Comparison of Endoscopic and Two-Incision Technique for Reconstructing a Torn Anterior Cruciate Ligament Using Hamstring Tendons

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Summary: This study compared the differences in clinical outcome between an endoscopic (67 of 70) and two-incision (41 of 49) technique used to reconstruct a torn anterior cruciate ligaments (ACL) utilizing a double-looped semitendinosus and gracilis (DLSTG) graft. In both techniques the graft was placed without roof impingement, the looped end of the graft was fixed around a post with bone compaction, and the free ends were fixed with either double staples or a soft tissue washer(s). No graft required suture fixation. The post-operative treatment featured an aggressive rehabilitation protocol without a brace, and allowed unrestricted sports participation four months post reconstruction. Age, sex distribution, duration from injury to surgery, and preoperative laxity were not significantly different between treatment groups. The operative time for the endoscopic technique averaged 48 minutes less than the two-incision technique. There were no significant differences in thigh circumference, knee extension, stability, and the single leg hop test between the two treatment groups at 4 and 24 months. Ninety-one percent of the knees in the endoscopic group and 90% in the two-incision group had less than a 3 mm increase in anterior translation compared to the normal knee using the manual maximum test (KT-1000) and had either a normal or near normal knee (IKDC score) at two years. A second surgery for removal of painful, prominent hardware was required in 21% of the subjects in the endoscopic group and 12% of the subjects in the two-incision treatment group. Patients preferred the endoscopic technique because the result was more cosmetic and aggressive rehabilitation could be accomplished without the assistance of a physical therapist. Unfortunately, objective stability could not be restored in about 10% of knees with either technique. Reoperation for removal of prominent staples and washers continues to be the primary source of postoperative morbidity. **Key Words:** Anterior Cruciate Ligament Reconstruction—Hamstring—Endoscopic.

Endoscopic techniques for reconstructing a torn anterior cruciate ligament (ACL) avoid the morbidity associated with a lateral femoral dissection and are more cosmetic than reconstructions using two-incisions. However, a potential disadvantage of the endoscopic technique is the inability to freely position the femoral tunnel inside the intercondylar notch because the femoral tunnel is drilled through the tibial tunnel. Because the placement of the femoral tunnel determines graft tension (1-4) and positioning of the femoral tunnel is constrained by the tibial tunnel with the endoscopic technique (5, 6) knee stability may be worse compared to the two-incision technique in which the femoral tunnel is positioned independently from the tibial tunnel.

This study was designed to determine if the clinical outcome of the endoscopic technique is as good or better than the two-incision technique at four months and two years postoperatively. To allow unrestricted sports participation four months post reconstruction both techniques had common features including a DLSTG graft, a customized tibial tunnel placed without roof impingement, fixation using a post with bone compaction for the looped end and double staples or a soft tissue washer(s) for the free ends, and an aggressive rehabilitation protocol without a brace. The second objective was to determine in the endoscopic group if the placement of the tibial tunnel in the coronal and sagittal planes was predictive of arthrometric knee laxity at two years.

Methods and Materials

Overview

The clinical outcome of 67 of 70 (96%) consecutively operated subjects whose knees were reconstructed using an endoscopic technique were compared to a previously reported study of 41 of 49 (84%) consecutively operated subjects whose knees were reconstructed using a two-incision technique (7). Three subjects in the endoscopic group and eight subjects in the two-incision group were excluded because they did not return for the two year evaluation. A single surgeon (SMH) performed all operations. The duration of surgery was recorded from inci-

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sion to application of the dressing for both techniques. Pre and postoperative data was collected prospectively, with the senior author (SMH) performing the evaluation at four months and an independent evaluator performing the evaluation at two years.

The endoscopic study group consisted of sixty-seven subjects; forty-seven males and twenty females operated on from January 1994 through December 1994. The mean age at the index operation was thirty years (range, sixteen to forty-seven years). All subjects were athletically active with sixty-two of sixty-seven subjects (93 per cent) having injured their knee during a sporting activity. Sixty knees had no previous operations. Seven subjects had prior surgeries; four had an arthroscopic partial medial menisectomy, one an open medial menisectomy and two an arthroscopic partial lateral menisectomy. Thirty-four reconstructions were performed early, within six months of injury, and thirty-three were performed later. One co-author (MLD) examined sixty-two subjects at a mean of twenty-five months (range, twenty-three to thirty-six months) postoperatively. Because of scheduling conflicts, the senior author evaluated the remaining five subjects.

The two-incision study group consisted of forty-one subjects; twenty-eight males and thirteen females operated on from May 1991 to February 1992. The mean age at the index operation was thirty-three years (range, fifteen to forty-eight years). Thirty-eight of forty-one subjects (93 per cent) injured their knee during a sporting activity. Thirty-four knees had no previous operations. Seven subjects had eight prior surgeries; four had an arthroscopic partial medial menisectomy, one an arthroscopic partial medial and lateral menisectomy, one an open medial collateral ligament repair, and two had an arthroscopic debridement. Twenty-five reconstructions were performed early, within six months of injury, and sixteen were performed later. Two subjects had tears of the medial collateral ligament. One co-author examined thirty-seven subjects at a mean of twenty-six months (range, twenty-four to thirty-two months) postoperatively. Because of scheduling conflicts, the senior author evaluated the remaining four subjects (7).

All subjects demonstrated ACL deficiency by arthrometric criteria preoperatively (KT-1000, MedMetric, San Diego, California) and an absent or non-functional ACL was observed intraoperatively.

Functional Assessment

At four months and two years the difference in thigh girth between the operative leg and the contralateral leg at five and fifteen centimeters proximal to the suprapatellar pole was calculated and assigned to one of four categories: 1) thigh girth of the operated knee was two centimeters or greater than the contralateral leg, 2) within 1 centimeter of the contralateral leg, 3) 2 centimeters less than the contralateral leg, and 4) more than 2 centimeters less than the contralateral leg. The difference in knee extension was calculated and assigned to one of three categories: 1) Extension of the operated knee equaled the contralateral knee, 2) hyperextended but does not equal the contralateral knee, and 3) extended to zero degrees. The single hop test was performed and the hop index was calculated as the mean distance jumped by the operated limb divided by the mean distance jumped by the contralateral limb expressed as a percentage (8).

