despite the current argument on the biological and biomechanical causes of tunnel widening, the consensus is that clinical outcome is not affected after tunnel widening.\textsuperscript{2,3,5} However, the prospective randomized study by Järvelä et al\textsuperscript{15} suggested that patients who had more tunnel widening had significantly more anterior and rotational laxity after single- and double-bundle hamstring ACL reconstructions. Using fixation points close to the joint was suggested to reduce tunnel widening when compared with a system where the distance between fixation points was long.\textsuperscript{1}

We have used the AperFix system (Cayenne Medical, Inc, Scottsdale, Arizona) in hamstring ACL reconstructions at our institution. The AperFix device provides strong fixation due to the circumferential intratunnel compression. Fixation of the hamstring tendon in the femoral and tibial tunnels is maintained by the polyetheretherketone (PEEK) polymer, a semicrystalline, polyaromatic, non-absorbable, radiolucent biomaterial that causes no inflammatory response.\textsuperscript{19,20} To our knowledge, no study reports the effect of this relatively new implant system on tunnel widening after ACL reconstruction. We questioned whether an implant composed of a PEEK polymer design affected tunnel widening after ACL reconstruction. We hypothesized that obviating an inflammatory response of the host bone as a potential cause of tunnel enlargement by using a PEEK polymer implant design during graft fixation may lead to decreased tunnel widening after ACL reconstruction. Thus, tunnel widening after hamstring ACL reconstruction with the AperFix device was compared with 2 other common fixation devices in transcondylar and extracortical fixation.

**MATERIALS AND METHODS**

Between 2007 and 2008, all patients with isolated total ACL ruptures who underwent arthroscopically assisted reconstructions using hamstring autografts in our institution were reviewed retrospectively. Patients with additional meniscal procedures, collateral ligament injuries, and advanced chondral defects were excluded from the study, leaving 67 patients with anterolateral knee instability due to complete ACL rupture diagnosed on clinical examination and confirmed at arthroscopy. Sport injury was the major etiology of trauma.

Patients were selectively divided into 3 groups in a nonrandomized fashion according to the fixation device used. The implant system available in the operating room at the time was chosen for each patient. In group 1, the TransFix device (Arthrex, Inc, Naples, Florida) was used for transcondylar femoral graft fixation in 29 patients (27 men and 2 women; mean age, 29.8 years). In group 2, the AperFix system was used for aperture femoral graft fixation in 18 patients (17 men and 1 woman; mean age, 27.4 years). In group 3, the EndoButton device (Smith & Nephew Endoscopy, Mansfield, Massachusetts) was used for extracortical femoral graft fixation in 20 patients (18 men and 2 women; mean age, 28.2 years). In groups 1 and 3, tibial graft was fixed using bioabsorbable interference screw and a U-staple. In group 2, a PEEK polymer tibial screw was engaged in a tibial sheath for tibial side graft fixation.

All surgeries were performed under general or spinal anesthesia using a pneumatic tourniquet in the supine position by the senior author (O.U.) in the same institution. Routine diagnostic arthroscopy was performed in all patients initially. A double-looped semitendinosus and gracilis tendon autograft via a 1-incision transtibial technique was used in all patients. After remnant debridement, the ACL femoral and tibial tunnels were reamed to the appropriate size according to the thickness of the hamstring grafts derived. The tibial tunnel was reamed first in all groups. The guide pin was inserted approximately 2 cm medial to the tibial tuberosity to approximately 6 to 7 mm anterior of the posterior cruciate ligament on the projection point of the notch, with an angle of 55° with the long axis of the tibia. As the guide pin was inserted, the knee was fully extended, and it was determined whether the pin touched the lateral condyle or the top of the femoral notch to avoid impingement.

