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Arthroscopically Assisted Anterior Cruciate Ligament Reconstruction Using Patellar Tendon Autograft

Five- to Nine-Year Follow-up Evaluation*

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ABSTRACT

We retrospectively reviewed the results of 97 patients with anterior cruciate ligament reconstructions using an arthroscopically assisted two-incision technique without extraarticular augmentation at an intermediate followup of 5 to 9 years postoperatively. Evaluation included detailed history, physical examination, functional testing, KT-1000 arthrometer measurements, multiple scoring systems, and radiographs. The results were compared with those from a previous study that evaluated a smaller patient cohort using the identical surgical technique at a 2- to 4-year followup. The postoperative physical examination and KT-1000 arthrometer results were statistically improved when compared with preoperative findings. A negative pivot shift result was noted in 83% of patients, and a 1+ result in 17% of patients. Seventy percent of patients had <3 mm difference on manual maximum side-to-side testing. Functional testing averaged less than 2% asymmetry for vertical jump, single-legged hop, or timed 6-meter hop. The Tegner activity level was significantly improved from prereconstruction ratings and similar to preinjury ratings. The mean Lysholm score was 87. The modified Hospital for Special Surgery scores resulted in good or excellent results in 82% of the patients (mean, 87 points). The mean Noyes sports function score was 89, and the reoperation rate for a symptomatic knee flexion contracture was 12%. Ninety-seven percent of patients indicated that they would undergo the procedure again. When compared with this same population at 2 to 4 years, we saw no deterioration in scoring scale results.

During the past decade arthroscopically assisted techniques have become accepted methods of reconstructing the ACL.[5–7,13,14,19,23,24,27,31,36,45,46] Despite many ACL-related articles in the literature, there are few intermediate- or long-term studies evaluating the results of current, commonly performed techniques.

The goals for this minimum 5-year follow-up study were to 1) evaluate clinical stability after this technique, 2) assess function, 3) evaluate patient satisfaction, and 4) compare our results at 5 to 9 years with those from an earlier study of 2 to 4 years' followup of this same surgical technique.[7]

MATERIALS AND METHODS

Patients who underwent two-incision arthroscopically assisted ACL reconstructions using patellar tendon autograft substitution without extraarticular augmentation between June 1987 and January 1991 were retrospectively reviewed. Patients were identified from a computerized data base maintained by the senior author (BRB), who performed all the surgical procedures. During this period, a variety of 189 knee ligament procedures were performed. Exclusionary criteria included concomitant extraarticular reconstruction; hamstring tendon, allograft, or revision ACL surgery; bilateral ACL reconstructions; contralateral ACL deficiency; multiligament reconstruction; combined high tibial osteotomy-ACL reconstructions;

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or concomitant medical illness that precluded follow-up evaluation.

One hundred forty-seven patients met our inclusionary criteria. Ninety-seven patients (66% followup) were evaluated between September 1, 1995, and April 1, 1996. Twenty-nine patients were contacted and unable to participate because of geographic constraints (20%); their completed questionnaires were not included in the study. Thus, 86% of our patients who met our inclusionary criteria were personally evaluated or identified and contacted. Twenty-one patients (14%) were lost to followup.

Surgical Technique

An arthroscopically assisted technique was performed as previously reported.[6] Partial meniscectomy or meniscal repair was performed concurrently with the ACL reconstruction if necessary. Meniscal repair sutures were tied with the knee in extension. Accepted principles of adequate notchplasty and anatomic placement of femoral and tibial tunnels were employed. In this study, isometry measurements were made on all patients. A midthird 10- or 11-mm wide patellar tendon graft was used. Interference screw fixation was used in almost all knees but was supplemented with a screw and post or staples in fewer than 10% of the cases. A lateral femoral incision was used to place the rear-entry femoral aiming device, to allow femoral tunnel reaming from "outside-in," and to assist in graft fixation using a femoral interference screw. Tibial fixation was performed with the knee in complete extension and screws were placed on the anterior surface of the tibial bone plug, adjacent to the cortical bone plug surface. Hemovacs were routinely used. A postoperative motion brace was applied at the conclusion of the procedure.

Postoperative Rehabilitation

Continuous passive motion machines were used postoperatively on all patients during hospitalization. Patients were generally hospitalized for 2 to 3 days. Motion was gradually increased within a range from −10° to 90° of knee flexion. Patients operated on after 1989 were allowed to immediately passively extend their knees to full extension. Particular emphasis was placed on obtaining full knee extension in the early postoperative phase. Touchdown weightbearing was allowed at 2 weeks and was advanced 15 pounds weekly with the goal of weaning the patient from crutches at 6 weeks postoperatively. The essentials of the supervised rehabilitation program included bicycling at 2 weeks, use of a stair climbing machine at 6 weeks, swimming at 8 weeks, straight ahead jogging at 20 weeks, and gradual return to sports at 6 to 8 months postoperatively if rehabilitation criteria were met. A custom ACL orthosis was worn from 6 weeks to 6 months postoperatively for activities of daily living and for sports activities from 6 months to 1 year. Bracing was discontinued at 1 year postoperatively. The rehabilitation program was not modified for those patients who underwent concomitant meniscal repair.

