Reconstruction of the Anterior Cruciate Ligament in Females: A Comparison of Hamstring Versus Patellar Tendon Autograft

Gene R. Barrett, M.D., Frank K. Noojin, M.D., Charles W. Hartzog, M.D., and Carrie R. Nash, B.S.

Purpose: To compare the clinical results of anterior cruciate ligament reconstruction in female patients using quadruple-looped hamstring autograft versus patellar tendon autograft at minimum 2-year follow-up. **Type of Study:** Case series. **Methods:** A prospective clinical review was performed to compare the results of ACL reconstruction with hamstring versus patellar tendon autograft in a group of female patients. Exclusion criteria included chronic injuries (greater than 3 months), associated collateral ligament injuries, Workers' Compensation or litigation cases, and bilateral anterior cruciate ligament injuries. There were 39 female patients in the hamstring group (average follow-up, 40.9 months) and 37 female patients in the patellar tendon group (average follow-up, 52 months). Both types of grafts were fixed with an EndoButton proximally and with sutures tied over a post or button distally. The postoperative rehabilitation regimen was identical for both groups. Objective parameters evaluated included preinjury and postoperative Tegner and Lysholm scores, side-to-side KT-1000 maximum-manual arthrometer differences, and clinical examination including Lachman and pivot-shift tests. Graft failure was defined by any one of the following: a KT-1000 difference of greater than 5 mm, a 2+ Lachman, a 1+ or greater pivot shift, or revision surgery. **Results:** The failure rate in the hamstring group was 23% versus 8% in the patellar tendon group, which was not statistically significant ($P > .1$). Comparison of preinjury Tegner activity scores to postoperative scores revealed that patients in the hamstring group did not return to their preinjury level of activity (preinjury 6.54 *v* postoperative 5.17) as well as patients in the patellar tendon group (preinjury 6.20 *v* postoperative 6.59). Patients in the hamstring group had a significant increase in pain compared with the patellar tendon group ($P = .034$). **Conclusions:** Although not statistically significant, the hamstring group had more failures, more laxity on clinical examination, and more patients with larger KT-1000 arthrometer differences. These results indicate a trend toward increased graft laxity in female patients undergoing reconstruction with hamstring autograft compared with patellar tendon when evaluated by a single surgeon using similar fixation techniques at short- to medium-range follow-up. More studies with larger patient numbers using current fixation techniques are necessary to confirm these findings. **Key Words:** ACL—Hamstring—Patellar tendon—Females—Graft fixation.

Increasing numbers of women and girls are now participating in recreational and competitive sports,[1] and this had led to an increase in the incidence of anterior cruciate ligament (ACL) injuries.[1-6] The physiologic reasons for the increase in female ACL injury are multifactorial.[2] Proposed etiologies for this gender variation include differences in conditioning, muscle strength, physiologic laxity, hormonal influence, and anatomic differences such as lower extremity alignment, notch width, and shape, and ligament size.[1,2,4,7]

The bone–patellar tendon–bone autograft is commonly accepted as the gold standard in ACL reconstruction with success rates documented at greater than 90%.[8-13] However, extensor mechanism problems and graft-site morbidity associated with use of

From the Mississippi Sports Medicine and Orthopaedic Center, Jackson, Mississippi, U.S.A.

Presented at the 67th Annual Meeting of the American Academy of Orthopaedic Surgeons, Orlando, Florida, March 15-19, 2000.

Address correspondence and reprint requests to Gene R. Barrett, M.D., Mississippi Sports Medicine and Orthopaedic Center, 1325 East Fortification St, Jackson, MS 39202, U.S.A. E-mail: gbarrett@netdoor.com

0749-8063/02/1801-2764$35.00/0
doi:10.1053/jars.2002.25974

patellar tendon grafts have led to a search for alternative graft sources.[8,14-18] Reconstruction of the ACL with an autogenous quadrupled hamstring graft is a viable alternative technique. Although some authors have found the hamstring tendon to be an inferior graft source in cases of chronic ACL insufficiency,[8,10,11,13] success rates for this technique in acute reconstructions have been documented from 82% to greater than 90%.[14,19-22] This technique is often recommended in the female population because of cosmesis, low morbidity, avoidance of patellofemoral problems, and easier rehabilitation. The purpose of this prospective study was to compare the clinical results of ACL reconstruction using semitendinosus and gracilis tendons versus patellar tendon in an acute female population.