At two years the International Knee Documentation Committee (IKDC) form was used to evaluate function (9). Knees were graded normal (A), nearly normal (B), abnormal (C), or severely abnormal (D) in seven categories. The categories that were evaluated included: the patient's assessment of their knee function, symptoms (pain, swelling, and giving way), motion, stability, crepitus in each knee compartment, harvest site pathology, and one-legged hop test. The lowest grade in any category was used as the final outcome for that patient's knee.

Each subject categorized their level of activity prior to injuring their knee, after injuring their knee but before the operation, and following the operation at two years into one of four levels. Strenuous activities included sports that required jumping, pivoting, and hard cutting maneuvers such as football, soccer, and basketball; moderate activities included heavy manual work, skiing, tennis, baseball, and volleyball; light activities were typified by light manual work, jogging, running, and cycling; sedentary activities included housework or a desk job with no sports participation.

Stability Assessment

Stability was determined by the combined results of the Lachman test, pivot-shift test and arthrometric laxity measurements. A stable knee had all three of the following findings: firm end-point, no pivot-shift or a subtle pivot-glide that was equal to the contralateral knee, and the difference in anterior displacement between the operated knee and contralateral knee during a manual maximum translation had to be less than three millimeters. An unstable knee had either a soft-endpoint, an increased pivot shift compared to the contralateral knee, or a three millimeter or greater increase in anterior displacement during a manual maximum translation compared to the contralateral knee.

Roentgenographic Assessment of Tibial Tunnel Placement

The placement of the tibial tunnel in the coronal and sagittal planes was determined at two years for the knees reconstructed using the endoscopic technique. In the sagittal plane the percentage of roof impingement and the location of the central axis of the tibial tunnel were determined from a lateral roentgenogram of the fully extended knee using a previously described technique (10) (Figure 1). In the coronal plane the angle of the tibial tunnel and the location of the central axis of the tibial tunnel were determined from an anteroposterior view of the intercondylar notch (Figure 2).

To allow a comparison of the tibial tunnel placement in the sagittal plane between the two-incision and endoscopic group the roof angle, center of the tibial tunnel, and percentage of roof impingement were determined from roentgenograms obtained two years postoperatively (Figure 1). A comparison of tibial tunnel placement in the coronal plane between treatment groups could not be made because anteroposterior roentgenograms were not obtained in the two-incision group.

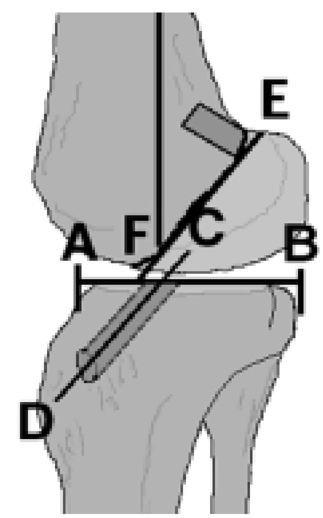

Figure 1. In the sagittal plane the position of the center of the tibial tunnel was determined by dividing the distance from the anterior edge of the tibia to the center of the tibial tunnel (AC) by the depth of the articular surface of the tibial plateau (AB), and multiplying by 100. The percentage of roof impingement was calculated by measurement of the distance from the point where the slope of the intercondylar roof (EF) intersected the tibial plateau (F) to the point where the anterior edge of the tibial tunnel intersected the tibial plateau. This distance was divided by the width of the tibial tunnel, and the result expressed as a percentage. The angle formed by ACD was defined as the tibial tunnel angle. The roof angle was defined as the angle subtended by the intersection of a line drawn along the long axis of the femur and the line along the slope of the intercondylar roof (EF).

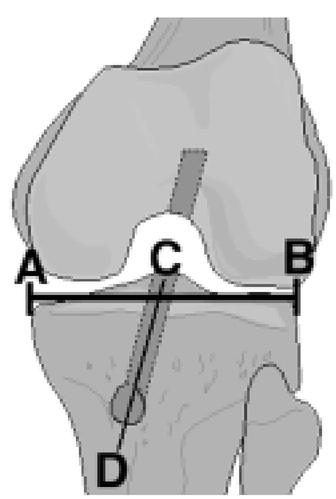

Figure 2. In the coronal plane the position of the center of the tibial tunnel was determined by dividing the distance from the medial edge of the tibia to the center of the tibial tunnel (AC) by the width of the articular surface of the tibial plateau (AB), and multiplying by 100. The angle formed by ACD was defined as the tibial tunnel angle.

Operative Technique

The endoscopic and two-incision technique used in this study for arthroscopically-assisted, intra-articular reconstruction of the anterior cruciate ligament with a DLSTG autograft has been previously published (6, 11). Both treatment groups had a customized tibial tunnel placement which accounted for variability in knee extension and roof angle between knees and avoided roof impingement (10, 12-15). The center of the tibial tunnel was positioned 4 to 5 millimeters posterior and parallel to the slope of the intercondylar roof with the knee in maximum extension using a guide system that keyed off the intercondylar roof (Impingement-Free or One-Step Tibial Guide, Arthrotek, Inc., Ontario, CA). The tibial tunnel was drilled. Bone was removed from the intercondylar roof and wall. Elimination of roof impingement was confirmed when a metal rod (Impingement-Free Tibial Guide System, Arthrotek, Inc.), the same diameter as the tibial tunnel, could be freely advanced through the tibial tunnel into the intercondylar notch with the knee in full extension (6, 11).