The tibial tunnel was drilled using a fully fluted reamer. After the tibial tunnel was rapped, the femoral guide pin was inserted through the tibial tunnel using the femoral offset guide, which was selected according to the graft thickness, when the knee was hyperflexed. In group 2, an AperFix femoral implant composed of PEEK polymer was used for femoral fixation. A double-looped hamstring autograft was inserted through the femoral implant, which was placed in the femoral tunnel through the tibial hole with the help of an inserter handle. After the removal of the safety pin on the handle, the graft was fixed in the tunnel using the implant deployment knob. During tibial fixation, AperFix PEEK polymer tibial implant sheaths were inserted in the tibial tunnel. The AperFix PEEK polymer tibial screw was engaged with the tibial sheaths under controlled tendon distraction when the knee was nearly extended, and the reconstruction was completed. In groups 1 and 3, TransFix and EndoButton devices were used for femoral graft fixation (Figure 1). In these groups, tibial graft fixation was maintained via bioabsorbable interference screws and U-staples.
All patients used a knee brace with an angle-adjustable hinge in the early postoperative period, and active quadriceps exercises were started immediately. The patients were allowed to flex their knees 90° at the end of the first postoperative week and 120° at the end of the second postoperative week. The patients started full weight bearing without a brace at the end of the second week under the control of a physiotherapist.

Tunnel-widening measurements were performed on anteroposterior (AP) and lateral digital plain radiographs taken during the first postoperative week and at final follow-up by an independent expert (M.Y.) using the method of Fauno and Kaalund. The wall prints in the early digital images and the sclerotic margins of the tunnels in the follow-up images were measured 1.0 cm below the tibial plateau and 1.0 cm above the femoral entrance. After magnification correction, tunnel widths were recalculated and noted for both tibial and femoral sides (Figure 2).

At final follow-up, patients were clinically assessed by the Lachman test, Lysholm scores, and arthrometric evaluation (KT-1000 Knee Ligament Arthrometer; MEDmetric Corp, San Diego, California). The arthrometer measured the anteroposterior translation of the operated and contralateral knees using standardized forces of 67 N the first time and 89 N the second time. The arthrometric measurement was the difference between the operated and contralateral knees.

Data for all groups were analyzed using SPSS for Windows version 11.5.0 software (SPSS, Inc, Chicago, Illinois). Pillai’s trace test was used to compare radiographic data between the 3 groups. Kruskal-Wallis test was used to compare age, follow-up, and arthrometric evaluation variables. Wilcoxon signed rank test was used to compare radiographic data between groups. Mann-Whitney U and Spearman correlation tests were used to evaluate the clinical outcome data. Pearson’s chi-square test was used for the Lachman and pivot shift comparisons. Statistical significance was set at \( P < .05 \).

RESULTS
Mean follow-up for all groups was 30 months (range, 24-38 months). No significant difference existed between the 3 groups in terms of follow-up \( (P > .05) \). Patients’ ages were similar \( (P = .351) \). In group 1, mean AP tibial tunnel diameter significantly increased from 10.1±1.22 mm preoperatively to 13.56±2.38 mm (34%) at final follow-up \( (P = .001) \). Average lateral tibial tunnel diameter significantly increased from 10.9±1.45 mm preoperatively to 14.19±2.29 mm (30%) at final follow-up \( (P = .001) \). Accordingly, mean AP femoral tunnel diameter significantly increased from 8.94±1.11 mm preoperatively to 11.88±2.99 mm (33%) at final follow-up \( (P = .001) \). Average lateral femoral tunnel diameter significantly increased from 8.97±1.46 mm preoperatively to 11.18±2.98 mm (25%) at final follow-up \( (P = .001) \). Average follow-up in group 1 was 29.4 months (range, 24-38 months).

In group 2, mean AP tibial tunnel diameter significantly increased from 11.74±2.04 mm preoperatively to 13.83±1.85 mm (18%) at final follow-up \( (P = .016) \). Mean lateral tibial tun-
nel diameter significantly increased from $11.79 \pm 2.24$ mm preoperatively to $14.05 \pm 1.43$ mm (19%) at final follow-up ($P = .007$). Average AP femoral tunnel diameter significantly increased from $9.29 \pm 1.22$ mm preoperatively to $11.49 \pm 2.19$ mm (24%) at final follow-up ($P = .005$). Mean lateral femoral tunnel diameter significantly increased from $9 \pm 1.09$ mm preoperatively to $10.99 \pm 1.9$ mm (22%) at final follow-up ($P = .001$). Average follow-up in group 2 was 28.2 months (range, 24-38 months).