Clinical Evaluation

Physical examination of both knees was performed by independent surgeons (ST or MEL). Range of motion was assessed by goniometer and prone heel height differences, and thigh circumferences were measured to the nearest centimeter. Patellofemoral crepitation was graded as 0 (absent), 1+ (minimal), 2+ (moderate), or 3+ (severe). Knee alignment, varus-valgus stability at 0° and 30° of flexion, 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) with the knee in abduction and external rotation.[9]

KT-1000 Arthrometric Testing

The KT-1000 arthrometric (MEDmetric, San Diego, California) measurements were performed by an experienced examiner (JB). Testing was performed as described by Daniel et al.[8,15] Manual maximum translations and manual maximum side-to-side differences were recorded. Tests were performed twice and averaged. An arthrometric failure was defined as a side-to-side difference of more than 5 mm.

Functional Testing

Functional testing included a single-legged hop for distance, a vertical jump, and a timed single-legged 6-meter hop. Testing was performed three times and averaged. Evaluations were performed by an athletic trainer (JB) and reported as side-to-side percentage differences. Cybex (Lumex, Inc., Ronkonkoma, New York) isokinetic evaluation was not performed in this study as a measure of functional recovery because of logistic and economic constraints.

Radiographic Assessment

Radiographic evaluation included standing AP and lateral radiographs. The Hospital for Special Surgery (HSS) ACL radiographic score, a 28-point scale, was used.[43] This score stratifies periarticular (central) and degenerative (peripheral) radiographic changes. The periarticular score is determined by the degree of tibial spine and patellar spurring as well as the medial and lateral osteophytic changes; a maximum of 10 points can be scored in this section. The degenerative score measures subchondral sclerosis, joint space narrowing, cystic changes, loose bodies, and angular deformities; a maximum of 18 points can be scored in this section. Radiographs were assessed independently by a board certified orthopaedic surgeon with fellowship training in sports medicine (CBJ).

Postoperative Rating Scales

Postoperative rating scales, including a modified HSS knee score (0 to 100 points), Lysholm postoperative rating

score (0 to 100 points), and Tegner activity level (0 to 10), were calculated.[4,26,46] The Cincinnati Knee Rating scores calculated included a sports activity scale (0 to 100), function in sports (0 to 100), function in activities of daily living (0 to 40), and problems with sports (0 to 100).[29] The change in sports activities, as described Noyes,[29] was also documented.

Subjective Assessment

Patients were asked if they would consider having the procedure performed on their opposite knee (yes or no) based on the result and experience of the affected knee. A secondary question evaluated satisfaction as being 1) completely satisfied, 2) mostly satisfied, 3) somewhat satisfied, or 4) dissatisfied. A visual analog scale (0 to 10 cm scale) was also used to assess satisfaction.

Data Acquisition and Analysis

Charts were independently reviewed (ST, MEL, or both) to eliminate surgeon's bias. Pre-, intra-, and postoperative data were obtained to supplement the follow-up evaluation. A previously developed questionnaire was modified to a computerized scantron form to facilitate data entry. A patient-administered, rather than physician-administered, questionnaire was used to eliminate interviewer bias. Statistical analysis, including descriptive statistics, analysis of variance testing (ANOVA), chi-square analysis, and linear regression analysis, were used when applicable as determined by our consultants in the Section of Biostatistics. Statistical analysis was performed using the SPSSX software package (SSPS, Inc., Chicago, Illinois). Statistical significance was established at $P < 0.05$.

RESULTS

Ninety-seven patients were clinically evaluated. There were 72 male and 25 female patients. There were 53 right and 44 left knees. The mean age at surgery was 26 years (range, 12 to 53; SD, 9). The mean interval from injury to surgery was 32 months (range, 0.25 to 232; SD, 47). The mean interval from surgery to followup was 79 months (range, 66 to 113; SD 14).

Twenty-four patients (25%) had ACL reconstructions at less than 6 weeks after injury, and 73 patients (75%) had reconstructions more than 6 weeks after injury. There was no relationship between the interval from injury to surgery (<6 months, 6 to 24 months, >24 months) and the HSS, Lysholm, or Noyes function, activities of daily living, or sports rating scores. Thigh girth atrophy at followup, prone heel height asymmetries at followup, patellofemoral chondromalacia at surgery, chondromalacia of the tibia and or femoral compartments, patellar pain as defined by pain climbing stairs, or the outcomes on the three functional tests reported were not different in the three time-interval subgroups. Ninety-three percent of the patients ($N = 90$) indicated that their original injury was sports related, with the predominant sports activities when injured being basketball, skiing, and football.

Previous Surgical Procedures

Forty-seven percent of the patients ($N = 46$) had at least one surgical procedure performed before their reconstruction. Thirty-nine patients had undergone a single previous surgical procedure, five had undergone two previous procedures, and two had undergone three or more procedures before the ACL reconstruction described here.

Associated Procedures and Surgical Findings at Reconstruction

At the time of ACL reconstruction, 50 knees had meniscal injuries that required surgery. Eighteen medial meniscal repairs, 7 lateral repairs, 18 partial medial meniscectomies, and 17 partial lateral meniscectomies were performed. Untreated stable partial-thickness meniscal tears are not reported. Varying degrees of chondromalacia were observed at reconstruction. Chondromalacia patellae was noted in 30 patients (31%) at reconstruction. Varying degrees of chondromalacia were noted on the medial femoral condyle (32 patients [33%]), lateral femoral condyle (14 patients [14%]), medial tibial plateau (17 patients [18%]), and lateral tibial plateau (17 patients [18%]). Loose bodies were removed from nine patients (9%). There was no statistical relationship between those patients with grade 3 or 4 chondromalacia in any compartment and age (stratified by decade), previous surgery, time to reconstruction, postoperative patellofemoral crepitation, postoperative thigh girth atrophy, asymmetric postoperative prone heel heights, abnormal functional testing (>10% side-to-side differences), Lysholm scores (<85) points, or HSS scores (<80 points).