METHODS

Exclusion Criteria

From December 1991 through October 1996, 690 patients underwent ACL reconstruction with autogenous graft sources. Of these patients, only 278 were female. All cases of bilateral or chronic ACL reconstruction, Workers' Compensation and litigation cases, and patients with less than 2 year follow-up were excluded. All patients with fixation other than EndoButton (Acufex, Mansfield, MA) proximally or button or post distally were also excluded. After these exclusions, 76 female patients having either quadruple hamstring or patella tendon ACL reconstruction remained for analysis. Quadrupled autogenous semitendinosus and gracilis tendons were used in 37 patients and autogenous bone–patellar tendon–bone grafts used in the remaining 39 patients. Only acute, isolated ACL reconstructions performed within 3 months of injury were included in this study to minimize the effects of associated injury bias and laxity of the secondary restraints on outcome and objective measurements. Graft selection was not randomized. During the initial study period, all female patients underwent reconstruction with patellar tendon autograft. Subsequently, hamstring autograft was used, employing similar fixation techniques.

Objective Data Collection

Results of each patient's initial examination, surgical findings, and follow-up examinations were prospectively entered into a computerized relational database (FoxPro 2.6; Microsoft, Redmond, WA). Patients were prospectively evaluated using objective and subjective criteria both preoperatively and postoperatively. All patients were examined by the senior author and postoperative data were collected at 3 months, 6 months, 9 months, 1 year, and annually thereafter.

Objective parameters used for evaluation included the presence of effusion and crepitus, Lachman and pivot-shift testing, KT-1000 arthrometer side-to-side differences, modified Lysholm knee function scores,[23] and Tegner activity scores.[24] Grading of the Lachman examination was defined as normal, 1+ (increased excursion with an end point), or 2+ (increased excursion without an end point). Pivot-shift examination was graded as normal, 1+ (glide), 2+ (clunk), or 3+ (gross subluxation). Using standard technique, maximum-manual KT-1000 arthrometer side-to-side differences in anterior tibial translation were recorded at 20° of knee flexion. Flexion and extension were measured with a goniometer and recorded at 3 months, 6 months, and annually thereafter. Quadriceps girth was measured 7 inches above the lateral joint line and compared with that of the contralateral extremity. Criteria for clinical failure included a 2+ Lachman test, a 1+ or greater pivot-shift test, a 5-mm or greater side-to-side difference in KT-1000 testing, or an ACL reconstruction revised for any reason. Knee function scores were determined preoperatively and postoperatively using a modified Lysholm score. The Tegner Activity Scale was used to quantitate patient activity levels both before injury and at latest follow-up.

Radiographs were obtained 3 months postoperatively for both groups. Tibial tunnel placement was posterior to an extension of Blumensaat's line on the lateral radiograph in all cases with the knee in full extension. Femoral tunnel placement was within 2 mm of the posterior femoral cortex on the lateral radiograph in all cases. No cases of aberrant tunnel placement were identified in either patient group that may have contributed to failure.

Subjective Data Collection

Subjective data was obtained from the Lysholm and Tegner activity scores. Additionally, the patients were asked to rate their pain at its worst on a scale from 0 to 10 with 0 representing no pain and 10 representing severe pain.

Surgical Technique: Hamstring Group

All reconstructions were performed within 3 months of injury by a single surgeon (G.R.B.). Patients were initially placed in a program of physical

therapy emphasizing techniques to regain motion and decrease swelling preoperatively. All patients underwent an examination under anesthesia and diagnostic arthroscopy with treatment of meniscal lesions before graft harvest. Semitendinosus and gracilis tendons were then harvested through a 3-cm vertical incision on the anteromedial aspect of the proximal tibia 3 to 4 cm distal to the joint line. The distal insertion of the tendons was released and prepared using a whipping stitch with nonabsorbable suture. Commercially available tendon strippers were used to harvest the grafts and the proximal ends prepared similarly with a nonabsorbable whipping stitch. After preparation, all grafts were preconditioned using the Graftmaster board (Dyonics, Smith & Nephew, Memphis, TN) at 15 lb of tension for 10 to 20 minutes. The EndoButton was prepared to allow for at least 20 mm of graft contained within the femoral bone tunnel. A nonabsorbable suture was tied to connect the EndoButton to the graft (no continuous loop). Notchplasties were performed arthroscopically to allow for adequate graft placement and to avoid impingement. The tibial guide pin was placed through the footprint of the ACL adjacent to the anterior horn of the lateral meniscus and the tibial tunnel was reamed. All tunnels were reamed to graft size as determined by graft sizers. The femoral guide pin was placed 5 mm anterior to the posterior cortex to allow for a 1 to 2 mm posterior cortical rim after reaming at the 11 o'clock (right) or 1 o'clock (left) position. Intraoperative radiographs were obtained to ensure proper femoral guide pin placement and the femoral tunnel was reamed until the anterolateral femoral cortex was reached but no further (approximately 30 to 40 mm). Graft fixation was accomplished with an EndoButton on the femoral side and either a button or post (suture tied over a screw with spiked washer) on the tibial side (Fig 1). The tibia was loaded with a maximal posterior force during fixation on the tibial side to minimize graft laxity present at the time of surgery. An intraoperative radiograph was again obtained to verify correct tunnel position and suction drains placed. The knee was placed in an immobilizer until physical therapy was initiated on the first postoperative day.

