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Single-Incision Endoscopic Anterior Cruciate Ligament Reconstruction Using Patellar Tendon Autograft

Minimum Two-Year Follow-Up Evaluation*

Bernard R. Bach, Jr.,† MD, Matthew E. Levy, MD, John Bojchuk, MS, ATC, Steven Tradonsky, MD, Charles A. Bush-Joseph, MD, and Nazeer H. Khan

From the Department of Orthopaedic Surgery, Section of Sports Medicine, Rush Medical College, Rush-Presbyterian-St. Luke's Medical Center, Chicago, Illinois

ABSTRACT

We conducted a retrospective, minimum 2-year follow-up study to evaluate the effectiveness of a single-incision endoscopic anterior cruciate ligament reconstruction technique using patellar tendon autograft without extraarticular augmentation and followed by accelerated rehabilitation. One hundred three patients were evaluated (mean followup, 36 months; range, 24 to 55). There were significant improvements in physical examination test results (Lachman, anterior drawer, and pivot shift) postoperatively, and 94 patients (91%) had negative pivot shift results. KT-1000 arthrometric testing showed a significant reduction in manual maximum anterior translation and side-to-side differences at followup. Good range of motion was achieved. Patients with asymmetric prone heel heights usually had hyperextension in the contralateral knee. Functional tests showed 4% to 6% differences in side-to-side comparisons for a timed single-legged hop, single-legged hop for distance, and vertical jump. Postoperatively, the results of the Tegner scale were similar to preinjury scores. The mean results of the Hospital for Special Surgery scale (90), Lysholm score (89), and Noyes sport function score (90) were all excellent or good. Only 5 patients (5%) required reoperations for flexion contractures. Ninety-six patients (93%) reported they were "mostly" or "completely" satisfied, and 98 (95%) would recommend the procedure to others. These results demonstrated encouraging outcome using this single-incision technique.

The purpose of this study was to review our initial experience with a single-incision arthroscopically assisted technique of ACL reconstruction using patellar tendon autograft secured in full extension. Our hypothesis was that reliable results could be achieved using this technique combined with early range of motion and weight-bearing. Additional goals of this study were to assess function in the ACL-reconstructed knee, to compare postoperative rating scales, and to evaluate patient satisfaction.

MATERIALS AND METHODS

Patients at our institution who underwent single-incision arthroscopically assisted ACL reconstruction using patellar tendon autograft without extraarticular augmentation between October 1991 and April 1994 composed the study group for this retrospective, minimum 2-year, follow-up study. Patients were selected from a computerized data base maintained by the senior author (BRB), who performed all the surgical procedures. During this period, 163 patients underwent a variety of 168 knee ligament procedures. Exclusionary criteria for this study included bilateral reconstructions, concomitant extraarticular augmentation, hamstring tendon autograft reconstruction, allograft ACL reconstruction, revision ACL reconstruction, multiligament reconstruction, associated posterolateral reconstruction, combined high tibial osteotomy-ACL reconstructions, or medical illness that precluded follow-up evaluation. One hundred twenty-eight patients

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† Address correspondence and reprint requests to Bernard R. Bach, Jr., MD, Rush-Presbyterian-St. Luke's Medical Center, 1725 W. Harrison St., Suite 1063, Chicago, IL 60612.
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met our inclusionary criteria. One hundred three of these patients (80% followup) were evaluated in person between September 1, 1995, and April 1, 1996. Twenty patients (16%) were identified and unable to participate because of geographic constraints. Five patients (4%) were lost to followup.

Surgical Technique

A single-incision arthroscopically assisted technique, as described by Hardin et al.,[28] was employed for all patients (Fig. 1). The principles of adequate notch preparation and notchplasty, proper placement of drill holes, rigid fixation of the graft using interference screws, and securing the tibial bone plug with the knee in extension were employed.[11] In general, a 10-mm, middle-third patellar tendon graft was obtained with 25-mm bone plugs on either end. Commercially available aiming devices were used for both femoral and tibial tunnel placement. Determination of screw length and diameter were made intraoperatively, but in general a 7 × 25 mm cannulated interference screw was used on the femoral side and a 9 × 20 mm screw was used on the tibial side. The graft was placed with the cortical edge oriented posteriorly within the femoral tunnel, and the screw was placed anteriorly to minimize soft tissue injury to the graft. This orientation also placed the graft more posteriorly. After femoral fixation, the knee was cycled multiple times to assess graft fixation and gross isometry. The tibial bone plug was rotated away from the lateral intercondylar wall, and the tibial interference screws were placed anteriorly on the cortical surface of the bone plug. All tibial screws were secured with the knee in complete extension or hyperextension while applying tension to the sutures on the tibial plug. Graft position, tightness, and clearance were inspected before closure. In less than 10% of cases the tibial bone plug was secured to the tibia with staples or a screw and post if graft construct-tunnel mismatch existed. If meniscal repair was performed, the sutures were secured with the knee in complete extension before graft fixation.

Rehabilitation

No patient had surgery performed until he or she had a near normal range of motion and minimal or no effusion. Postoperatively, patients were seen in physical therapy where they underwent gait training, straight leg raising, prone heel hangs, and range of motion exercises. The patients were generally admitted to the hospital overnight, and the mean hospitalization was 1.3 days for the study group. While hospitalized, patients used a continuous passive motion machine. Full weightbearing was permitted immediately after surgery. A hinged knee brace locked in full extension was used for the first 6 weeks postoperatively to protect the donor site. Patients were allowed to unlock or remove the brace for range of motion exercises. Patient comfort was used as a criterion for discontinuation of crutches, which usually occurred by 1 week after surgery. A formal supervised rehabilitation program was prescribed using a standard protocol so that