The average tourniquet time was 88 minutes (range, 0 to 150; SD, 31).

Clinical Evaluation Findings

Preoperative. The Lachman test was graded as negative in 2 patients, 1+ in 17 patients (19%), 2+ in 50 patients (57%), and 3+ in 19 patients (22%). In 9 patients the preoperative Lachman was noted as abnormal but not graded. The anterior drawer test was graded 1+ in 37 patients, 2+ in 18 patients, and 3+ in 1 patient; the remaining tests had negative results. The pivot shift was graded as negative in 9 patients, 1+ in 31 patients, 2+ in 26 patients, and 3+ in 1 patient. In 30 knees the preoperative pivot shift could not be determined because of pain, muscle spasm, or patient apprehension. Ten patients demonstrated 1+ laxity to valgus stress, five had 2+ laxity, and two had 3+ laxity. Two patients had 1+ laxity to varus stress when examined preoperatively.

When examined under anesthesia, all patients except one had a demonstrable pivot shift. Seventeen patients (18%) had a grade 1 pivot shift, 55 patients (60%) had a grade 2 pivot shift, and 19 patients (21%) had a grade 3 pivot shift. Five patients had an abnormal nongraded pivot shift recorded in the operative report dictation. The one patient with a negative pivot shift had a diagnosis of partial ACL injury by virtue of a negative pivot shift when

examined under anesthesia in spite of obvious injury to the ACL. An attempt was made to rehabilitate the patient's knee, but he developed recurrent instability and an ACL reconstruction was subsequently performed.

Postoperative. At followup, 58 patients (60%) had negative Lachman results, 37 patients (38%) had 1+ Lachman results with a firm end point, 2 patients (2%) had 2+ Lachman results. Eighty-one patients (84%) had negative pivot shift results and 16 patients (16%) had 1+ pivot shift results at followup. No patient demonstrated a 2+ or 3+ pivot shift. The postoperative reduction in the anterior drawer, Lachman, and pivot shift results were all statistically significant ($P < 0.0001$) when compared with the preoperative or examination under anesthesia findings.

The mean postoperative extension was 0° (range, −10° to +10°; SD, 3.0), and the mean postoperative flexion as measured by goniometer was 137° (range, 115° to 160°; SD, 7.3). Two patients (2%) had greater than 5° of extension loss (10° each). Knee extension postoperatively was also assessed by evaluation of prone heel height differences (Fig. 1). The mean postoperative prone heel height difference was 1.8 cm (range, 0 to 8; SD, 1.9). Fifty-one patients (53%) had heel height differences of 1 cm or less, 19 patients (20%) had 2-cm differences, and 27 patients (28%) had more than 2-cm differences (range, 2 to 8 cm).

At follow-up examination, patellofemoral crepitus was noted in 44 patients (45%). This was graded as 1+ (minimal) in 40 patients (91%) and 2+ (moderate) in 4 patients (9%). Preoperative patellofemoral crepitus was not routinely recorded so we cannot comment on any postoperative conversion. Thirteen percent ($N = 13$) of our patients had some degree of discomfort related to stair climbing; all but one patient characterized this as "mild." When patellofemoral pain was defined by stair-related symptoms, there was no significant relationship between patellofemoral pain and the presence of intraoperative patellofemoral chondromalacia, postoperative patellofemoral crepitation, knee flexion contracture, thigh girth atrophy, or prone heel height asymmetry. There was also no correlation between problems with stairs and patient age (stratified by decade), interval from injury to surgery, abnormal functional tests (>10% side-to-side deficits), or HSS scores (<80 points).

At followup, the mean thigh girth asymmetry was 1 cm (range, 0 to 5; SD, 1). Seventy-two patients had atrophy of 1 cm or less. Thigh girth asymmetry of more than 1 cm was noted in 25 patients (27%). In those patients who demonstrated measurable thigh girth atrophy, the difference was 2 cm in 19 patients and 3 cm or more in 6 patients. There was no significant difference between thigh girth differences of 2 cm or less and time interval to reconstruction, presence of postoperative patellofemoral crepitation, asymmetric postoperative prone heel heights, abnormal functional testing (>10% side-to-side differences), Lysholm scores (<85) points, or HSS scores (<80 points).

KT-1000 Arthrometric Results

Preoperative KT-1000 arthrometer data were available on 76 patients. The mean preoperative manual maximum translation was 13.1 mm (range, 4 to 22; SD, 3.4). The mean manual maximum side-to-side difference preoperatively was 7.6 mm (range, 0.5 to 13.5; SD, 3.1). The side-to-side difference was 3 mm or less in 7 patients (9%), between 3 and 5 mm in 10 patients (13%), and 5 mm or more in 59 patients (78%).

The mean postoperative manual maximum translation in the reconstructed knee was 6.3 mm (range, 1 to 12; SD, 2.4). The mean side-to-side difference was 1 mm (range, −11.5 to 7; SD, 3.0). Twenty-eight knees (30%) had negative ("tighter") side-to-side differences postoperatively. Fifteen of these were tighter than the nonoperated side by 1 mm or less, seven were tighter by 1.5 to 3 mm, and six were tighter by more than 3 mm (Fig. 2). At the final followup in 94 knees, the manual maximum side-to-side difference was less than 3 mm in 66 patients (70%), 3 to 5 mm in 24 patients (26%), and more than 5 mm in 4 patients (4%).