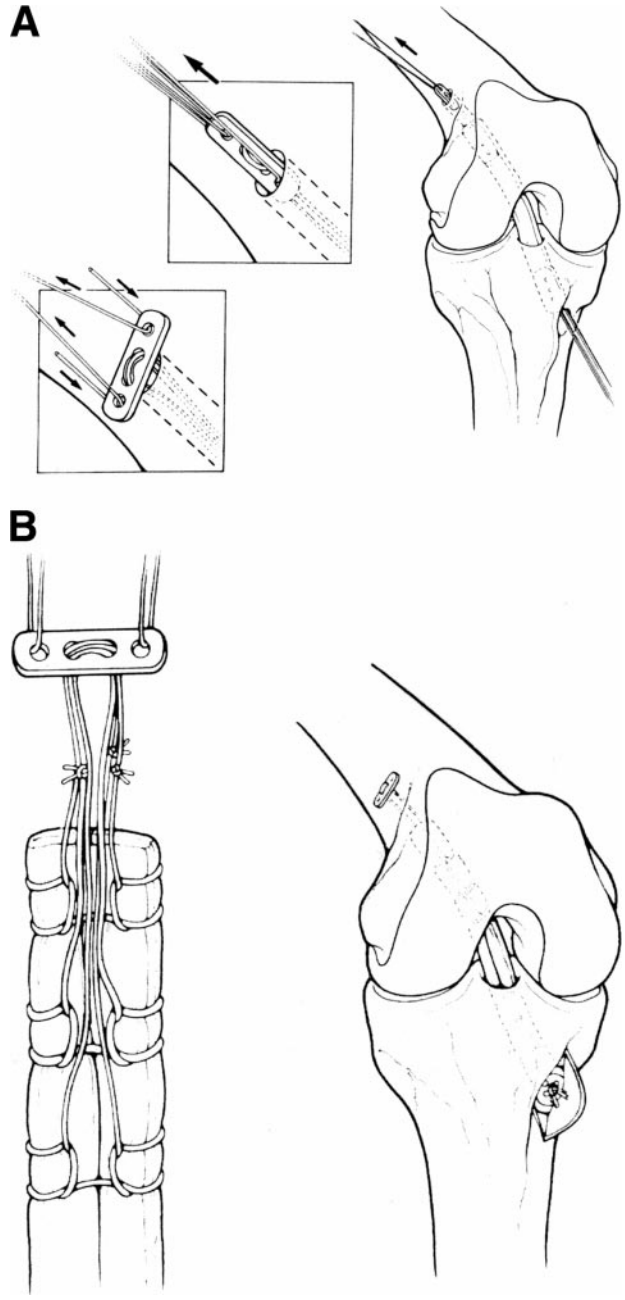

FIGURE 1. The fixation techniques used for the ACL reconstructions. (A) The EndoButton is deployed through the femoral tunnel. (B) EndoButton/button fixation is adapted to a hamstring tendon graft. (Top) Preparation of the hamstring tendon graft. (Bottom) Completed graft placement.

Surgical Technique: Patellar Tendon Group

Patients in the patellar tendon group underwent a preoperative physical therapy protocol identical to the hamstring group. All grafts were harvested through an 8- to10-cm incision centered over the medial aspect of the patellar tendon. The paratenon was incised and preserved for closure. Patellar tendon grafts 10 mm wide were obtained with a 10 $\times$ 25 mm patellar bone plug and a 10 $\times$ 30 mm tibial bone plug. Techniques for tunnel placement, graft preconditioning, and graft fixation were all identical to the hamstring group.

Bone–patellar tendon–bone reconstruction was performed using a standard endoscopic technique with an EndoButton proximally and a button or suture tied over a post distally. The EndoButton loop was than tied using a nonabsorbable suture (no continuous loop). Intraoperative radiographs were obtained to ensure correct tunnel placement and graft position in all cases. The incisions were closed over suction drains and the leg placed in a knee immobilizer.