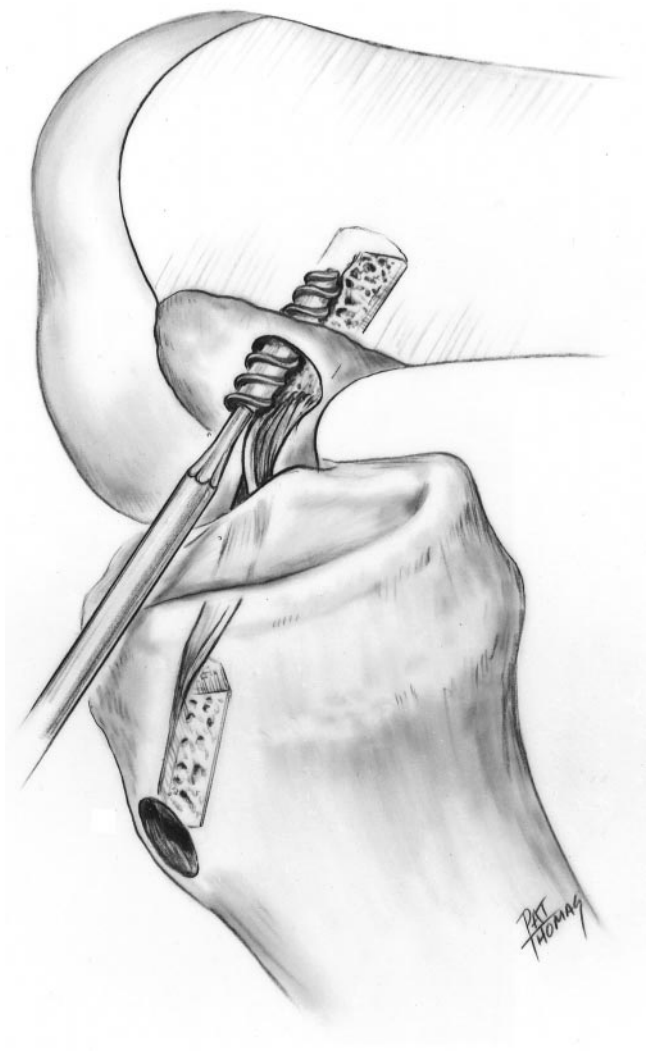

Figure 1. This lateral illustration depicts the salient features of the endoscopic or single-incision technique. The femoral tunnel is placed at the 11 o'clock (right knee) or 1 o'clock (left knee) position. A commercially available femoral guide is used to assist in consistent placement of a 10-mm femoral tunnel, which leaves a 1- to 2-mm posterior cortical rim. A relatively steep (55°) 11-mm tibial tunnel is created. The graft is passed using a "push-in" rather than "pull through" technique. The cortical edge of the femoral bone plug is oriented posteriorly. A flexible pin is placed anteriorly in the graft tunnel interface and, with the knee further flexed, a cannulated 7 × 25 mm interference screw is placed on the anterior cancellous surface. The knee is cycled several times to assess graft fixation. The tibial plug is secured with the knee in complete extension or hyperextension. The cannulated interference screw is positioned anteriorly along the cortical surface of the bone plug. (Reprinted with permission from Hardin et al.[28])

patients could have their postoperative rehabilitation at outside facilities. This formal rehabilitation program was initiated within the 1st postoperative week. In general, bicycling was allowed by 2 weeks, use of stair climbing machines was permitted at 4 to 6 weeks, straight ahead jogging was allowed at 12 to 16 weeks, and gradual return to sports was allowed between 4 and 6 months postoperatively if rehabilitation criteria were met. Some patients were allowed to return to sports at earlier intervals if their rehabilitation progressed more rapidly. A custom ACL orthosis was worn from 6 weeks to 6 months for activities of daily living and was used for sports from 6 months to 1 year after surgery. The rehabilitation program was not modified for those patients who underwent meniscal repairs.

Physical Examination

The follow-up physical examination of both knees was performed by one of our two sports medicine fellows (ST or MEL), who evaluated patients independently of the treating surgeon (BRB). The evaluation included supine range of motion measurements with a goniometer, prone heel height differences measured to the nearest centimeter, thigh circumference measurements, and evaluation of patellofemoral compartment crepitation. Patellofemoral crepitation was graded as 0 (absent), 1+ (mild), 2+ (moderate), or 3+ (severe). Varus-valgus stability at 0° and 30°, Lachman, anterior and posterior drawer, and pivot shift tests were performed. Ligamentous laxity was graded as 1+ (0 to 5 mm), 2+ (6 to 10 mm), or 3+ (>10 mm). The pivot shift phenomenon was graded as 1+ (slip), 2+ (jump), or 3+ (transient lock) in the position of thigh abduction and external rotation, which maximizes the pivot shift phenomenon.[15]

Functional Examination

All patients underwent bilateral knee functional testing at the follow-up examination by an experienced athletic trainer (JB). The functional indexes recorded were timed single-legged 6-meter hop, measured single-legged hop, and single-legged vertical jump. All patients underwent three trials of each functional test on each leg; the trials were then averaged and reported as side-to-side percentage differences.

Arthrometric Examination

Each knee was tested preoperatively and postoperatively with the KT-1000 arthrometer (MEDmetric, San Diego, California) by an experienced independent examiner (JB). Testing was performed as described by Daniel et al.[14,23] Anterior manual maximum and manual maximum side-to-side differences were calculated. An arthrometric failure was defined as side-to-side difference of more than 5 mm.

Questionnaire

A detailed questionnaire was developed so that the modified Hospital for Special Surgery (HSS) knee ligament questionnaire and Lysholm and Noyes Cincinnati rating scales could be subsequently determined.[5,33,37,57] The questionnaire was completed by the patient to eliminate interviewer bias.