In the endoscopic group the femoral tunnel was positioned using one of a series of femoral guides inserted through the tibial tunnel (Size-Specific Femoral Guide, Arthrotek, Inc.)(Figure 3). The tip of each guide had a tongue-like extension that was hooked posterior or proximal to the intercondylar roof in the over-the-top position and was oriented at approximately 11 o'clock for the right knee or 1 o'clock for the left knee. The distance from the tongue to the guide wire varied dependent on the diameter of the tunnel (i.e. 4.5, 5, 5.5 mm for a 7, 8, and 9 mm in diameter tunnel respectively). The use of a size-specific femoral aimer resulted in a 1 mm thick posterior wall that assured that the femoral tunnel was positioned as posteriorly as possible. A 25 mm in length, closed-end femoral tunnel was drilled. A fixation device (Bone Mulch Screw, Arthrotek, Inc.) was inserted through the lateral femoral condyle until the beam of the device crossed the femoral tunnel. Graft length was conserved by looping the mid-point of each tendon over the beam positioned 18 mm inside the femoral tunnel. The free ends of each bundle exited the tibial tunnel. With the knee in full extension, an unmeasured tension was applied and the graft was secured to the tibia with two soft tissue staples in sixty-three subjects (Smith and Nephew, Inc., Memphis, TN) and with a 20 mm in diameter soft tissue washer in four subjects (Linvatec, Inc., Largo, FL). Bone reamings were impacted into the femoral tunnel through the bore in the femoral fixation device (6, 11).

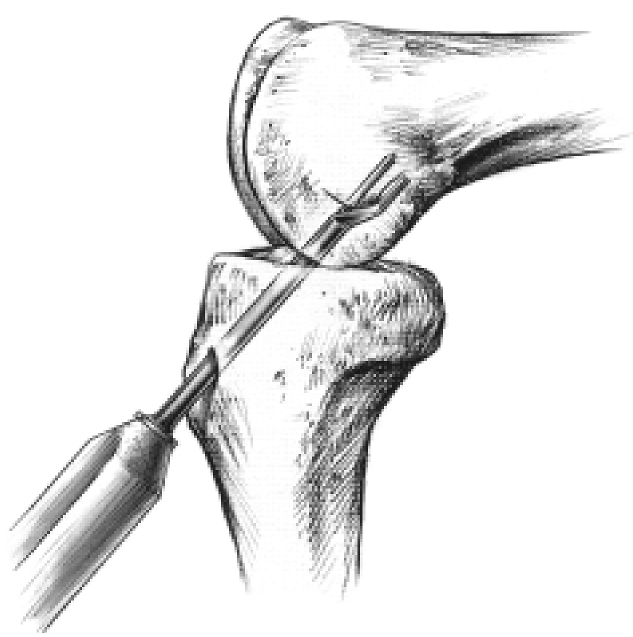

Figure 3. In the endoscopic technique the angle and position of the tibial tunnel determined the angle and position of the femoral tunnel. The similar diameters of the femoral aimer and tibial tunnel prevented independent positioning of the femoral aimer inside the intercondylar notch in both the coronal and sagittal planes.

In the two-incision group a 5 cm anterolateral incision was used to elevate the vastus lateralis anteriorly just proximal to the knee. Either a rear-entry or front entry femoral guide system (Acufex Microsurgical, Norwood, MA) was used with the goal of positioning the center of the femoral tunnel 5 to 7 millimeters distal to the proximal edge of the intercondylar roof at 11 o'clock for the right knee or 1 o'clock for the left knee. The femoral tunnel was drilled through the lateral incision. Graft length was conserved by looping the midpoint of each tendon around a fixation post (4.0 millimeter diameter small fragment cancellous screw, Synthes, Paoli, Pa) countersunk inside the tibial tunnel. A drilling device (Tibial Fixation Device, Arthrotek, Inc.) positioned the fixation post fifteen millimeters inside the tibial tunnel. The free ends of each tendon extended outside the femoral tunnel while the midpoint of each tendon was looped around the recessed screw. With the knee in full extension, an unmeasured tension was applied manually to the free ends of the tendons exiting the femoral tunnel, and the graft was secured to the lateral femoral cortex in thirty-nine knees with either one or two 6.5 millimeter cancellous screws and ligament washers (Synthes, Paoli, Pennsylvania) and in two subjects two soft tissue staples (Stryker Inc., Kalamazoo, MI). Bone reamings were impacted into the tibial tunnel with an impingement rod to fill any voids between the tendon, screw, and tunnel walls.

Rehabilitation Program

The rehabilitation program in both the endoscopic and two incision group was performed without either immobilization or bracing. Subjects in both groups were released to unrestricted activities four months postoperatively.

In the endoscopic group the subjects were discharged on the day of surgery, instructed to bear weight as tolerated, begin unrestricted closed and open-chain knee extension exercises at week 4, and resume straight-line running at week 8-10. Thirty-five per cent of subjects (25\67) rehabilitated their knee without the assistance of a physical therapist and sixty-seven per cent (45\67) required less than 15 rehabilitation treatments.

In the two-incision group the subjects were hospitalized and used continuous passive motion for 1 to 2 days, instructed to toe-touch weight bear for 3 weeks, discard the crutches after week 3, perform unrestricted closed and open-chain knee extension exercises beginning at week 4, and resume straight-line running at week 8-10. Seven per cent (3\41) rehabilitated their knee without the assistance of a physical therapist and eighty per cent (33\41) required less than 15 rehabilitation treatments.

Complications

A chart review and consultation with the patient at final follow-up were used to determine the occurrence of complications including infection, deep vein thrombosis, loss of sensation in the skin overlying the proximal lateral tibia due to injury to the infrapatellar branch of the saphenous nerve, arthrofibrosis, hardware prominence, and the need for additional surgery.

Data Analysis

The unpaired Student's T-test was used to compare continuous data and the Mann-Whitney test was used to compare ordinal data between the two treatment groups. Contingency tables were used where comparisons of nominal data were appropriate. A step-wise multiple regression was used to compare angle and position of the tibial tunnel in the coronal plane and the degree of roof impingement and location of the tibial tunnel in the sagittal plane to the difference in anterior laxity between the reconstructed and normal knee under a manual maximum test at two years.