Postoperative Rehabilitation

The rehabilitation protocol was identical for both groups with passive range of motion exercises instituted immediately and progression to active closed-chain exercises achieved by 6 weeks postoperatively. Patients were allowed full weight bearing 3 weeks postoperatively in a hinged brace and returned to running at 3 months. Return to sports participation was allowed at 6 months. Delayed rehabilitation (period of limited weight bearing, hinged knee brace, delayed running) was utilized in the patellar tendon group to simulate the protocol believed appropriate for the hamstring group.

Statistical Analyses

Statistical analyses included 2-sample *t* tests and χ-square analysis.

RESULTS

Demographic Data: Hamstring Group

There were 39 female patients with an average age of 23.2 years (range, 14 to 47 years) who underwent quadruple-looped hamstring ACL reconstruction; 18 right knees and 21 left knees were injured. Thirty-five (90%) of these injuries occurred during sports participation and 10 (26%) were considered contact injuries. The average preoperative Lysholm score for these patients was 46.6 and the average preinjury Tegner Activity level was 6.54.

There were associated injuries in 14 of the 39 female patients (36%). None of these injuries involved other knee ligaments. All associated lesions involved either the meniscus or the articular cartilage. There were 3 medial meniscal tears, 2 of which were repaired using an inside-out technique and the remaining 1 underwent partial medial meniscectomy. There were 7 lateral meniscal tears, 2 of which were repaired using an inside-out technique. Partial lateral meniscectomy was performed in 5 cases. There were 5 osteochondral lesions, 4 of which underwent debridement and arthroscopic lavage and 1 drilling.

Demographic Data: Patellar Tendon Group

The patellar tendon group was composed of 37 female patients with an average age of 25.2 years (range, 13 to 52 years). The right knee was involved in 18 patients and the left involved in 19 patients. Thirty-five patients (95%) were injured during sports participation. Thirty patients (81%) were injured by a noncontact mechanism and 7 patients (19%) by contact mechanisms. The average preoperative Lysholm score for the patellar tendon group was 49.97 and average preinjury Tegner activity level was 6.20.

Associated injuries involving the meniscus occurred in 16 patients (43%). There were 10 medial meniscal tears. Nine of these tears were repaired using an inside-out technique and 1 underwent partial medial meniscectomy. Lateral meniscal tears occurred in 8 patients with 2 undergoing repair using an inside-out technique and 6 treated with partial lateral meniscectomy.

The two groups were similar at the time of initial evaluation with respect to age, mechanism of injury, and associated injuries. The hamstring group had achieved a higher preinjury activity level with a Tegner score of 6.54 compared with 6.20 in the patellar tendon group. There were no deep infections, neurologic complications, or wound problems in either group postoperatively.

Hamstring Group

On analysis of the final results, there were no significant changes in postoperative effusion or crepitus. The average preoperative Lysholm score was 46.6 (range, 28-90) and the average preinjury Tegner Activity Level was 6.54 (range, 0-7). The average follow-up was 40.9 months (range, 24 to 81 months). There were 10 cases (26%) in which the Lachman was graded as 1+ and 4 cases (10%) in which it was graded as 2+. The remaining 25 knees were normal by Lachman examination. Eight knees (18%) had a 1+ pivot-shift and 1 (3%) had a 2+ pivot-shift. The remaining 30 knees were normal on pivot-shift testing. The average maximum-manual KT-1000 arthrometer side-to-side difference within this group was 2.14 mm (range, 0 to 8 mm). Thirty knees (77%) had a side-to-side difference of $\leq$3 mm, 7 knees (18%) had a difference between 3 and 5 mm, and 2 knees (5%) had a difference of greater than 5 mm. The average postoperative Lysholm score at final follow-up was 85.1 (range, 29-100) and the average postoperative Tegner

TABLE 1. *Analysis of Failures in the Hamstring Group*

Patient No.	Lachman	Pivot-Shift	KT-1000 Difference	Tibial Fixation	Length Follow-up	Outcome
1	2+	1+	8 mm	Button	33 mo	Brace/active
2	2+	1+	3 mm	Button	24 mo	Revision
3	1+	1+	6 mm	Button	48 mo	Brace/inactive
4	1+	1+	3 mm	Post	24 mo	Brace/active
5	2+	1+	5 mm	Button	42 mo	Revision
6	2+	2+	6 mm	Button	29 mo	Revision
7	1+	1+	2 mm	Button	26 mo	No brace/active
8	1+	1+	3 mm	Post	24 mo	Brace/active
9	1+	1+	2 mm	Button	49 mo	Awaiting revision

Activity Score 5.17 (range, 2-7), which was significantly decreased from the preinjury value of 6.54 ($P = .001$).