Subjective Assessment

Subjective patient satisfaction was evaluated using several methods. Patients were asked to respond with a simple "yes" or "no" if they would consider having the procedure on the opposite knee if faced with similar circumstances. They were asked to categorize their satisfaction level as "completely," "mostly," or "somewhat" satisfied, or "dissatisfied."

Data Acquisition and Analysis

To eliminate the surgeon's bias, review of the chart and recording of the data were performed independently of the treating surgeon by the sports medicine fellows. Preoperative, intraoperative, and postoperative data were obtained to supplement the follow-up evaluation. All data were recorded on computerized scantron sheets so that the data could be automatically input into a computer program. Descriptive statistics, analysis of variance testing (ANOVA), chi-square analysis, and linear regression analysis were employed where applicable. Statistical analysis was performed using the SPSSX software package (SPSS, Inc., Chicago, Illinois). Statistical significance was established at $P < 0.05$.

RESULTS

The average age of our patients at the time of injury was 25.2 years (range, 10.4 to 52.7; SD, 9.4). The average age of our study population at the time of followup was 30.7 years (range, 15 to 56; SD, 9.4). There were 65 men and 38 women. Fifty-six right knees and 47 left knees had ACL reconstructions. The initial injury was sports related in 86 patients (84%).

The mean interval from injury to reconstruction was 34 months (range, 2 weeks to 249 months; SD, 54.6). No knee was operated on within 2 weeks after the injury. Nineteen knees (18%) had reconstructions at less than 6 weeks after injury, and 84 knees (82%) had reconstructions more than 6 weeks after injury. Overall, 44 patients (43%) had reconstructions at less than 6 months after injury, 23 patients (22%) had reconstructions between 6 and 23 months after injury, and 36 patients (35%) had reconstructions at more than 2 years after injury. The mean interval from surgery to followup was 36 months (range, 24 to 55; SD, 11.5).

Previous Surgical Procedures

Before the single-incision ACL reconstruction described here, 45 patients (44%) had other surgical procedures

performed. Thirty-six patients had one prior procedure, and nine patients had two prior procedures.

Associated Procedures and Surgical Findings

At the time of the ACL reconstruction, eight patients underwent medial meniscal repairs and five patients underwent lateral meniscal repairs. One patient had a medial meniscal repair combined with a partial lateral meniscectomy. Eighteen patients (17%) had partial medial meniscectomies, and 21 patients (20%) had partial lateral meniscectomies. Untreated, stable, partial-thickness meniscal tears are not reported.

At surgery, varying degrees of chondromalacia were noted (Table 1). Overall, 52 patients (50%) had some degree of chondromalacia in at least one of the three articular compartments. Chondromalacia patellae was noted in 31 patients (30%). Chondromalacia was observed on the medial femoral condyle in 29 patients (28%), on the medial tibial plateau in 16 patients (16%), on the lateral femoral condyle in 22 patients (21%), and on the lateral tibial plateau in 22 patients (21%). Loose bodies were removed in four patients (4%).

A pneumatic tourniquet was used in 85 patients (83%). When used, the average tourniquet time was 61 minutes (range, 8 to 152; SD, 28.1).

Physical Examination

Preoperative. Before surgery, 2 patients (2%) had negative Lachman results, 18 patients (17%) had 1+ results, 54 patients (52%) had 2+ results, and 22 patients (21%) had 3+ results. Six patients had abnormal Lachman examination results that were not graded, and one result was not reported. The anterior drawer was graded as negative in 23 patients (22%), 1+ in 50 patients (49%), and 2+ in 16 patients (16%). The anterior drawer test result was not available for the remaining 14 patients. The preoperative pivot shift test results were 1+ in 34 patients (33%), 2+ in 28 patients (27%), and 3+ in 6 patients (6%). Patient apprehension precluded the determination of the pivot shift in the remaining 35 patients (34%). All patients who had negative pivot shift results preoperatively demonstrated a positive pivot shift while under anesthesia, except one patient who had no demonstrable ACL tissue at arthroscopic surgery. One patient had grade 1 varus laxity preoperatively, five patients had grade 1 valgus laxity, and three patients had grade 2 valgus laxity.

Postoperative. After ACL reconstruction, 76 patients (74%) had negative Lachman test results. Twenty-five patients (24%) had grade 1 Lachman results with a firm end point. Two patients had grade 2 Lachman results. Ninety-three patients (90%) had negative anterior drawer results at follow-up examination, and 10 patients (10%) had grade 1 anterior drawer results. Ninety-four patients (91%) had negative pivot shift results (Fig. 2). Nine patients (9%) had grade 1 pivot shift results. There were no grade 2 or 3 pivot shift results at followup. The postreconstruction improvements in the Lachman, anterior drawer, and pivot shift test results were statistically significant when compared with preoperative or examination under anesthesia findings ($P < 0.0001$).

Postoperatively, the range of motion as measured by a goniometer was 1° of hyperextension (range, 10° hyperextension to 10°; SD, 2.8) to 137° of flexion (range, 115° to 155°; SD, 8.0). Knee extension was also assessed by evaluation of prone heel height differences (Fig. 3). The mean prone heel height difference was 1.4 cm (range, 0 to 10; SD, 1.7). Sixty-three patients (61%) had less than 1 cm prone heel height difference. Forty patients (39%) had mild flexion contractures measured as 2 cm or more prone heel height difference. Eighty-four patients (82%) had 2 cm or less difference on prone heel height evaluation. In those patients with prone heel height differences of more than 1 cm, the difference was largely due to the hyperextension in the nonoperated knee.