Results

Subjects

There was no significant difference between the mean age (p=0.83), gender distribution (p=0.19), mean interval from injury to surgery (p=0.07), or the incidence of prior knee surgery (p=0.56) between the endoscopic and two-incision treatment groups. The pre-injury activity level of the endoscopic group was significantly less than the two-incision group (p=0.01) with a lower percentage of subjects participating in strenuous activities (Table I). In contrast the pre-surgery activity level was the same between treatment groups (p=0.35). The duration of surgery was significantly less for the endoscopic technique (68 ± 16 min.) compared to the two-incision technique (116 ± 17 min.) (p=0.001). In the endoscopic group, meniscal tears were treated concomitantly with the ACL reconstruction in 33 (49%) of the knees including 5 (7%) partial medial menisectomies, 15 (22%) partial lateral menisectomies, 7 (10%) partial medial and lateral menisectomies, and 6 (9%) medial meniscal repairs. In the two-incision group, concomitant treatment of meniscal tears was required in 20 (48%) of knees including 9 (21%) partial medial menisectomies, 8 (19%) partial lateral menisectomies, and 3 (7%) medial meniscal repairs.

Functional Assessment

At four months there was no significant difference in thigh girth at five and fifteen centimeters proximal to the suprapatellar pole, knee extension, and the hop index between the endoscopic and two-incision treatment groups (Table II). The girth of the thigh was 1 cm less and knee extension was one degree less than the contralateral knee. More subjects in the endoscopic group (thirty-five per cent) rehabilitated their knees without the assistance of a physical therapist compared to the two-incision group (seven per cent) (p=0.005), however; there was no significant difference in the number of physical therapy visits between the two treatment groups (p=0.523) (endoscopic 11 ± 11, two-incision 9 ± 7 visits).

At two years the endoscopic group had a significantly lower IKDC score than the two-incision group (p=0.008) (Table III). Ninety per cent of the knees in both treatment groups were rated in the normal and nearly normal categories, however; only thirty-one per cent were rated normal in the endoscopic group compared to sixty-three per cent in the two-incision group. The lower final IKDC score in the endoscopic group was caused by a higher percentage of nearly normal ratings in the subjective categories of function, activity level, and pain instead of normal ratings.

The level of sports and work activity were significantly improved by the operation (p=0.009) but were not restored to the pre-injury level (p=0.01) in either the endoscopic or two-incision treatment group (Table I).

Stability Assessment

At four months there was no significant difference in stability between the endoscopic and two-incision treatment groups (p=0.12) (Table II). A stable knee with a solid endpoint on Lachman testing, a less than 3 mm increase in anterior laxity compared to the normal knee measured using the manual maximum test, and an absent pivot-shift or a subtle pivot-glide that was equal to the contralateral knee was observed in 93% of the subjects in the endoscopic group and in 82% of the subjects in the two-incision group (7) at four months.

At two years sixty-one (91%) of the sixty-seven treated knees were objectively stable in the endoscopic treatment group. The instability in five of the six knees was detected at four months. Four of these five knees had an increase in anterior laxity with a maximum manual test between 3 and 5 mm at both four months and two years and were considered unstable, but were rated as nearly normal using the IKDC scoring scale. The fifth subject had a 6 mm increase in anterior laxity at both evaluations and was rated as having a severely abnormal knee. The final subject developed instability after being stable at four months by reinjuring his knee during a motorcycle accident that tore the ACL graft and medial collateral ligament.

In the two-incision treatment group thirty-seven (90%) of the forty-one treated knees were objectively stable at two years (7). The instability in all four knees was detected at four months. One knee had an increase in anterior laxity with a maximum manual test between 3 and 5 mm at four months and two years and was considered unstable, but was rated as nearly normal using the IKDC scoring scale. Two knees had an increase in anterior laxity with a maximum manual test between 3 and 5 mm at four months that became greater than a 5 mm increase in anterior laxity at two years and were rated as having an abnormal knee. The fourth subject had a greater than 5 mm increase in anterior laxity at both four months and two years and was rated as having an abnormal knee.

Roentgenographic Assessment of Tibial Tunnel Placement

In the endoscopic group there was no significant relationship between the location of the center of the tibial tunnel in the sagittal plane (47 ± 4, range 40 to 55 per cent), the percent of impingement (-4 ± 10, range 0 to -50 per cent), the center of the tibial tunnel in the coronal plane (46 ± 3, range 41 to 51 per cent), the angle of the tibial tunnel in the coronal plane (76 ± 3, range 68 to 84 degrees) and the stability of the knee measured using the manual maximum test at 2 years (p=0.134). Impingement of the graft by the intercondylar roof was eliminated in every knee, as the anterior border of the tibial tunnel was in line or posterior to the slope of the intercondylar roof with the knee in maximum extension. In the coronal plane, the width of the tibial tunnel was contained between the medial and lateral eminences in 66 of 67 knees.

The center of the tibial tunnel in the sagittal plane was significantly different between the endoscopic and two-incision group because there was a significant difference in roof angle. In the endoscopic group the average roof angle was 35 ± 4.5 degrees (range 26 to 48) which was 3 degrees more horizontal than in the two-incision group (38 ± 4.3 degrees, range 26 to 44) (p = 0.005). Since the tibial guide referenced the slope of the intercondylar roof and the roof angle was 3 degrees more parallel to the long axis of the femur in the endoscopic group the center of the tibial tunnel was accordingly 4% more posterior (47 ± 4, range 40 to 55 per

Table 1: Comparison of Levels of Activity Participation before the Injury of the Knee, Preoperatively, and Two Years after the Operation between the Endoscopic and Two-Incision Treatment Groups *

Activity Level†	Treatment Group	Preinjury	Preop	Postop
Strenous (activities involving jumping, pivoting, hard cutting, football, soccer and basketball)	Endoscopic	31 (46%)	2 (3%)	27 (40%)
	Two Incision	32 (78%)	2 (4%)	25 (61%)
Moderate (activitities involving heavy hanual work, skiing tennis, baseball and volleyball)	Endoscopic	33 (49%)	6 (9%)	32 (48%)
	Two Incision	9 (22%)	9 (22%)	13 (32%)
Light (activities involving light manual work, jogging, running and cycling)	Endoscopic	2 (3%)	27 (40%)	6 (9%)
	Two Incision	—	11 (27%)	1 (2%)
Sedentary (activities involving household work, desk job no sports)	Endoscopic	1 (2%)	32 (48%)	2 (3%)
	Two Incision	—	19 (48%)	2 (5%)

*Values given as the number of patients

†International Knee Documentation Committee categories for level of athletic participation.