The preoperative manual maximum anterior translation was significantly greater when the injured and unin-

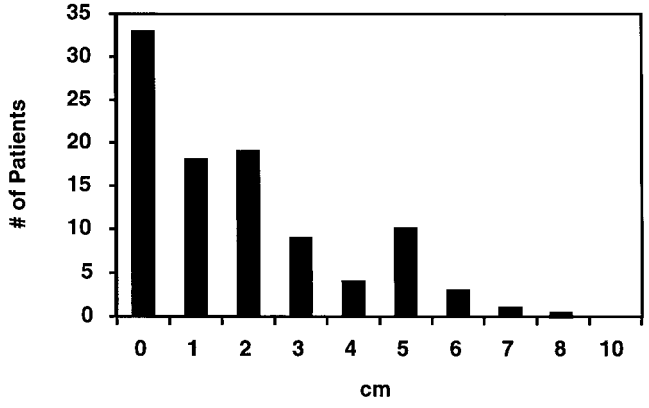

Figure 1. Postoperative prone heel height discrepancies are demonstrated. Note that the majority of heel height differences are less than 2 cm.

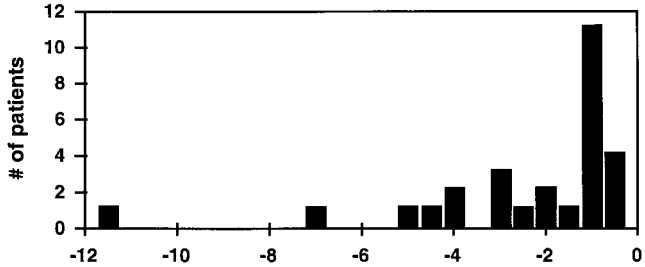

Figure 2. This figure depicts the stratification of negative or "tighter" KT-1000 arthrometric values on manual maximum side-to-side testing. Note that the majority are within 3 mm. When considering KT-1000 arthrometric manual maximum differences it may be advisable to stratify negative or "tighter" values as <−3 mm, −3 to −5 mm, and >−5 mm as a measure of "tightness."

jured limbs were compared ($P < 0.001$). The anterior manual maximum translation was significantly reduced when the postoperative translations were compared with the preoperative translations ($P < 0.001$). The average decrease in the side-to-side difference from pre- to postoperative testing was 6.6 mm (range, 3 to −16; SD, 3.7). The reductions in absolute translation and side-to-side differences were significant ($P < 0.001$) (Fig. 3).

Functional Testing

The functional parameters measured included a timed single-legged 6-meter hop (94 patients), a single-legged hop for distance (94 patients), and a vertical jump for distance (93 patients). The mean deficit for the affected knee was 2% (range, −54% to 28%; SD, 9.5) for the timed single-legged hop. A mean deficit of 1% (range, −47% to 33%; SD, 10) was observed on the single-legged hop for distance. A mean deficit of 1% (range, −166% to 37%; SD, 24) was noted for the vertical jump. For the three functional tests 86 (92%), 84 (89%), and 78 (84%) patients, respectively, had less than 10% side-to-side deficits. There were significant correlations between the outcomes on the single-legged hop for distance and the timed single-legged hop ($P < 0.012$), and between the vertical jump and postoperative prone heel height asymmetries (>2 cm) ($P < 0.005$). No statistical relationship was noted in those patients who had side-to-side functional test differences less than 10% and grade 3 or 4 chondromalacia in any compartment, age (stratified by decade), previous surgery, interval to reconstruction, postoperative patellofemoral crepitation, postoperative thigh girth atrophy, asymmetric postoperative prone heel heights, Lysholm scores (<85 points), or HSS scores (<80 points).

Radiographic Analysis

The average radiographic score at followup was 25.2 (range, 17 to 28; SD, 2.7) of a maximum possible 28. The average periarticular score was 8.2 of a possible 10 points (range, 3 to 10; SD, 1.6). The average degenerative score was 17.1 of a possible 18 points (range, 12 to 18; SD, 1.3).

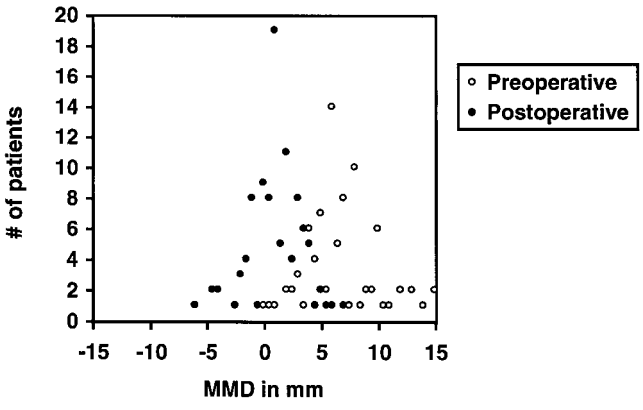

Figure 3. The distribution of the preoperative and postoperative KT-1000 arthrometric manual maximum side-to-side differences (MMD). Note the significant "shift to the left" postoperatively.

Postoperative Rating Scales

The mean retrospective Tegner score before injury was 7.1 (range, 4 to 9; SD 1) and this decreased to 3.5 (range, 0 to 9; SD, 1.6) after injury and before surgery. The average Tegner score at the final evaluation was 6.3 (range, 2 to 9; SD, 1.6). There was a statistically significant difference in the Tegner rating from the preinjury to the preoperative value, and from the preoperative to the postoperative value ($P < 0.0001$), whereas the slight difference between preinjury and postreconstruction Tegner levels was not significant.