At follow-up evaluation 14 patients (14%) had mild pain associated with ascending or descending stairs, and 41 patients (40%) had patellofemoral crepitus. Thirty-five of the 41 patients (85%) had mild grade 1 crepitus. Thigh girth measurements revealed 1 cm or less difference from the contralateral leg in 76 patients (74%) (mean, 1 cm;

TABLE 1
Articular Cartilage Abnormalities Noted at ACL Reconstruction

Joint surface	Grade[a]			
	1	2	3	4
Patellofemoral	13	5	13	0
Medial femoral condyle	11	5	12	1
Medial tibial plateau	11	3	1	1
Lateral femoral condyle	6	6	10	0
Lateral tibial plateau	16	1	5	0

[a] Grades: 1, blistering; 2, fissuring; 3, fragmentation; 4, exposed bone.

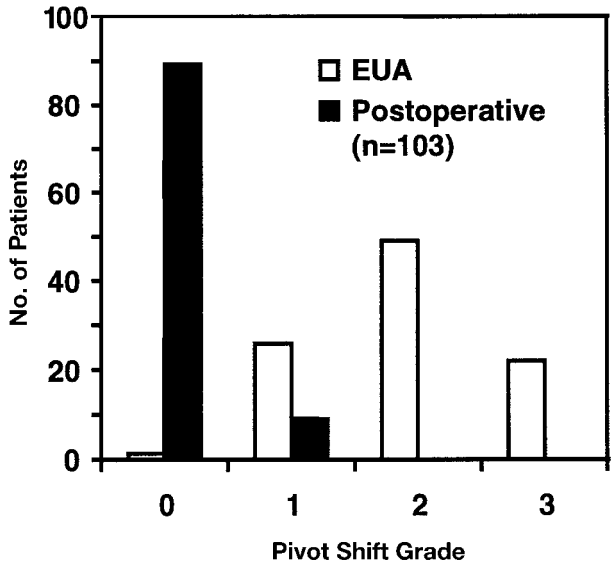

Figure 2. Comparison of examination under anesthesia (EUA) and postoperative pivot shift test results.

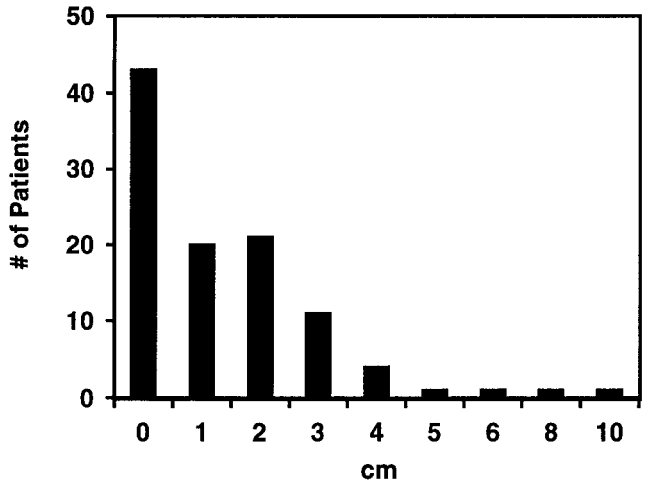

Figure 3. Postoperative prone heel height assessment.

range, 0 to 4 cm; SD 0.97). Twenty-seven patients (26%) had thigh girth atrophy of more than 1 cm. No statistical correlation was established between the variables of prone heel height asymmetries, thigh girth atrophy, patellofemoral crepitation, and patellar pain symptoms as defined by pain associated with stair climbing.

Functional Examination

The functional parameters measured included a timed single-legged 6-meter hop, a single-legged hop for distance, and a vertical jump. The mean deficit for the affected knee was 4% (median 0%; range, −56% to 22%; SD, 11%) for the timed single-legged hop. A mean deficit of 5% (median, 3.5%; range, −46% to 32%; SD, 10%) was observed on the single-legged hop. A mean deficit of 6% (median, 5%; range, −47% to 46%; SD, 15%) was noted for the vertical jump. For the three functional tests, 88%, 92%, and 85% of patients , respectively, had less than 10% side-to-side deficits (Table 2). Interestingly, 40% (37 of 93) of patients tested better on the affected knee than on the contralateral knee on the timed single-legged hop; 67% (61 of 93), on the single-legged hop for distance; and 66% (61 of 92), on the vertical jump test.

Arthrometric Examination

Preoperative. KT-1000 arthrometric testing was recorded on 86 patients. The mean manual maximum translation was 11.9 mm (range, 5.0 to 23; SD 3.5). The mean side-to-side difference was 6.5 mm (range, −5 to 15; SD, 3.5). Manual maximum testing revealed statistically significant differences in injured and uninjured knees preoperatively ($P < 0.0001$). The side-to-side difference was 3 mm or less in 10 patients (12%), between 3 and 5 mm in 16 patients (18%), and 5 mm or more in 60 patients (70%). All uninjured contralateral knees demonstrated less than 10 mm of manual maximum translation.

Postoperative. KT-1000 arthrometric testing was performed on all patients postoperatively. The mean manual maximum translation was 6.3 mm (range, 2 to 16; SD, 2.4). The mean side-to-side difference was 1.1 mm (range, −6 to 7; SD, 2.3). Eighty-six patients (83%) had side-to-side differences of 3 mm or less, 14 patients (14%) had differences between 3 and 5 mm, and 3 patients (3%) had differences of 5 mm or more. Of the three patients who met our criteria for failure by arthrometric evaluation (side-to-side difference >5 mm), none demonstrated a positive pivot shift result. Statistically significant differences were observed in the reductions in manual maximum translation values in the affected knee from pre- to postoperative levels ($P < 0.0001$). There was no statistical difference in the contralateral knees when compared preoperatively and postoperatively. Postoperatively, there was no statistical difference in reconstructed and contralateral knees. Statistically significant reductions were observed in the side-to-side differences (Fig. 4) postoperatively when compared with preoperative findings ($P < 0.0001$). Twenty-two patients (21%) had "tighter" knees by KT-1000 arthrometric testing, demonstrated by a negative side-to-side difference (mean, −2.1 mm; range, −0.5 to −6). The subgroup of patients with tighter knees by arthrometric testing exhibited no differences with respect to patellar pain symptoms, knee flexion contracture, patellofemoral crepitus, functional indexes, subjective satisfaction, or radiographic changes from the group as a whole. These observations are consistent with our previous data reported on two-incision arthroscopically assisted ACL reconstruction patients with a tighter knees on arthrometric testing.[12]