Failures: Failure of the graft had occurred in 9 cases (23%) at final follow-up (Table 1). These failures were determined by the presence of a 1+ pivot-shift in 5 cases, KT-1000 arthrometer differences of greater than 5 mm in 1 case, and by the presence of a 2+ Lachman and a 1+ or 2+ pivot shift test in 4 cases. Two of these patients have undergone revision ACL reconstruction with patellar tendon allograft and 1 patient had revision ACL reconstruction with patellar tendon autograft. One patient was awaiting revision at the time of publication of this article.

Subsequent Surgery: Three patients underwent repeat arthroscopy for meniscal tears. One patient had a partial lateral meniscectomy 34 months postoperatively and another a partial lateral meniscectomy 18 months postoperatively. Another patient underwent a medial meniscus repair with Menisus Arrows (Bionx, Blue Bell, PA) 48 months postoperatively who did not have a medial meniscal tear at the index procedure. Two of these meniscal tears were considered to result from failed meniscus repairs that never healed. None of the failed grafts in the female group had clinically failed meniscus repairs.

Patellar Tendon Group

The average follow-up for the patellar tendon group was 52.0 months (range, 24 to 58 months). Thirty-one patients were normal by Lachman testing, 5 patients (14%) had a 1+ Lachman, and 1 patient (3%) had a 2+ Lachman at follow-up examination. Thirty-four patients were normal by pivot-shift testing. Two patients (5.4%) had a 1+ pivot-shift and 1 patient (2.7%) had a 2+ pivot shift on follow-up examination. The average maximum-manual KT-1000 arthrometer side-to-side difference was 2.2 mm in this group (range, 0 to 15 mm). Thirty-one patients (84%) had side-to-side differences of $\leq$3 mm, 3 patients (8%) had side-to-side differences between 3 mm and 5 mm, and 3 patients (8%) had a side-to-side difference of greater than 5 mm. The average Lysholm score was 87.41 and the average Tegner activity score was 6.59 at final follow-up in this group. Compared with their average preinjury Tegner value of 6.20, these patients not only returned to their preinjury activity level but, in several cases, exceeded it.

Failures: Clinical failure occurred in 3 patients (13%). Two patients had a 1+ pivot-shift and 1+ Lachman and 1 patient had a 2+ Lachman and a 2+ pivot shift. This patient had revision surgery with an allograft during the follow-up period (Table 2).

Subsequent Surgery: Two of 37 patients in the patellar tendon group had subsequent surgery. One patient underwent a partial lateral meniscectomy 5 years after the index procedure and had a stable graft when examined under anesthesia. The second patient, who did not undergo a medial meniscal repair at the

TABLE 2. *Analysis of Failures in the Patellar Tendon Group*

Patient No.	Lachman	Pivot-Shift	KT-1000 Difference	Tibial Fixation	Length Follow-up	Outcome
1	1+	1+	6 mm	Button	24 mo	Brace/inactive
2	1+	1+	11 mm	Interference screw	24 mo	Brace/inactive
3	2+	2+	15 mm	Button	15 mo	Revision

index procedure, had a partial medial meniscectomy 18 months postoperatively.

Comparison of Hamstring and Patellar Tendon Groups

The data obtained for both groups are summarized in Table 3. Analysis of results from the 2 groups showed no significant differences in the presence of crepitus, KT-1000 measurements, or Lysholm scores. Results of a subjective questionnaire revealed a significant difference between the 2 groups when patients were asked how bad the pain was at its worst with the hamstring group being worse ($P = .034$). In addition, there were no significant differences with regard to thigh circumference difference, effusion, or range of motion between the 2 groups. Fourteen patients in the hamstring group were graded as having either a 1+ or 2+ Lachman compared with 6 in the patellar tendon group, which was not statistically significant. Five patients in the patellar tendon group were found on physical examination to have crepitus compared with 2 patients in the hamstring group. The average extension difference between knees was 2° in the patellar tendon group compared with 2.87° for the hamstring group. The average flexion was 142.6° for the patellar tendon group and 139.4° for the hamstring group. These differences were not statistically different.