The mean Lysholm score postoperatively was 87 (range, 34 to 100; SD, 12). Fifty-seven percent of the 92 patients ($N = 52$) with available data scored between 90 and 100 points, 24% ($N = 22$) scored between 80 and 89 points, 12% ($N = 11$) scored between 70 and 79 points, and 8% ($N = 7$) scored less than 70 points (Fig. 4). There was significant correlation between those patients who scored less than 85 points on the Lysholm scale and those patients who scored less than 80 points on the HSS scale ($P < 0.002$).

The mean HSS score was 87 (range, 72 to 100; SD, 8). The modified HSS score ratings are excellent (90 to 100), good (80 to 89), fair (70 to 79), and poor (<70). Of the 92 patients with data, there were 40% excellent ($N = 37$), 42% good ($N = 39$), and 17% fair ($N = 16$) results (Fig. 5).

The mean Noyes sports function score was 89 (range, 27 to 100; SD, 13), and the Noyes activities of daily living score was 36 of a possible 40 points (range, 20 to 40; SD, 4). The Noyes sports activity scale had a mean value of 87 (median 90, range, 20 to 100; SD, 10.5), and the Noyes problems with sports score had a mean value of 85 (range, 30 to 100; SD, 19).

When 91 patients were asked to indicate their change in sports activity level using the Noyes scale, 42 patients (46%) indicated no change in sports with no problems during sports, and 11 patients (12%) indicated no change in sports with moderate problems during sports. Twelve

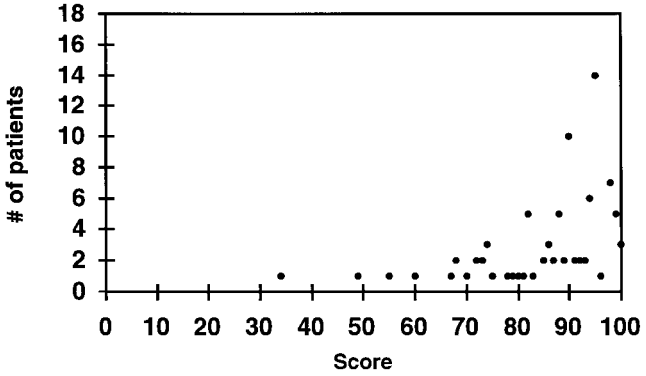

Figure 4. The distribution of postoperative Lysholm scores at followup is shown. The mean Lysholm score was 87 (range, 34 to 100; SD, 12).

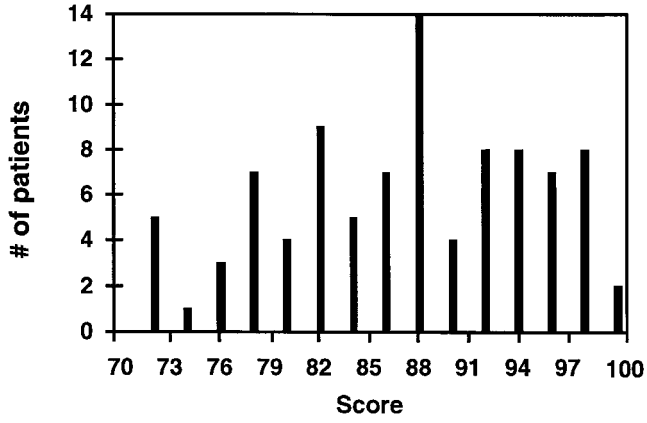

Figure 5. The distribution of postoperative HSS scores at followup is shown. The mean HSS score was 87 (range, 72 to 100; SD, 8). There were 82% good and excellent results.

patients (13%) indicated a decrease in activity with no problems, 5 (5%) a decrease in activity with moderate problems, and 14 (15%) a decrease in activity unrelated to the knee. Three (3%) patients stated they had stopped all sports because of knee problems, and four (4%) had stopped sports for problems unrelated to their knee. Eighty-four patients (87%) reported no problems in ascending stairs, 12 patients (12%) reported mild discomfort, and only 1 patient reported moderate problems.

Subjective Analysis

Ninety-one patients (94%) indicated that they would repeat the procedure, and 89 of the 92 patients who responded to the subjective questionnaire declared they were completely or mostly satisfied. Three patients indicated that they were somewhat satisfied. No patient was dissatisfied. A 10-cm ruled visual analog scale was used to assess overall satisfaction compared with the opposite knee. The average postoperative score using the visual analog scale was 7.8 (range, 2 to 10; SD 1.6). The mean retrospective preinjury subjective score was 9.3 (range, 3 to 10; SD, 1.3). Postoperatively, 59 patients (61%) rated their knees from 8 to 10, 30 patients (31%) ranked their knees from 5 to 7, and 8 patients (8%) ranked their knee as less than 5.

Complications

Twenty-five patients (26%) required 31 operative procedures after the ACL reconstruction described here. Nineteen patients underwent a single additional procedure and six patients required two operations. Six patients had removal of painful tibial screws, four patients sustained a new meniscal tear, and three patients retore the meniscal repair performed at the time of ACL reconstruction. One patient with a workers' compensation case fell at 6 weeks postoperatively and ruptured his infrapatellar tendon. This was repaired with primary tendon repair with hamstring tendon augmentation and a figure-of-8 tension band.[20] He returned to work full duty as a police officer at 6 months after surgery. At final followup, this patient had a range of motion from 5° to 140°, with a 5-cm prone heel height difference. One patient underwent a lateral femoral chondroplasty by another surgeon 1 year after his ACL reconstruction. Another patient developed hemarthrosis after a motor vehicle accident 6 months after his ACL reconstruction. At repeat arthroscopic surgery, the hemarthrosis was drained and minor graft attenuation with a negative pivot shift was noted. At final followup the patient had a 1+ Lachman and a negative pivot shift result. No patient who had a positive pivot shift at followup could recollect a traumatic event that would imply graft disruption. Thirteen patients (12%) required reoperation for a symptomatic knee flexion contracture. Two of these patients required two procedures each before they were able to achieve a satisfactory range of motion.