TABLE 2
Distribution of Functional Testing Comparisons of Side-to-Side Testing

Score[a]	Timed single-legged hop *N* (%)	Single-legged hop *N* (%)	Vertical jump *N* (%)
>−20% deficit	2 (2)	4 (4)	6 (7)
−19% to −10%	9 (10)	3 (3)	8 (9)
−10% to 0%	45 (48)	25 (27)	17 (18)
0%—10%	33 (35)	50 (54)	40 (43)
10%—20%	2 (2)	10 (11)	14 (15)
>20%	2 (2)	1 (1)	7 (8)
% within 10%	88%	92%	85%
Total	93	93	92

[a] Represents comparison with the normal knee. Negative values represent inferior results on functional testing in the affected knee; whereas positive results indicate that the affected knee performed better. Tests were performed three times and averaged.

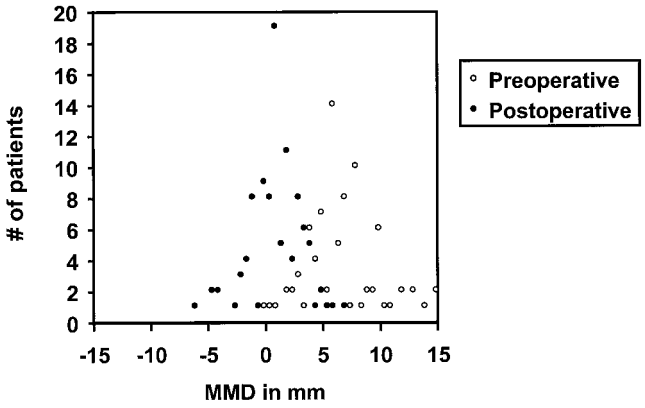

Figure 4. Comparison of preoperative and postoperative KT-1000 manual maximum side-to-side differences (MMD).

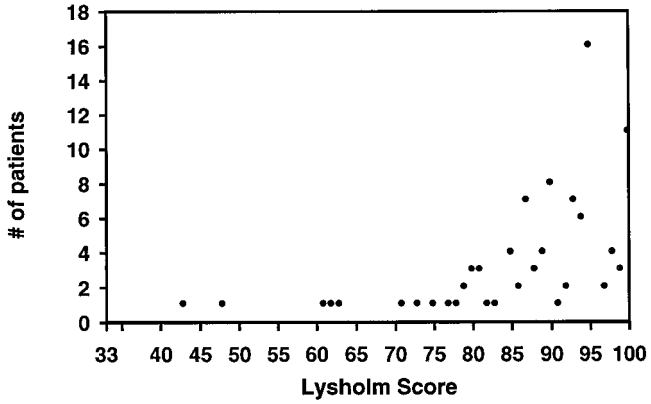

Figure 6. Postoperative Lysholm scores.

Rating Scales

The mean retrospective Tegner rating before injury was 7.3 (range, 4 to 9; SD, 1). The mean Tegner rating after injury but before surgery was 3.5 (range, 0 to 7; SD, 1.4). The mean Tegner rating after surgery was 6.5 (range, 2 to 9; SD, 1.5). The changes from preinjury to postinjury ratings and postinjury to postoperative ratings were significant ($P < 0.0001$). The preinjury and postoperative Tegner ratings were not significantly different.

The mean postoperative modified HSS score was 90 (range, 72 to 100; SD, 6.8). This scoring system defines an excellent result as 90 to 100, good as 80 to 89, fair as 70 to 79, and poor as less than 70. There were 62 excellent results (61%), 33 good results (33%), and 6 fair results (6%) (Fig. 5).

The mean postoperative Lysholm score was 89 (range, 43 to 100; SD,10.2). Stratification of these results revealed 62 patients (60%) between 90 and 100, 29 patients (28%) between 80 and 89, 7 patients (7%) between 70 and 79, and 5 patients (5%) less than 70 (Fig. 6).

The mean postoperative Noyes sports activity scale was 88 (median, 95; range, 0 to 100; SD, 15.1). The mean postoperative Noyes function activities of daily living score was 37 of a possible 40 (range, 20 to 40; SD, 3.6). The mean postoperative Noyes function sports score was 90 (range, 33 to 100; SD, 12.6). The mean postoperative Noyes problems with sports score was 85 (range, 30 to 100; SD, 15.5).

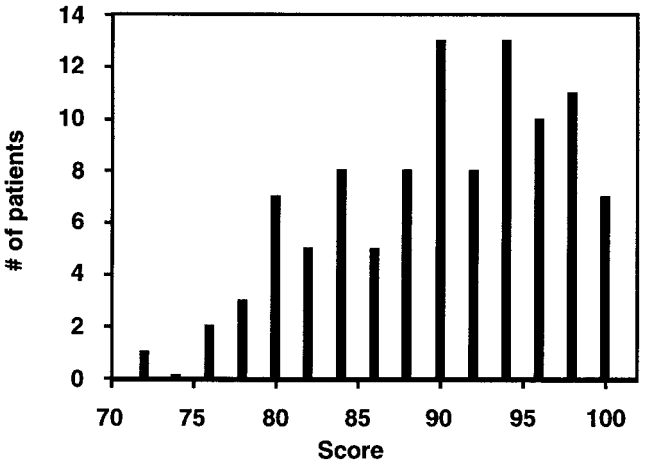

Figure 5. Postoperative HSS knee ligament rating scale results.