Table 2: Comparison of Knee Function and Stability at 4 months Between Endoscopic and Two Incision Treatment Groups*

Variable	Endoscopic§	Two Incision§	*P* Value
5cm thigh girth (cm)‡			0.79†
Thigh girth in reconstructed leg is:			
2cm or more greater than contralateral leg	0 (0%)	0 (0%)	
Within 1 cm of contralateral leg	51 (81%)	29 (78%)	
2cm less than contralateral leg	7 (11%)	6 (16%)	
More than 2cm less than contralateral leg	4 (7%)	2 (6%)	
15cm thigh girth (cm)‡			0.84†
Thigh girth in reconstructed leg is			
2cm or more greater than contralateral leg	0 (0%)	0 (0%)	
Within 1 cm of contralateral leg	52 (83%)	19 (51%)	
2cm less than contralateral leg	7 (11%)	11 (30%)	
More than 2cm less than contralateral leg	4 (7%)	7 (19%)	
Knee extension‡			0.72†
The reconstructed knee:			
Extends the same as contralateral knee	47 (77%)	26 (70%)	
Hyperextends but doen't equal contralateral knee	13 (22%)	9 (24%)	
Extends to zero degrees	1 (1%)	2 (6%)	
One-legged hop test for distance			0.84†
Number of subjects completing test	52 of 62 (84%)	29 of 37 (78%)	
Distance jumped on reconstructed knee is:			
Greater than 105% of the contralateral leg	0 (0%)	0 (0%)	
Between 95% and 105% of the contralateral leg	7 (14%)	9 (31%)	
Between 85% and 94% of the contralateral leg	15 (29%)	9 (31%)	
Between 75% and 84% of the contralateral leg	12 (23%)	4 (14%)	
Between 65% and 74% of the contralateral leg	5 (10%)	2 (7%)	
Between 55% and 64% of the contralateral leg	4 (8%)	2 (7%)	
Less than 55% of the contralateral leg	8 (16%)	3 (10%)	
Manual-maximum test‡¶			0.12†
(-1) to <0mm	6 (10%)	2 (6%)	
0.5 to 2.5mm	49 (83%)	26 (76%)	
3 to 4.5mm	3 (5%)	5 (15%)	
≥ 5mm	1 (2%)	1 (3%)	

*Values given as the number of subjects with the percentage in parentheses.
†Unpaired Student's Test
‡The difference between the involved knee and that of the contralateral knee.
§Five subjects from the endoscopic group and four from the two-incision group did not return for the 4 month evaulation.
¶Three patients from each treatment group had bilateral ACL tears and were excluded from the laxity comparison.

cent) compared to the two-incision group (43 ± 3, range 40 to 55 per cent), (p = 0.0001). A 4% difference in the location of the tibial tunnel translates into a 2 mm difference in placement (i.e. average sagittal depth of the tibial plateau is 60 mm (13)). Roof impingement was eliminated in both treatment groups with the percentage of roof impingement being 5 per cent less in the endoscopic group (-3 ± 10, range -50 to 0 per cent) than in the two-incision group (2 ± 10, range 0 to 52 per cent) (p = 0.006).

Complications

No subjects developed a joint infection, or a deep venous thrombosis. Almost all had anesthesia in a several-square-centimeter area of skin overlying the proximal-lateral aspect of the tibia due to injury of the infrapatellar branch of the saphenous nerve, however no symptomatic neuromas were reported. In the endoscopic treatment group, an additional operation after the reconstruction was required in 16 (24%) of the subjects; 14 had removal of the hardware because of discomfort at the site of tibial fixation, one required a manipulation because of difficulty in regaining flexion past 100 degrees, and the subject with the traumatic rerupture had a second reconstruction. In the two-incision treatment group, an additional operation was required in 7 (17%) of the subjects; 5 had removal of the hardware, one had partial excision of the medial meniscus after a failed repair, and one a lateral release for anterior knee pain. There was no significant difference in the incidence of additional surgery between the two treatment groups (p=0.132).

Discussion

There did not appear to be any clear superiority of either the endoscopic or two-incision technique for reconstructing a torn ACL using direct fixation of a DLSTG graft and rehabilitating the knees without a brace. No significant differ-

Table 3. Comparison of International Knee Documentation Committee Scoring Scale of Endoscopic and Two-Incision Results at Two Years