There were no infections, patellar fractures, or neurovascular complications. There were no significant differences in Lysholm, Noyes, or HSS scores when comparing patients who required a reoperation for a knee flexion contracture, or for any other cause, and the entire group.

Comparison with Previous Study

The results of this study were compared with those of a previously published study that evaluated this same population at a 2- to 4-year follow-up interval.[7] In that study, 62 of 75 eligible patients (83%) were evaluated. Forty-nine patients of the 62 that were evaluated in the previous study were seen again for this study (79%). The follow-up Lachman result in the former study was negative in 48 patients (77%) and grade 1 in 12 (19%); the pivot shift result was graded as negative in 57 patients (92%), 1+ in 3 (5%), and 2+ in 2 (3%). Although there was no change in the Lachman test results when the negative and grade 1 groups were combined, there was an increase in the number of knees that demonstrated a 1+ pivot shift in this study at the 5- to 9-year followup. The incidence of patellofemoral crepitation was decreased (60% versus 45%). The patellofemoral crepitation noted in the initial study was mild in 43% (27 patients) and moderate or severe in 19% (12 patients). In this study, patellofemoral crepitation was mild in 41% and moderate in only 4%. Patellar pain as defined by pain associated with stair climbing was 18% in the former study and 13% in the current longer-term follow-up study. The range of motion, KT-1000 comparative data, and Tegner, Lysholm, HSS, and Noyes rating scales were nearly identical with no significant deterioration over time.

DISCUSSION

This study has some inherent weaknesses in that it is retrospective and nonrandomized. These patients represent a consecutive series of patients, which introduces a component of the learning curve reflective in any surgeon's initial experience. Follow-up evaluation included 66% of the patient group who were personally evaluated and an additional 20% of the study group who were con-

tacted but unable to return for personal evaluation. Overall, 14% of the study group were lost to followup. Nevertheless, it represents one of the few intermediate-term follow-up studies of contemporary ACL surgical techniques.

This study demonstrates that ACL reconstruction using autogenous bone-patellar tendon-bone autograft without extraarticular augmentation yields durable stability results at an intermediate (5 to 9 years) followup. A slight deterioration in stability, as determined by a positive pivot shift, occurred in this group reviewed at an average of 79 months postoperatively, in contrast to a smaller subgroup that we reported on at an average of 37 months postoperatively.[7] In our initial study, 92% of our patients had a negative pivot shift; in this study, 84% of our patients had a negative pivot shift. In both studies the pivot shift grades were improved postoperatively from the preoperative or examination under anesthesia findings. Only two of the patients who demonstrated a positive pivot shift result had instability either with activities of daily living or with sporting activities in this current study. No patient in this study demonstrated a 2+ or 3+ pivot shift test. Pivot shift tests were performed in the position of abduction and external rotation, which has been shown to maximize the pivot shift phenomenon.[9]

These intermediate-term findings of sustained stability suggest that extraarticular reinforcement, an adjunctive treatment that was popular during the period that many of these reconstructions were performed, is unnecessary. Additionally, during this period early range of motion protocols were evolving. The aggressive postoperative protocols popularized by Shelbourne and colleagues,[34,38–42] characterized by immediate full range of motion, full weightbearing, and early return to sports, was not entirely incorporated. Nevertheless, our motion protocols were moderately aggressive for the period involved and did not adversely affect ultimate knee stability.

The negative pivot shift rate demonstrated in this series is comparable with that from other reports of ACL reconstruction using a similar technique. At a mean followup of 48 months, O' Brien et al.[30] reported on the results of ACL reconstruction using patellar tendon performed via an arthrotomy in 79 patients, and they noted that 84% of their subjects had negative pivot shift results. Specchiulli et al.[45] reported a 90% "negative or doubtful" pivot shift result rate at a mean followup of 89 months in 30 patients with patellar tendon autograft ACL reconstructions via an arthrotomy and selectively augmented with an extraarticular repair and casted postoperatively. At a mean followup of 42 months, Buss et al.[13] reviewed 67 patients who underwent patellar tendon autograft ACL reconstructions performed with a two-incision arthroscopically assisted technique and noted a negative pivot shift incidence of 89%. Aglietti et al.[2] retrospectively reviewed 30 patients at a mean followup of 28 months and noted a negative pivot shift incidence in 79%. Marder et al.[27] prospectively compared the results of arthroscopically assisted hamstring and patellar tendon autografts for ACL reconstruction and, at an overall mean followup of 24 months, noted that 78% of their subjects had negative pivot shift results.