When patients were asked to indicate their change in sports activity level using the Noyes scale, 42 (41%) indicated no change in sports and no problems during sports, and 19 (18%) indicated no change in sports activity and moderate problems during sports. Nineteen patients (18%) indicated a decrease in sports activity with no problems, and 11 (11%) stated a decrease in level of sporting activity with moderate problems. Six patients (6%) indicated a decrease in sporting activity unrelated to the knee, two (2%) stopped all sporting activity because of problems with the knee, and two patients (2%) stopped all sporting activity because of problems unrelated to the knee.

There was a significant difference in clinical results, as determined by the Noyes sports functional score ($P = 0.026$), and the interval to surgery using the stratified periods (<6 months, 6 to 23 months, and >2 years). There were no significant differences in interval to surgery, however, when compared with the HSS and Lysholm scores.

Subjective Results

Ninety-five of 100 patients questioned (95%) indicated that, given similar circumstances, they would undergo the procedure again. Ninety-two patients (92%) indicated they were completely or mostly satisfied with the surgical procedure. Seven patients (7%) were somewhat satisfied, and one patient (1%) was dissatisfied. Of those eight patients who stated they were only somewhat or not satisfied, five indicated that they would undergo the procedure again. Two patients who were somewhat or not satisfied had second surgical procedures (one for a retorn meniscus and one for knee flexion contracture).

A 10-cm ruled visual analog scale was used to assess overall satisfaction compared with the opposite knee. The mean preinjury subjective score was 9.3 (range, 3 to 10; SD, 1.7). Postoperatively, 65 of 99 subjects (66%) ranked

the reconstructed knee from 8 to 10, 29 patients (29%) ranked the knee from 5 to 7, and only 5 patients (5%) ranked the knee less than 5. The average postoperative score using the visual analog scale was 7.8 (range, 3 to 10; SD, 1.6).

Complications

There were no infections, patellar fractures, infrapatellar tendon ruptures, neurovascular complications, thrombophlebitis, or pulmonary emboli. Fifteen patients (15%) required reoperations. Five (5%) patients had symptomatic knee flexion contractures in which a characteristic intercondylar notch fibroproliferative nodule (cyclops lesion) was debrided. Seven patients (7%) with stable knees required arthroscopic evaluation for meniscal tears. Three of these tears were previously repaired menisci, which represented 23% of our meniscal repairs, and four were new tears.

DISCUSSION

This study demonstrates that an endoscopic technique for ACL reconstruction using a central-third patellar tendon autograft secured in full extension results in reliable stability when combined with a postoperative protocol that included immediate weightbearing and range of motion.

Our incidence of a postoperative positive pivot shift phenomenon was 9%. Of those knees that demonstrated an abnormal pivot shift result, all were graded as 1+. Some authors combine negative and 1+ pivot shift test results as normal; others note a statistical reduction in the individual pivot shift grade. Using strict criteria, we consider patients with a positive postoperative pivot shift result as having failed results, despite their high subjective satisfaction and functional levels. Our stability rates are comparable with those of other studies on arthroscopically assisted ACL reconstruction, despite the fact that our patients were enrolled in an accelerated rehabilitation protocol, were permitted immediate full weightbearing, and the graft was secured in complete extension.[2,3,6–9,17,19,21,24,29–31,33,34,39,40,45,46,56,58]

The high percentage of patients that demonstrated a negative pivot shift at follow-up evaluation confirms our opinion that extraarticular augmentation is unnecessary. These findings agree with those of O' Brien et al.,[38,39] who reported that in patients who underwent reconstruction via arthrotomy there were no differences in subjective findings of instability or arthrometric results between those patients who had intraarticular reconstructions and those who had combined intra- and extraarticular reconstructions. Shelbourne and colleagues,[43,48,49,52] Aglietti et al.,[2] Bach et al.,[12] and Sgaglione et al.[45,47] have also concluded that extraarticular augmentation is unnecessary.

Daniel et al.[24] reported a significant deterioration in radiographic and bone scan findings in ACL-reconstructed knees when compared with the contralateral, noninjured knee. Of significance in their population was that in 43 patients with early reconstructions (<3 months), there was a 64% incidence of a positive postoperative pivot shift results, and only 33% of these knees had side-to-side arthrometric differences of less than 3 mm. In their 33 patients who had reconstructions 3 months or more after injury, the side-to-side difference was less than 3 mm in 30%, and the incidence of positive postoperative pivot shift was 48%. In our opinion, the presence of a positive pivot shift result postoperatively is an objective measure of surgical failure of the reconstruction. The radiographic and bone scan observations that Daniel et al. noted were made in subgroups of patients who had an unacceptably high failure rate.

Evaluation with the KT-1000 arthrometer provides another objective parameter of knee stability. Our arthrometric data compared favorably with our clinical findings. Our KT-1000 arthrometric data are similar to those reported by Buss et al.,[19] Sgaglione and Schwartz,[46] Harner et al.,[29] Arciero et al.,[10] and O'Neill.[40] Eighty-three percent of our patients had side-to-side differences of 3 mm or less. Four patients had differences of 5 mm or more, which met our criteria for arthrometric failure. The reductions in postoperative manual maximum translation and manual maximum differences were significant ($P < 0.0001$).

The timing of surgical intervention has received considerable attention.[22,26,29,36,41,53] Our average interval from injury to reconstruction was 34 months. Ten percent of our patients had their reconstructions performed at less than 6 weeks after injury. In those patients who had surgery at less than 6 weeks after injury, the principles of obtaining full or nearly full range of motion before reconstruction were emphasized. A higher reoperation rate was not demonstrated in this subgroup. Shelbourne and Nitz[49] and Harner et al.[29] independently demonstrated that knee flexion contractures and postoperative stiffness can be diminished if surgery is delayed for 3 or 4 weeks after injury. In our opinion, recovery of range of motion and resolution of postinjury inflammation are probably more important factors than an absolute time period in the timing of ACL reconstruction.