A comparison of preinjury and postoperative activity level was performed using the Tegner Activity Scale. The hamstring group did not return to their preinjury activity level, with an average postoperative Tegner score of 5.17 versus a preinjury score of 6.54 ($P = .05$). The patellar tendon group, however, not only returned to their preinjury activity level but in some cases surpassed it with average Tegner scores increasing from 6.20 to 6.59 postoperatively.

Clinical failure occurred in 9 patients (23%) from the hamstring group and in 3 patients (8%) from the patellar tendon group. The differences in overall failure rates for the 2 groups were not statistically significant but approached significance with a χ-square value of 3.2 ($P < .1$).

TABLE 3. *Comparison of Objective Measurements Between the Hamstring and Patellar Tendon Groups*

Objective Measurement	Patellar Tendon Group (n = 37)	Hamstring Group (n = 39)
1+ Lachman	5 (13.5%)	10 (26%)
2+ Lachman	1 (2.7%)	4 (10%)
1+ Pivot-shift	2 (5.4%)	8 (20%)
2+ Pivot-shift	1 (2.7%)	1 (2.6%)
0-3 mm KT difference	32 (94%)	30 (77%)
3-5 mm KT difference	3 (8%)	7 (18%)
>5 mm KT difference	2 (5.4%)	2 (5%)
Failures	3 (8%)	9 (23%)

DISCUSSION

Most previous studies have not found any statistically significant differences when comparing males with females using either hamstring or patellar tendon grafts.[8,14,25-28] However, Corry et al.[29] compared 82 patellar tendon ACL reconstructions with 85 hamstring ACL reconstructions and did find a statistically significant increase in KT-1000 arthrometer differences for the females in the hamstring group with an average difference of 2.5 mm, which was significantly different from the male hamstrings ($P < .0001$), the male patellar tendons ($P < .0003$), and the female patellar tendons ($P < .001$).[29] In their study, metal interference screws were used for aperture fixation in all groups. To the authors' knowledge there are no other prospective studies that have reported inferior results in acute females when using hamstring autograft. The purpose of this prospective study was to determine if the results of ACL reconstruction using hamstring autograft were inferior to those of patellar tendon in female patients with acute isolated injuries.

In this study, the patients in the hamstring group showed increased graft laxity compared with the patients in the patellar tendon group as measured by KT-1000, Lachman, and pivot shift tests. Our criteria for failure included a 2+ Lachman, a 1+ or greater pivot shift test, a greater than 5 mm side-to-side difference with KT-1000 arthrometer testing, or revision surgery. Siegel and Barber-Weston[28] defined graft failure as KT-1000 differences of greater than 5.5 mm or a 2+ pivot shift. Aglietti et al.[14] evaluated 69 ACL reconstructions and also used KT-1000 arthrometer differences of greater than 5 mm and a positive pivot shift test as criteria for determining graft failure. Our criteria of defining a 1+ pivot shift (glide) as a failure did increase the failure rate and may be criticized as a limitation of this study. Postoperative radiographic evaluation for both groups did not reveal any cases of aberrant tunnel placement that may have contributed to increased graft laxity, which has been a cause for failure in other studies.[30] Patients in this study did not undergo an aggressive postoperative rehabilitation program, which has been shown to yield good clinical results but also has been associated with increased graft laxity by KT-1000 examination.[31] One interest-

ing finding of this study is the lack of correlation of KT-1000 arthrometer side-to-side differences with clinical failure, Lachman testing, and pivot shift testing. In analyzing failures of both groups in Tables 1 and 2, only 3 of 9 hamstring failures (33%) had a KT-1000 arthrometer difference of greater than 5 mm compared with 3 of 3 of the patellar tendon failures. Two failures in the hamstring group that had a 1+ pivot shift test result had a KT-1000 difference of only 2 mm. Interestingly, the KT-1000 arthrometer data did not correlate well with the clinical result in the hamstring failures but did in the patellar tendon failures. We offer no explanation for this rather unique finding other than the possibility of measurement error.