	Normal	Nearly Normal	Abnormal	Severely Abnormal	Total No. Patients
Endoscopic Group					
Knee Function	33 (50%)	29 (44%)	3 (4.5%)	1 (1.5%)	66
Activity Level	35 (53%)	27 (40%)	3 (4%)	2 (3%)	67
Pain	37 (56%)	26 (39%)	2 (3%)	1 (1.5%)	66
Swelling	52 (78%)	11 (16%)	2 (3%)	1 (1.5%)	66
Partial Giving Way	61 (91%)	5 (7.4%)	0 (0%)	1 (1.4%)	67
Full Giving Way	65 (97%)	1 (1.4%)	0 (0%)	1 (1.4%)	67
Range of Motion	60 (90%)	5 (7.5%)	1 (1.5%)	0 (0%)	66
Pivot Shift	60 (90%)	5 (7.5%)	1 (1.5%)	0 (0%)	66
Lachmans Test	64 (96%)	1 (1.5%)	1 (1.5%)	1 (1.5%)	67
Overall Stability	59 (88%)	7 (10%)	0 (0%)	1 (1.5%)	67
Patellofemoral Crepitation	62 (94%)	3 (4.5%)	1 (1.5%)	0 (0%)	66
One-leg hop	46 (75%)	12 (19%)	3 (5%)	0 (0%)	61
Overall Score	21 (31%)	40 (60%)	4 (6%)	2 (3%)	67
Two-Incision Group					
Knee Function	36 (88%)	3 (7.3%)	2 (5%)	0 (0%)	41
Activity Level	36 (88%)	3 (7.3%)	2 (5%)	0 (0%)	41
Pain	36 (88%)	5 (12%)	0 (0%)	0 (0%)	41
Swelling	36 (88%)	4 (10%)	1 (2%)	0 (0%)	41
Partial Giving Way	36 (88%)	3 (7.3%)	2 (5%)	0 (0%)	41
Full Giving Way	36 (88%)	3 (7.3%)	2 (5%)	0 (0%)	41
Range of Motion	38 (92%)	3 (7.3%)	0 (0%)	0 (0%)	41
Pivot Shift	35 (85%)	4 (10%)	2 (5%)	0 (0%)	41
Lachmans Test	39 (95%)	2 (5%)	0 (0%)	0 (0%)	4 1
Overall Stability	35 (85%)	4 (10%)	2 (5%)	0 (0%)	41
Patellofemoral Crepitation	35 (85%)	6 (15%)	0 (0%)	0 (0%)	41
One-leg hop	31 (79%)	6 (15%)	2 (5%)	0 (0%)	39
Overall Score	26 (63%)	11 (26%)	4 (10%)	0 (0%)	41

ences were observed in thigh girth, knee extension, the single leg hop test, and stability at four months, nor was there any significant difference in the stability and the level of return to sports and work activity at two years between the two treatments.

The endoscopic technique had improved cosmesis compared to the two-incision technique, and a significantly shorter operative time by an average of 48 minutes. The shorter operative time was related to a number of factors including elimination of the opening and closing of the femoral dissection, improved instrumentation, and honing of surgical skills. Concomitant procedures including meniscal repair or excision could not be implicated as a factor as 49% of the subjects in the endoscopic group and 48% of the subjects in the two-incision group required meniscal surgery.

Rehabilitation may have been easier for the knees reconstructed with the endoscopic technique since 35% of the subjects rehabilitated their knee without the assistance of a physical therapist compared to only 7% in the two-incision group. A technique that requires less formal rehabilitation without compromising the outcome is both cost-effective and perceived as time-efficient by patients that have to balance the time demands of formal rehabilitation with work and family.

The pre-injury activity level of the two treatment groups were not perfectly matched with the percentage of subjects participating in strenuous activities being significantly greater in the two-incision group (78%) than in the endoscopic group (46%). However the percentage of subjects that resumed strenuous activities post-operatively was greater in the endoscopic group (87%) than in the two-incision group (78%). Therefore, the endoscopic procedure restored subjects that participated in strenuous activities pre-injury to normal more consistently, and it is not unreasonable to predict that the percentage of subjects returning to strenuous activities would have been greater if more subjects had initially participated in strenuous activities.

Although, the percentage of knees with IKDC scores in the normal and nearly normal categories were similar in both the endoscopic (91%) and two-incision (89%) treatment groups, 32% more knees in the two-incision group achieved a normal rating. Lower overall knee ratings in the endoscopic group were caused by a higher percentage of nearly normal ratings in the subjective subcategory of pain. A nearly normal category was assigned for pain if the subject complained of pain occurring with strenuous work or sports with the ability to perform moderate work and sports including running, twisting, and turning without symptoms. Most of the subjects complained of a general ache that was not associated with anterior knee pain, an effusion, or pain directly referable to the fixation devices. We were not able to determine the reason for the significant difference between treatment groups.

Objective stability could not be restored in 10% of knees in both the endoscopic and two-incision treatment groups at four months and two years. However, since the failure rate was similar between the two techniques it is unlikely that the method for locating and drilling the femoral tunnel that differed between the two techniques was a cause. We were concerned that customizing the placement of the tibial tunnel in the sagittal plane to adjust for variability in roof angle and knee extension and avoid roof impingement may have interfered with the femoral tunnel from being consistently positioned in an acceptable location with the endoscopic technique. The lack of any correlation between tibial tunnel placement in the sagittal and coronal planes and the percentage of impingement, and instrumented laxity at two years indicated that the stability of the knee was not affected by drilling the femoral tunnel through an impingement-free, customized tibial tunnel.

Comparing the placement of the femoral tunnel placement measured from the roentgenograms would have been a more direct method to determine if femoral tunnel position affected stability. However, consistent with the experience of others, neither the angle nor the position of the femoral tunnel could be reliably measured from roentgenograms (5, 16). In the endoscopic group, the problem was further complicated in our study by the compaction of cancellous bone into the femoral tunnel through the femoral fixation device (5). Bone compaction made the sclerotic outline of the short femoral tunnel much less distinct than the tibial tunnel. Computerized tomography and MRI were used in a pilot study to determine if they could better define the femoral tunnel than roentgenography, however the femoral fixation device produced image artifacts which further obscured the femoral tunnel.

Other evidence that the femoral tunnel can be consistently positioned in an acceptable location with the endoscopic technique was observed during in an in vivo study that measured the tension in a DLSTG graft looped around a post in an endoscopically-placed femoral tunnel. The tension in the anterior bundles increased in flexion and the tension in the posterior bundles increased in extension similar to the reciprocal behavior of the functional bands of the normal ACL. For reciprocal tensile behavior to have occurred the femoral tunnel had to be positioned partially anterior and posterior to the most isometric line. Varying the center of the femoral tunnel a few millimeters would have eliminated the reciprocal behavior. The tension in all the bundles would have behaved similarly; either increasing in flexion with anterior placement or increasing in extension with posterior placement (5).