The postoperative range of motion in our patients was excellent. Our reoperation rate for symptomatic knee flexion contracture was 5%. Despite having 41 patients (40%) with prone heel height differences of 2 cm or greater, our average extension measured by goniometer was 1° of hyperextension. We attribute these minimal prone heel height differences to the hyperextension noted in the contralateral knees. Shelbourne and Nitz defined knee flexion contractures as asymmetric prone heel heights that take into account the contralateral knee hyperextension, and Harner et al.[29] described knee flexion contracture as greater than 10° loss of extension. Two of our patients lost 10° of extension. In this study and our previous report on the two-incision technique using patellar tendon autograft evaluated at a 2- to 4-year postoperative interval, we were unable to establish a statistical relationship between knee flexion contractures and the variables of patellar pain, thigh girth atrophy, patellar crepitation, and postoperative rating scales.[12]

Patellofemoral pain symptoms after ACL reconstruction have received considerable attention.[1,4,11,20,32,34,42,44,51,53,55]

Patellofemoral pain has been attributed to preexisting patellofemoral disease cartilage, articular damage at the time of ACL injury, preoperative range of motion, violation of the extensor mechanism, closure of the patellar tendon rent, tourniquet times, postoperative knee flexion contracture, and inappropriate postoperative rehabilitation. Proponents of hamstring tendon ACL reconstructions report few problems with patellofemoral pain symptoms.[27,31,45,47] The incidence of patellofemoral pain after hamstring tendon ACL reconstructions has ranged from 12% to 28%.[27,31,32,45,47] Weiss et al.[58] reviewed patellar pain symptoms in their 50 hamstring tendon, 37 patellar tendon allograft, and 50 patellar tendon autograft patients. They reported a preoperative patellar pain incidence of 17%, 14%, and 26%, respectively, and a postoperative patellar pain incidence of 14%, 22%, and 47%, respectively.

In this study, 14 patients (14%) had patellofemoral pain, defined as difficulties ascending or descending stairs. In a previous report of two-incision arthroscopically assisted ACL reconstructions using patellar tendon autograft, the senior author noted that 18% of the cohort had mild patellar pain symptoms with stair climbing.[11] In the Weiss study, statistical correlation was established between difficulty with stairs and problems with squatting ($P < 0.05$). When patellofemoral pain was defined as difficulties with ascending or descending stairs, there was no significant relationship to the presence of a knee flexion contracture, thigh girth atrophy, prone heel height differences, patellofemoral crepitus, or age stratified by decade. Forty percent of our study group demonstrated some degree of patellofemoral crepitus, but this did not correlate with symptomatic patellofemoral pain.

The low incidence of patellar pain noted in this study contrasts with other studies that have used patellar tendon autografts.[1,19,34] Our results compare favorably with the incidence of patellar pain reported in nonoperatively treated ACL-deficient knees or with hamstring tendon reconstruction techniques.[18,27] The incidence of patellar pain is slightly less than our previously reported data on two-incision arthroscopically assisted ACL reconstructions evaluated at 2 to 4 years postoperatively ($N = 62$ patients) and equal to our group ($N = 97$ patients) evaluated at 5 to 9 years postoperatively.[13] Our low incidence of patellar pain is likely multifactorial. Intraoperatively, the patellar defect is bone grafted, the patellar rent is reapproximated, and the graft is secured in full extension to avoid overtightening the knee. Postoperatively, all patients were enrolled in an early accelerated rehabilitation protocol that emphasized quadriceps muscle strengthening, patellar mobilization, and obtaining immediate knee extension. Rehabilitation was focused on closed kinetic chain exercises, open kinetic chain quadriceps muscle extension exercises were used minimally, and isokinetic quadriceps muscle training was avoided. In general, it was interesting to note that patients reported that patellar pain symptoms dissipated over time. Lateral release was not routinely performed at the time of surgery as advocated by some authors.[48]

Shelbourne and Trumper[51] recently retrospectively reviewed 602 patients to assess patellofemoral problems after patellar tendon autograft ACL reconstructions. A 100-point patellar pain (kneecap) score stratified for five categories assessed 1) pain with strenuous work or sports, 2) pain while climbing stairs, 3) pain with prolonged sitting, 4) pain with activities of daily living, and 5) pain while kneeling. Overall, the mean score was 89.5. There was no significant difference when compared with results from a control group of young patients with normal knee examinations (mean score, 90). There were no differences in patellar pain scores in subgroups of patients with ACL reconstructions and grade 3 or 4 chondromalacia compared with those with normal patellar surfaces. The authors concluded that patellar pain was not a significant problem in patients with patellar tendon autografts who undergo an accelerated rehabilitation program postoperatively, although they did not report their actual incidence of patellar pain symptoms.

When comparing the operated to the nonoperated knee, we saw no statistical difference in the results of the three functional tests used for evaluation. The mean difference compared with the other leg on average was 5% on each of the tests. Daniel et al.[25] reported a less than 10% side-to-side difference in the single-legged hop for distance in 95% of 100 uninjured subjects. Isokinetic testing was not used in our study because costs, the logistics of scheduling at an outside facility, and patient time were considered. Furthermore, Daniel et al.[23] and Barber et al.[16] indicated that functional testing is a more reliable indicator of functional recovery than isokinetic testing.

Postoperative rating scales have been used to compare results in ACL reconstructions. The Tegner activity scale and Lysholm score are the most commonly used scores.[32,57] The significant improvement in Tegner activity levels after reconstruction when compared with the preoperative Tegner score underscores the importance of this procedure. The modified HSS score and Noyes function, activities of daily living, and sports scales were also employed.[37] This is our second ACL follow-up study reporting multiple scoring scales that facilitate cross comparison with other studies. Our good and excellent results compare favorably with the results of Karlson et al.,[31] O'Brien et al.,[38] Buss et al.,[19] and Arciero et al.[10] who have reported clinical follow-up studies using two-incision ACL reconstruction techniques with either patellar tendon or hamstring tendon grafts. There is little information currently available in the literature regarding endoscopic ACL reconstruction clinical results.