In 1993, Otero and Hutcheson[12] reported their comparison of ACL reconstruction using patellar tendon and hamstring grafts. Patients were evaluated using objective criteria including Lachman and pivot-shift testing, KT-1000 testing, and extension loss. Success rates in patellar tendon reconstructions at 1-year, 2-year, and 3-year follow-up were 98%, 96%, and 96%, respectively. Success rates over the same time period for the doubled semitendinosus and gracilis grafts were 94%, 83%, and 81%, respectively. These authors felt that patients who had reconstructions with patellar tendon showed consistently greater stability. However, the distribution of reconstructions for acute and chronic injuries was not specified in their report. Other investigators have noted an increased failure rate and increased graft laxity for chronic ACL reconstructions when using hamstring graft compared with patellar tendon.[8,10,11,13]

Our results are similar to those of Otero and Hutchenson,[12] with an overall success rate of 87% in the patellar tendon group. However, the hamstring group had an inferior success rate of 77%. Although the numbers are not statistically significant, the hamstring group had twice as many failures as the patella tendon group. This increased failure rate combined with the greater number of 1+ and 2+ Lachman (14 patients *v* 6 patients) and 1+ and 2+ pivot shift tests (9 patients *v* 3 patients) in the hamstring reconstructions indicates a trend toward increased objective stability with the use of patellar tendon graft in females. The success rate for both groups would possibly be higher had interference screws been used for aperture fixation. However, during the time interval for this study, post fixation was most commonly used. Previous studies have shown that it requires at least 8 to 12 weeks for soft tissue grafts to become incorporated into bone tunnels in dogs.[32] Recent biomechanical studies have shown that quadruple-looped hamstring autograft has stiffness comparable to the native ACL and to patellar tendon autografts,[33] implicating graft fixation as the weak link. In this study, both groups had similar fixation and interference screws were not used in either group. The more rapid healing of the bone plugs into the graft tunnels may account in part for the decreased failure rate noted in the patellar tendon group, although this was not specifically evaluated. Neither group underwent an accelerated postoperative rehabilitation protocol and running was delayed until 3 months postoperatively. This protocol was implemented to allow for adequately healing of the hamstring grafts within the bone tunnels while maintaining similarity for both groups.

The patellar tendon group had higher postoperative Tegner scores than the hamstring group, which reflects a return to higher activity level. Whether or not the superior graft stability noted in the patellar tendon group affected the activity level is uncertain; studies have found that KT-1000 arthrometer side-to-side differences and objective measurement of knee stability are not directly correlated with knee outcome scores.[34,35] Other factors such as the increased pain with activities reported on the visual analog scales for the hamstring group may have contributed to the disparity in Tegner scores. The exact reason for this discrepancy is unknown, was not otherwise investigated, and could reflect a population bias between the 2 groups. However, the postoperative Lysholm scores for the 2 groups were virtually identical. There were no significant differences between the 2 groups in the number of meniscal or osteochondral lesions that could have contributed to the increased subjective pain reported in the hamstring group. There were also no significant differences in flexion, extension, thigh circumference difference, average age, or preoperative and postoperative Lysholm scores. Additionally, these subjective factors do not account for the substantial differences in objective stability measurements between the 2 groups.

This study has several limitations that warrant review before definitive conclusions can be drawn. Current fixation techniques for soft-tissue grafts are superior to those used during the time of this study and these could possibly have diminished the increased laxity noted in both populations. Post fixation combined with interference screws has been shown to be superior to post fixation alone for hamstring grafts in recent cadaver studies.[36] The use of suture with post fixation has also been shown to have decreased failure strength.[37] Most current fixation techniques eliminate suture within the fixation construct to minimize elon-

gation at the fixation site. Generalized ligamentous laxity that is more frequently present in the female was not evaluated and could have contributed to the increased graft laxity noted in both groups. However, despite these limitations, the value of this study lies in the fact that the hamstring group had twice the failure rate and 2 to 3 times as many positive Lachman and pivot shift tests at minimum 2-year follow-up with the same surgeon, the same postoperative protocol, similar activity levels and age, and similar graft fixation.

Our results show a trend toward an increased failure rate in acute, isolated ACL injuries in female patients who undergo reconstruction with an autogenous quadrupled hamstring tendon graft compared with those who undergo reconstruction using an autogenous bone–patellar tendon–bone graft. The exact cause for this discrepancy cannot be determined from this study. Future studies with larger patient groups using current fixation techniques are necessary to corroborate these findings.