In group 3, mean AP tibial tunnel diameter significantly increased from $10.22 \pm 1.72$ mm preoperatively to $12.39 \pm 2.18$ mm (21%) at final follow-up ($P = .001$). Mean lateral tibial tunnel diameter significantly increased from $10.13 \pm 1.86$ mm preoperatively to $12.50 \pm 1.68$ mm (23%) at final follow-up ($P = .001$). Accordingly, mean postoperative AP femoral tunnel diameter significantly increased from $8.15 \pm 1.30$ mm preoperatively to $11.48 \pm 1.64$ mm (41%) at final follow-up ($P = .001$). Mean lateral femoral tunnel diameter significantly increased from $8.42 \pm 1.84$ mm preoperatively to $11.08 \pm 1.52$ mm (32%) at final follow-up ($P = .001$). Average follow-up in group 3 was 32.3 months (range, 30-35 months).

In terms of coronal and sagittal femoral tunnel widening, an increase that was not statistically significant occurred between the 3 groups according to comparison analysis (coronal: $P = .464$, $P = .769$, $P = .565$, respectively; sagittal: $P = 1$, $P = 1$, and $P = 1$, respectively). The tibial tunnel diameter increase in the coronal plane was significantly higher in the AperFix group than in the EndoButton group ($P = .03$). The tibial tunnel diameter increase in the sagittal plane was significantly smaller in the EndoButton group than in the TransFix and AperFix groups ($P = .013$ and $P = .003$, respectively).

The Lysholm score in the AperFix group was significantly higher than that in the TransFix group ($P = .003$) and was similar to that in the EndoButton group ($P = .093$). The differences between the 3 groups in terms of arthrometric evaluation and Lachman and pivot shift testing were not significant (arthrometric evaluation at 67 N, $P = .74$; arthrometric evaluation at 89 N, $P = .831$; Lachman test, $P = .988$; pivot shift test, $P = .959$). No correlation was found between the amount of tunnel enlargement and clinical outcomes of ACL surgery according to the non-parametric correlation (Spearman) test ($r < 0.3$ (Table)).

No compartment syndrome, deep vein thrombosis, implant breakage, rerupture of the reconstructed ligament, or joint infection occurred in any patient.

**Discussion**

Potential causes of tunnel enlargement after ACL reconstruction are heat necrosis due to drilling, graft movement inside the tunnel, early aggressive rehabilitation, the distance of fixation points to the articular surface, and nonspecific inflammatory response.1,2 Obviating an inflammatory response of the host bone as a potential cause of tunnel enlargement was hypothesized in the current study to obtain superior results in terms of tunnel widening after ACL reconstruction. Thus, the AperFix device, composed of PEEK polymer (which is supposed to cause no inflammatory response) was used for aperture fixation in hamstring ACL reconstruction, and its effect on tunnel widening was investigated radiographically in comparison with 2 other common fixation devices for transcondylar and extracortical fixation. The results displayed significant widening in tibial and femoral tunnels irrespective of clinical outcome at final follow-up compared with the immediate postoperative period.

The relation between the clinical outcome and tunnel widening after ACL reconstruction has been a topic of debate for the past decade. Fauno and Kaalund1 compared suspensory with aperture fixation of the graft during hamstring ACL reconstruction. A TransFix implant and an interference screw in the tibial tunnel or an EndoButton implant in the femur and bicortical screw and washer distal to the tibial tunnel were used for graft fixation. They concluded that tunnel widening was influenced by the mechanical properties of the implants, but the difference between the 2 techniques did not reach statistical

<table>
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*Arthrex, Inc, Naples, Florida.
Cayenne Medical, Inc, Scottsdale, Arizona.
Smith & Nephew Endoscopy, Mansfield, Massachusetts.
In the current study, all bone tunnel enlargement did not affect the clinical outcome of ACL reconstruction surgery in the short term. According to the results of the current study, tunnel enlargement after ACL reconstruction is influenced by the type of graft fixation on the tibial side irrespective of clinical outcome, but aperture graft fixation was used on the tibial side across all groups, which could eliminate the windshield wiper phenomenon that may be a major cause of tunnel widening after suspensory graft fixation in ACL surgery.