Sgaglione and Schwartz[46] retrospectively compared 45 consecutive two-incision and 45 consecutive endoscopic ACL reconstructions that used patellar tendon autografts. The follow-up intervals were 24 months (range, 18 to 31) for the endoscopic group and 41 months (range, 24 to 77) for the two-incision group. No statistical differences were noted for stability in their reported abstract. The KT-1000 arthrometric side-to-side differences were less than 3 mm in 79% and 82% of the patients, respectively. Good-to-excellent results were reported in 80% of the endoscopic group and 89% of the two-incision group. A statistically significant reduction in operative time and hospitalization

was observed for the endoscopic group. Overall, the authors concluded that satisfactory results could be achieved with either technique.

Harner et al.[30] prospectively studied 31 two-incision and 32 single-incision patellar tendon autograft and allograft reconstruction patients. At short-term evaluation, ranging from 24 to 35 months, they concluded that there was no significant difference in postoperative rating scales. At follow-up evaluation, they observed that 19% of their patients had grade 2 pivot shift results (glide). The KT-1000 arthrometer manual maximum differences demonstrated that 62% of patients had less than 3 mm differences, 35% had 3 to 5 mm differences, and 3% had more than 5 mm differences on side-to-side testing. They reported that 81% of their endoscopic patients had normal or near normal ratings on the International Knee Documentation Committee scale at follow-up evaluation. They noted that there did not appear to be any significant differences in subjective or objective results with these two techniques, but they concluded that the single-incision technique was less invasive and cosmetically superior.

Arciero et al.[10] also compared 51 patients with two-incision reconstructions and 31 patients with endoscopic reconstruction, both with patellar tendon autograft with a minimum 2-year follow-up interval. In the endoscopic group, the mean Lysholm score was 85 points. Eight patients (26%) had grade 1 pivot shift results, and one patient (3%) had a grade 2 pivot shift result at followup. The KT-1000 arthrometer manual maximum differences averaged 1.8 mm (range, −1 to 9). They noted a trend toward a residual pivot shift glide in the endoscopic group. The authors concluded that both procedures yielded satisfactory results.

O'Neill[40] prospectively compared 40 patients with two-incision arthroscopically assisted semitendinosus-gracilis tendon autograft reconstructions, 40 patients with two-incision patellar tendon autograft reconstructions, and 45 patients with endoscopic patellar tendon autograft reconstructions. The mean follow-up durations were 38 months, 48 months, and 39 months postoperatively, respectively. An early weightbearing, full range of motion rehabilitation program that emphasized closed kinetic chain strengthening exercises was used postoperatively for all three study groups. The KT-1000 arthrometer side-to-side differences were less than 3 mm in 83% of patients in the first group, 93% in the second group, and 87% in the third group. Excellent functional results were reported for all three groups. Mean deficits of less than 10% were noted for all three groups on single-legged hop testing. The Lysholm scored was greater than 90 points in 88%, 90%, and 93% of the patients, respectively, for each group studied. The incidence of a positive pivot shift result or patellar pain symptoms at followup was not reported. The author concluded that there was no clear advantage with any of these three procedures.

Our study, we believe, represents the largest series to date of endoscopic ACL reconstructions using patellar tendon autograft. Our stability rates, as determined by a negative pivot shift result, KT-1000 arthrometric side-to-side difference of less than 3 mm, functional results, postoperative scoring scales, and patient satisfaction levels compare favorably with the aforementioned endoscopic studies. Unlike the authors of those studies, we did not directly use a two-incision group as a control; however, our previously reported results with a two-incision technique using patellar tendon autograft serve as a historical control. Although much of our study was designed and the data collected prospectively, this should be considered a retrospective study because we did not determine Lysholm, Noyes, or HSS rating scores preoperatively. Although we determined by SF-36 outcome evaluations that this group did not differ from an age-matched group of uninjured subjects, we were unfamiliar with the SF-36 forms in 1991.[35] Our postoperative radiographs revealed a mean HSS radiographic score of 25 of 28 points, demonstrating minimal radiographic changes postoperatively, but access and standardization of preoperative radiographs and economic constraints that precluded using the opposite knee as a control at followup reduced the value of these observations.[54]

This study reports the senior author's initial experience with an endoscopic single-incision ACL reconstruction with patellar tendon autograft secured in full extension. When comparing these results with those from the senior author's previously reported initial experience using a two-incision technique during a similar postoperative interval, it was noted that patient satisfaction, stability, KT-1000 arthrometric parameters, functional testing, postoperative rating scale scores, range of motion, and the incidence of reoperations were similar. The incidence of patellofemoral crepitation was reduced from 60% to 38% in the current study. The incidence of moderate to severe crepitation decreased from 19% to 6% in the current study, which we attribute to an immediate extension, full weightbearing, accelerated rehabilitation program, and the avoidance of isokinetic training. We believe that the similar results from the initial experience in these two studies demonstrate that as long as the basic principles of ACL reconstruction are adhered to, reliable results may be achieved with either a single- or a two-incision technique of ACL reconstruction.

SUMMARY

Our data demonstrate encouraging results using a single-incision technique for ACL reconstruction with patellar tendon autograft secured in full extension. Reliable stability, excellent motion, favorable postoperative rating scales, a low incidence of postoperative patellofemoral pain, and excellent patient subjective satisfaction lead us to conclude that this technique provides a reasonable alternative for reconstructing the ACL-deficient knee. Realizing that this is a short-term followup and close long-term observation of these patients is necessary, we intend to review this patient cohort at a minimum 5-year interval.

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