Harner et al.[22] prospectively compared the results of 31 two-incision versus 32 single-incision arthroscopically assisted ACL reconstructions using patellar tendon auto- and allograft tissues. The authors reported a negative pivot shift rate of 79% and 81%, respectively. Arciero et al.[5] compared the results of 51 two-incision versus 31 single-incision ACL reconstructions with patellar tendon autograft and noted negative pivot shift results in 76% and 71%, respectively, at mean followups of 31 and 25 months, respectively. Sgaglione and Schwartz[37] compared the results of 90 patients who underwent either two-incision or single-incision ACL reconstruction with patellar tendon autograft at a mean followup of 41 and 30 months, respectively, and noted a 91% negative pivot shift incidence for each group of 45 patients. All of the aforementioned studies, except that of Specchiulli et al., represent shorter-term follow-up results.

One of the major criticisms of the patellar tendon autograft is the donor site morbidity, including patellar tendinitis, patellar fractures, patellar tendon ruptures, and patellar pain.[2,3,18,20,21,23,25,32,33,35,40,42,44] Patellar tendinitis is, in our opinion, a self-limiting problem that affects fewer than 10% of patients during a period 3 to 6 months after surgery. No patients in this study demonstrated clinical findings of chronic patellar tendinitis, and in more than 675 ACL reconstructions performed by the senior author to date no patient has required surgery for chronic patellar tendinitis. There were no patellar fractures in this study cohort. Patellar fractures may occur intraoperatively, resulting generally in a sagittally oriented intraoperative fracture pattern, whereas postoperative patellar fractures, which usually are related to significant trauma, have a transverse fracture configuration. The overall incidence of patellar fractures after ACL reconstruction is less than 1%.[11]

Attention to intraoperative detail may further minimize this complication; the graft should not be levered from its bed, one should avoid taking more than a 6- to 8-mm thick graft from the patella, and the patellar defect should be routinely bone grafted with cancellous reamings obtained when the femoral and tibial tunnels are reamed. One patient in our study sustained a patellar tendon rupture postoperatively after a fall. At that time, patients were allowed free motion while walking in their postoperative brace. Based on this isolated experience we altered our protocol and had patients bear weight with their operated knee locked in extension to protect the donor site should a slip or fall occur. We continue to use this protocol and have not experienced any subsequent patellar tendon ruptures or patellar fractures. Surgeons should be cognizant that the accelerated rehabilitation protocols that are commonly used today place the donor site at risk, particularly during the first 6 weeks postoperatively. For this reason we have not followed an immediate "brace-free" postoperative protocol.

Patellar pain after an autograft ACL reconstruction is probably the most common problem after ACL reconstructive surgery.[1,3,18,21,25,30,32,33,41,42,44] Proponents of hamstring tendon grafts for ACL reconstruction maintain that because of decreased donor site morbidity there is a lower

incidence of patellofemoral symptoms.[19,24,36] Grana and Hines[19] and Karlson et al.[24] reported an approximately 12% incidence of patellofemoral symptoms in patients who underwent hamstring tendon autograft reconstructions. Other authors have reported the incidence of patellofemoral problems ranging from 28% to 58%.[1,25,30,32] These differences may be partly explained by the method used to define or document patellar pain as well as variability in injuries, surgical technique, rehabilitation protocols, and time from surgery. It is important to note that ACL-deficient patients have patellar pain problems. Buss et al.[12] reviewed the subject of patellar pain in a group of 55 nonoperatively managed ACL-deficient patients and noted an incidence of 22%.

The low incidence of patellar pain specific to stair climbing noted in this study (13%) contrasts with that in many studies that have used patellar tendon autografts for reconstruction.[3,21,32,33] It compares favorably with the incidence of symptoms reported for nonoperated ACL-deficient knees as reported by Buss et al. In a smaller group of patients ($N = 62$) reported on in 1994 at a 2- to 4-year followup, an 18% incidence of mild patellar pain was noted.[7] Much of our discussion with patients during this study focused on patellar pain issues, and we consistently noted a decrease in symptoms with time. Martin et al.[28] retrospectively reported that those patients who underwent grafting of their distal patellar defects had less localized tenderness at the graft site, superior patellofemoral pain scores, and improved radiographic evidence of healing during the first 2 years after surgery. The low incidence of patellar pain cannot be accounted for by a single factor; however, the authors were early proponents of grafting the patellar defect, loosely approximating the tendon defect with the knee flexed, and securing the tibial interference screw with the knee in full extension. Although recent attention has been focused on securing the graft in full extension, the senior author has used this technique since 1987 because of concerns regarding overconstraining the knee by securing the graft in flexion with a posterior force applied to the proximal tibia. As our treatment for the ACL-deficient knee evolved into an endoscopic single-incision technique in October 1991, along with full incorporation of the accelerated ACL rehabilitation program advocated by Shelbourne et al.,[38–42] the incidence of patellar pain has remained low. The principles of patellar mobilization, full immediate weightbearing, an emphasis on immediate recovery of extension, early quadriceps muscle rehabilitation, and avoidance of isokinetic quadriceps training are currently recommended.

Shelbourne and Trumper[40] recently reported on patellofemoral problems after patellar tendon autograft reconstruction for ACL deficiency. In the 602 patients reviewed who underwent an accelerated rehabilitation program, patellar pain symptoms were not a significant problem. The authors noted no difference in patellar pain symptoms in those patients who had grade 3 and 4 patellar chondromalacia versus those patients with normal patellar surfaces. They described a 100-point patellar pain score with five categories. They assessed 1) pain with strenuous work or exercise, 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 for their patient population was 89.5, although they did not specifically state their actual incidence of patellar pain.