The consistent clinical outcome using the endoscopic technique was achieved in part because of customized, anatomic placement of the tibial tunnel and avoidance of roof impingement. The method of customizing the placement of the tibial tunnel for variability in roof angle and knee extension and confirming that roof impingement was eliminated before graft implantation by free passage of an impingement rod through the tibial tunnel into the intercondylar notch with the knee in full extension is a technique that has been evaluated extensively and is consistently effective (7, 10, 13, 14).

It is unknown whether the same results can be achieved when the tibial tunnel is positioned using free-hand techniques (17) or guides that key off deformable soft tissue structures such as the ACL remnant (10) or the posterior cruciate ligament (18). These techniques do result in higher variability and non-anatomic placement of the graft (i.e. graft fibers outside the normal intraarticular pathway of the original ACL) (19). It remains to be determined whether anatomic placement of the femoral tunnel can be achieved endoscopically with these other techniques for placing the tibial tunnel.

The restoration of laxity in 90% of subjects treated with aggressive rehabilitation without a brace in this study was higher compared to other studies that used hamstring tendons and a more restricted rehabilitation program. In other studies, the percentage of knees with a < 3mm increase compared to the normal knee at either a 134 N or manual maximum anterior force was 50% (31 of 62) (20), 78% (53 of 68) (21), 83% (33 of 40) (22), and 83% (15 of 18) (23). One of the worst stability rates was reported by Pinzcewski et als in which a quadruple hamstring graft was fixed with soft tissue interference screws. At just 89N of anterior force only 72% of knees had stability restored to the normal range at two years (24).

The reason for the higher stability rate in our study may have been related to a variety of technical factors. Some of these factors may have included the use of a high strength and stiff DLSTG graft, consistent customized, impingement-free placement of the tibial tunnel, consistent posterior placement of the femoral tunnel, conservation of graft length by fixing the looped end of the graft inside a bone tunnel around a post, direct compression of the free ends of the graft to bone without using suture bridges, and improved biologic bonding by compacting bone into bone tunnels.

There are differences in the operative technique and structural properties between the Bone Mulch Screw and other cross-pin techniques that may affect the clinical outcome. With other cross-pin techniques the fixation device is inserted with the DLSTG graft already inside the femoral tunnel (23, 25). The blind insertion of the beam across the femoral tunnel prevents the surgeon from verifying that both loops of tendon are around the post and that the device is fully seated inside the femur. Slippage of one or two bundles off the beam is a potential problem. Loss of fixation and irritation of the iliotibial band from prominent hardware has required a second surgery to reinsert or remove the screw (23).

In contrast the Bone Mulch Screw is inserted before the graft which allows the surgeon to view the tip of the beam as it is advanced across the femoral tunnel into the medial wall of the tunnel. Embedding the tip insures that the graft can not slip around the tip of the beam and that the body of the screw is countersunk inside the femur avoiding hardware symptoms. The surgeon can assess the fixation by viewing both graft bundles as they are pulled around the beam by sutures (Figure 4).

It is unlikely that the strength and stiffness of the other cross-pin techniques will be as high as the Bone Mulch Screw because the diameter of the threaded portion is smaller and bone cannot be compacted into the femoral tunnel. The smaller diameter may be a reason the other cross-pins tend to migrate. Clark et al reported that migration of the cross-pin occurred in 11% of their reconstructions and necessitated a subsequent surgery to reposition the device (23). Because the diameter of the body of the other cross-pin devices is less than the Bone Mulch Screw and the devices rely on cancellous bone there is a potential that their structural properties will be inferior when tested in young human femur.

Because the structural properties of the other cross-pin devices has not been determined in young human bone their performance in patients remains unknown even though these devices are in clinical use. Yield load for a 35 and 70 mm in length cross-pin devices was determined in porcine bone and ranged from 725 to 1363N respectively. Stiffness was not measured (23). Porcine bone significantly overestimates the structural properties of fixation devices that rely on cancellous bone for fixation compared to results from tests in young human bone. For example, the yield load of soft tissue interference screws was 598 N in porcine tibia but significantly less at 350 N in young human tibia (26). Therefore the performance of the smaller diameter cross-pin devices should be assumed to be overestimated until reevaluated in young human femur.

In contrast, the Bone Mulch Screw is the only cross-pin that has been tested in young human femur. The strength of this device (1126 N) exceeds the expected loads in the ACL (750 N) (27) and ACL graft (550 N) (28) during aggressive rehabilitation, and the stiffness (225 N/mm) is within the range of the normal ACL (182 (29) to 303 N/mm (30)). The structural properties of fixation with the Bone Mulch Screw are sufficient to permit aggressive rehabilitation and are superior to interference screw fixation of the bone-patellar tendon-bone graft (412 N and 51 N/mm) (30).

Cross-pin fixation without bone compaction (23) should not be misconstrued as being the same as cross-pin fixation with bone compaction. The compaction of bone into the femoral tunnel through the Bone Mulch Screw has measurable benefits besides filling voids between the graft and tunnel wall in an effort to promote biologic bonding. The compaction of bone increases the stiffness of the fixation 41 N/mm (31), and increases friction so that the graft has reciprocal tensile behavior even though a single femoral tunnel is used (5).

This study should not be interpreted as a comparison of femoral and tibial "cross-pin" fixations because the weakest and least stiff of the fixations was the method used to fix the free-ends of the graft. The structural properties of the graft-fixation complex (i.e. femoral fixation method-graft-tibial fixation) is determined by the weakest and least stiff method of fixation because the DLSTG graft is stronger