Biomechanical properties of the implants are paramount to understanding tunnel widening after ACL reconstruction. In a recent comparison study of 3 devices, including the RetroButton (Arthrex, Inc), ToggleLoc (Biomet, Warsaw, Indiana), and EndoButton, biomechanical properties of implants were studied in terms of maximum pullout force and plastic displacement on fresh porcine knees. The authors of the study advocated the EndoButton combined with a stiff loop material to minimize micromotion and provide maximum pullout strength for the best biomechanic solution for tunnel widening after ACL reconstruction.

In the current study, the AperFix system composed of PEEK polymer in fixation implants was used for aperture fixation of the hamstring autograft. A combined experimental and analytical study performed by Ferguson et al reported the influence of the physiological environment on the mechanical stability of PEEK polymer; their results verified the mechanical stability of the PEEK polymer in a simulated physiological environment and over extended loading periods. In a biomechanical comparison study, PEEK polymer in fixation implants was used for single tunnel–double bundle ACL reconstruction in fresh-frozen human cadaveric knee specimens, and favorable biomechanical results were reported. However, few studies exist about the influence of the physiological environment and over extended load periods. In a biomechanical comparison study of human cadaveric knee specimens, and favorable biomechanical results were reported. However, few studies exist about the influence of the physiological environment and over extended load periods.

Several reports exist on the timeline of tunnel widening after ACL reconstruction. Peyrache et al reported that tunnel widening occurred in the early postoperative period and stabilized within 1 year postoperatively. Fauno and Kaalund reported radiographic results of tunnel widening after ACL surgery via 1-year radiographs. Webster et al compared hamstring with patellar tendon grafts in terms of tunnel widening after ACL reconstruction; their results revealed that tunnel enlargement at 4 months did not significantly change at 1 and 2 years postoperatively. In the current study, mean follow-up for all groups was 30 months (range, 24-38 months). Tunnel-widening measurements were performed at 1 week postoperatively and at final follow-up. No significant difference was found between the 3 groups in terms of follow-up, and the radiographic evaluation period for postoperative tunnel enlargement was similar among the 3 groups.

In the past, digital plain radiography, magnetic resonance imaging (MRI), and computed tomography (CT) were used to assess bone tunnel widening after ACL reconstruction. Marchant et al recommended CT scan for the evaluation of bone tunnels in patients with tunnel widening regardless of plain radiograph quality. However, Webster et al found digital plain radiography to be a reliable method for detecting bone tunnel enlargement; no widening was missed with the use of radiography compared with CT. In the prospective randomized study of Fauno and Kaalund, tunnel widening measurements based on plain radiographs correlated well with those based on MRI. Buelow et al reported that MRI did not add significant information and accuracy to plain radiograph measurements. In the current study, digital plain radiography was used for the assessment of bone tunnel enlargement after ACL reconstruction. No difficulties were encountered in the determination of tunnels, even in early postoperative radiographs. Cost effectiveness when compared with MRI and low-dose irradiation when compared with time-consuming CT were other factors that directed us to use digital plain radiography.

Nonaccelerated rehabilitation, drilling tunnels smaller than the measured graft diameter, insertion of large interference screws, and a bone impaction technique were suggested by several studies for preventing tunnel widening after ACL reconstruction. Fauno and Kaalund reported radiographic results of tunnel widening after ACL surgery via 1-year radiographs. Webster et al compared hamstring with patellar tendon grafts in terms of tunnel widening after ACL reconstruction; their results revealed that tunnel enlargement at 4 months did not significantly change at 1 and 2 years postoperatively. In the current study, mean follow-up for all groups was 30 months (range, 24-38 months). Tunnel-widening measurements were performed at 1 week postoperatively and at final follow-up. No significant difference was found between the 3 groups in terms of follow-up, and the radiographic evaluation period for postoperative tunnel enlargement was similar among the 3 groups.

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results achieved by an extracortical suspension device when compared with the others in terms of tunnel enlargement. No correlation was found between the amount of tunnel widening and clinical outcomes of ACL surgery, including functional and arthrometric evaluation.

REFERENCES