As knee surgeons have continued to refine ACL surgical techniques, results have become more predictable, surgical morbidity has been reduced, and rapid return to athletics has become commonplace, we have become increasingly more critical of our results. In our opinion, the high incidence of subtle knee flexion contractures is related to avoiding complete extension immediately after surgery, and not a reflection of abnormal tunnel placement. Furthermore, these subtle knee flexion contractures do not imply that the knee joint has been "captured" or overconstrained, because the graft was routinely secured in complete extension.

The final range of motion at followup was acceptable (average extension, 0°; average flexion, 137°) by the standards at the time these procedures were performed. Shelbourne et al. have popularized the goal of achieving complete matched extension or hyperextension of the contralateral knee. Extension was measured using a goniometer with the patient in the supine position as well as by comparison of prone heel heights. In the supine position, 16 patients had losses of extension to neutral, ranging from 3° to 10°. The average prone heel height difference in our population was 1.8 cm. Forty-four knees had differences between 1 and 5 cm, and only four knees had more than 5 cm of prone heel height difference. Sachs et al.[35] demonstrated that 1 cm of prone heel height difference is equal to approximately 1° of extension loss, depending on patient height. Shelbourne and Nitz,[39] by contrast, defined knee flexion contractures by asymmetric prone heel heights of more than 1 cm. Daniel et al.[16] reported a mean heel height difference of 1.7 cm in a group of patients who underwent early (<3 months) ACL reconstruction.

Most studies evaluate extension with the patient in the supine position, which may not fully reflect the more subtle loss of hyperextension that we have documented. Many patients have some degree of hyperextension in the contralateral normal leg, and prone heel height difference appears to be a more sensitive indicator of subtle loss of extension because it takes into account hyperextension in the opposite extremity. It is of interest to note that in this study, and for our reported 2- to 4-year follow-up study of this two-incision technique, we were unable to correlate these subtle knee flexion contractures with scoring scales, patellar pain, thigh girth atrophy, functional testing, or patient satisfaction. We are concerned particularly for those patients who had more than 5-cm prone heel height asymmetries. Perhaps longer-term followup will reveal a more significant deterioration of overall outcome.

None of the three functional tests (single-legged hop, timed single-legged 6-meter hop, and vertical leap) showed any significant difference when comparing the operated to the nonoperated side. Although the mean differences for these tests averaged less than 2%, it is more

meaningful to note that 96%, 88%, and 77% of our patients had less than 10% side-to-side deficits for these tests, respectively. Moreover, 40%, 66%, and 66%, respectively, had results that exceeded the opposite normal knee. These findings suggest that our patients' functional testing results were highly acceptable or that the methods of testing do not critically assess functional recovery as well as previously reported. We observed that the vertical jump was the functional test that was most commonly abnormal. Daniel et al.[17] reported that there was less than 10% mean side-to-side difference in the single-legged hop test in 95% of a normal population. Our study demonstrated less than 2% mean side-to-side difference for any of the tests performed. Isokinetic dynamometer testing was not performed in this study, but Daniel et al. and Barber et al.[10] have indicated that functional testing is a more reliable indicator of functional recovery than isokinetic testing.

Few studies have evaluated the long-term radiographic changes after ACL reconstruction. Using the same scoring system that we employed, Sherman et al.[43] radiographically evaluated a population of ACL-deficient patients from 6 months to 43 years after injury and documented a mean radiographic score of 23.7 (maximum possible, 28). They noted an inverse correlation of score with time from injury, and in their patients with a minimum of 5 years from injury the mean score was 22.4. Our average HSS radiographic score was 25 (17 points for degenerative changes and 8 points for periarticular changes). Sherman et al. state that periarticular (central) changes are the result of instability, and peripheral changes result from progressive joint degeneration. The two can occur independently and should therefore be evaluated separately. The patients in this study demonstrated high periarticular and degenerative scores, reflecting minimal overall joint deterioration.

Although we did not compare knees with the uninjured side and did not have preoperative radiographs for comparison, we hope that our radiographic findings are a direct result of our improved stability rates. Eighty-six percent of patients had a manual maximum side-to-side difference of 3 mm or less, and three patients had more than 5 mm of side-to-side difference at the final followup. A manual maximum difference of more than 5 mm has been suggested to represent an arthrometric failure.[36] Although there was little radiographic deterioration in our study, evaluation at a longer followup is critical. This patient population is at risk for degenerative joint disease in our opinion because 47% of our patients had previous arthroscopic surgery before their reconstructions, nearly 50% required some form of meniscal surgery concurrent to our reconstruction, and nearly 33% of the patellar surfaces and medial femoral condyles demonstrated evidence of chondromalacia (the other articular surfaces were involved to a lesser degree).

Daniel et al.[16] reported a significant deterioration in radiographic findings in a group of ACL-reconstructed knees when compared with the contralateral uninjured knee. Of significance in that population was that of the 43 patients with early reconstructions (<3 months), 64% demonstrated a positive pivot shift and only 33% had KT-1000 arthrometer side-to-side differences less than 3 mm. In their 33 patients with reconstructions after 3 months, the KT-1000 arthrometer manual maximum difference at followup was less than 3 mm in 30% and the pivot shift was positive in 48%.

In conclusion, this study demonstrates that at an intermediate postoperative followup, ranging from 5 to 9 years, ACL reconstruction using a patellar tendon autograft secured in full extension provides a durable result. Reliable stability, excellent functional testing results, postoperative rating scales comparable with other reported studies, and an extremely high level of patient satisfaction were noted. There were no significant clinical changes when this population was compared with our earlier patient group who underwent the same procedure and were reported at a 2- to 4-year follow-up interval. A long-term investigation of this technique will be performed at a 10- to 15-year follow-up interval.

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