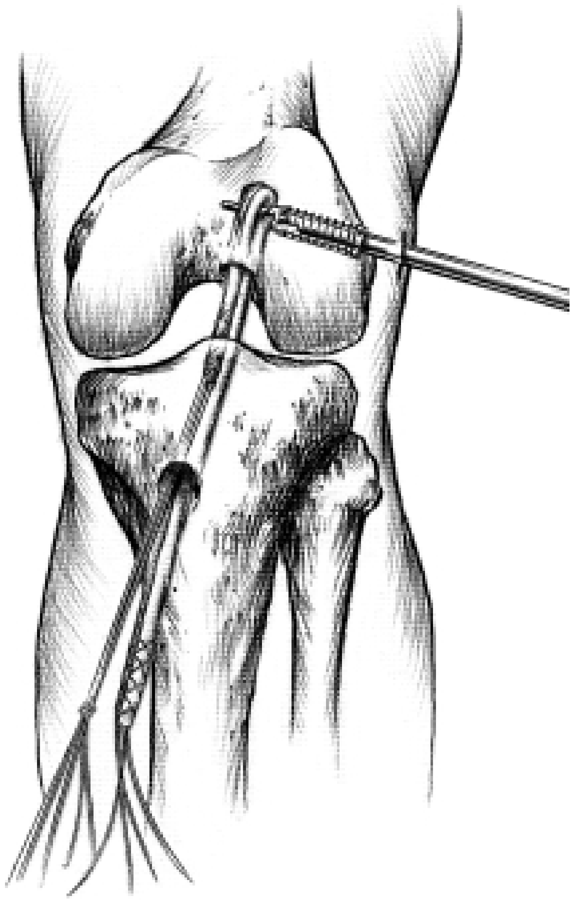

Figure 4. The femoral tunnel was nearly collinear with the tibial tunnel in the endoscopic technique. The beam of the Bone Mulch Screw was positioned 18 mm inside the femoral tunnel to conserve graft length. By pulling on the sutures attached to the DLSTG graft the passage of both the gracilis and semitendinosus tendons around the tip of the Bone Mulch Screw can be verified arthroscopically. With the knee in full exten-sion, an unmea-sured tension was applied and the graft was secured to the tibia with two soft tissue staples in sixty-three subjects and with a 20 mm in diameter soft tissue washer in four subjects.

and stiffer than currently available fixation methods (11, 26, 31). In young human femur post-fixation with the Bone Mulch Screw and bone compaction has an average strength of 1126 N and an average stiffness of 225 N/mm (31). To our knowledge the structural properties of post fixation with bone compaction in the tibia has not been reported, but is assumed to be similar for this discussion. In contrast, double staples (785 N, 118 N/mm) and single washer and screw (724 N, 126 N/mm) fixation tested in porcine tibia are both weaker and less stiff than fixation with the Bone Mulch Screw. The performance of these two methods of fixation can be expected to be less in human knees because fixation performance is overestimated when tested in more dense porcine bone (26). Furthermore, fixation using two soft tissue washers and bicortical screws tested in young human tibia is also less strong and less stiff (768 N, 181 N/mm) than fixation with the Bone Mulch Screw. The clinical outcome was more likely influenced by the methods used to fix the free ends of the graft because they were less strong and stiff than cross-pin fixation with bone compaction.

Removal of hardware continues to be the most common reason for additional surgery using the hamstring tendons as a graft. In our study a second surgery for hardware removal was required in 21% of the subjects in the endoscopic group and 12% of the subjects in the two-incision treatment group. In the endoscopic group the tibial fixation was the principle reason for hardware removal because the countersunk femoral fixation device was asymptomatic. In contrast, in the two-incision group the femoral fixation was more symptomatic because the prominent washer and screw(s) irritated the iliotibial band during flexion and extension of the knee.

Clark et al reported a similar 22% (4 of 18) incidence of hardware removal with two subjects requiring femoral cross-pin removal and two subjects requiring hardware removal from the tibia (23). Siegel et al removed washers and staples from the tibia in 26% (21 of 82) of subjects (21). Clearly, the most effective way to reduce postoperative morbidity and the associated costs of additional surgery would be to improve the tibial fixation (23).

A simple solution for hardware prominence would be to use interference screws to secure the soft tissue graft, however the strength of this fixation in young human bone is poor. Interference screw fixation of a DLSTG graft failed at 350 N in young human tibia (11, 26). The loads in the ACL during daily activities can be expected to be about 750 N (27) which exceed the failure load of the interference screw by 400 N. It remains to be determined if aggressive, brace-free, rehabilitation can be used with interference screw fixation of hamstring grafts without compromising the stability of the knee (32).

Since August 1997 we have been using a new tibial fixation (WasherLoc, Arthrotek, Inc) in an effort to reduce post-operative morbidity. The WasherLoc is countersunk inside the tibial tunnel to minimize hardware prominence and is significantly stronger (905 N) and stiffer (249 N/mm) in young human tibia than fixation with interference screws, staples, washers, and sutures. The average prominence of the WasherLoc is only 2 mm which was significantly less than staples (7 mm) and washers (7 to 8 mm) (26). Although the clinical experience is too brief (i.e. 16 months) to determine the 2 year incidence of hardware removal compression of the soft tissues overlying the WasherLoc during kneeling and laxity testing has not resulted in pain in our patients.

The decision when to permit a patient to return to unrestricted activities and sports has remained empirical because a method has not been available for measuring the strength of an ACL graft after implantation. Unnecessarily delaying the return to unrestricted activities is undesirable to the worker or athlete, but so is a premature return that could injure the graft. In our study the decision to avoid immobilization and bracing, and allowing early weight-bearing and resumption of unrestricted strengthening exercises at 4 weeks postoperatively appeared to be safe because 107 of the 108 knees that were stable at four months remained stable at two years.

The inability to determine which technique is superior is not dependent on the source of graft material. Reat et al, using autogenous bone-patellar tendon-bone as the graft, could not detect any significant differences between the outcomes of the endoscopic and two-incision technique (33). Similarly, Harner et al compared both techniques using autogenous and allograft bone-patellar tendon-bone as the graft and found no significant functional or radiographic differences at a minimum of two-year follow-up (34).

In conclusion, both techniques provided similar stability and clinical outcome at four months and two-years when the knee is reconstructed using an autogenous DLSTG graft and rehabilitated intensively without immobilization or a brace. The surgical principles for placing the tunnels and fixing the graft were the same for both treatment groups, and as this study demonstrated, similar results were achieved. Hardware prominence continues to be the primary source of postoperative morbidity for both techniques using a hamstring graft. We prefer the endoscopic technique because it is more cosmetic and quicker to perform.

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