REFERENCES

1. Hutchinson MR, Ireland ML. Knee injuries in female athletes. *Sports Med* 1995;19:288-301.
2. Arendt E, Dick R. Knee injury patterns among men and women in collegiate basketball and soccer: NCAA data and review of literature. *Am J Sports Med* 1995;23:694-701.
3. Chandy TA, Grana WA. Secondary school athletic injury in boys and girls: A three-year comparison. *Physician Sportsmed* 1985;13:106-111.
4. Engström B, Johansson C, Törnkvist H. Soccer injuries among elite female players. *Am J Sports Med* 1991;19:372-375.
5. Gray J, Taunton JE, McKenzie DC, Clement DB, McConkey JP, Davidson RG. A survey of injuries to the anterior cruciate ligament of the knee in female basketball players. *Int J Sports Med* 1985;6:314-316.
6. Ireland ML, Wall C. Epidemiology and comparison of knee injuries in elite male and female United States basketball athletes. *Med Sci Sports Exerc* 1990;22:S82 (suppl).
7. Zelisko JA, Noble HB, Porter M. A comparison of men's and women's professional basketball injuries. *Am J Sports Med* 1982;10:297-299.
8. Aglietti P, Buzzi R, Zaccherotti G, De Biase P. Patellar tendon versus doubled semitendinosus and gracilis tendons for anterior cruciate ligament reconstruction. *Am J Sports Med* 1994; 22:211-218.
9. Clancy W Jr, Nelson DA, Reider B, Narechania RG. Anterior cruciate ligament reconstruction using one-third of the patellar ligament augmented by extra-articular tendon transfers. *J Bone Joint Surg Am* 1982;64:352-359.
10. Holmes PF, James SL, Larson RL, Singer KM, Jones DC. Retrospective direct comparison of three intraarticular anterior cruciate ligament reconstructions. *Am J Sports Med* 1991;19: 596-600.
11. Marder RA, Raskind JR, Carroll M. Prospective evaluation of arthroscopically assisted anterior cruciate ligament reconstruction. Patellar tendon versus semitendinosus and gracilis tendons. *Am J Sports Med* 1991;19:478-484.
12. Otero AL, Hutcheson L. A comparison of the doubled semitendinosus/gracilis and central third of the patellar tendon autografts in arthroscopic anterior cruciate ligament reconstruction. *Arthroscopy* 1993;9:143-148.
13. Wachtl SW, Imhoff A. Retrospective comparison of four intraarticular anterior cruciate ligament reconstructions using three evaluation systems. *Arch Orthop Trauma Surg* 1994;114: 25-31.
14. Aglietti P, Buzzi R, Menchetti PPM, Giron F. Arthroscopically assisted semitendinosus and gracilis tendon graft in reconstruction for acute anterior cruciate ligament injuries in athletes. *Am J Sports Med* 1996;24:726-731.
15. Bonamo JJ, Krinick RM, Sporn AA. Rupture of the patella ligament after use of its central third for anterior cruciate ligament reconstruction: A report of two cases. *J Bone Joint Surg Am* 1984;66:1294-1297.
16. Christen B, Jakob R. Fractures associated with patellar ligament grafts in cruciate ligament surgery. *J Bone Joint Surg Br* 1992;74:617-619.
17. DeLee JC, Craviotto DF. Rupture of the quadriceps tendon after a central third patellar tendon anterior cruciate ligament reconstruction. *Am J Sports Med* 1991;19:415-416.
18. Skelly WA, DeVita P. Compressive and shear forces on the tibia and knee during landing. Proceedings of the 6th Biennial Conference of the Canadian Society for Biomechanics, 1990; 59-60.
19. Barrett GR, Miller C, Richardson K. Combined single-strand distal semitendinosus-iliotibial band tenodesis (Puddu) for anterior cruciate ligament augmentation. *Am J Knee Surg* 1995; 8:13-19.
20. Gomes JLE, Marczyk LRS. Anterior cruciate ligament reconstruction with a loop or double thickness of semitendinosus tendon. *Am J Sports Med* 1984;12:199-203.
21. Zaricznyj B. Reconstruction of the anterior cruciate ligament of the knee using a doubled tendon graft. *Clin Orthop* 1987; 220:162-175.
22. Zarins B, Rowe CR. Combined anterior cruciate ligament reconstruction using semitendinosus tendon and iliotibial tract. *J Bone Joint Surg Am* 1986;68:160-177.
23. Lysholm J, Gillquist J. Evaluation of knee ligament surgery results with special emphasis on use of a scoring scale. *Am J Sports Med* 1982;10:150-154.
24. Tegner Y, Lysholm J. Rating systems in the evaluation of knee ligament injuries. *Clin Orthop* 1985;198:43-49.
25. Maeda A, Shino K, Horibe S, Nakata K, Buccafusca G. Anterior cruciate ligament reconstruction with multistranded autogenous semitendinosus tendon. *Am J Sports Med* 1996;24: 504-509.
26. Otto D, Pinczewski LA, Clingeleffer A, Odell R. Five-year results of single-incision anterior cruciate ligament reconstruction with patellar tendon autograft. *Am J Sports Med* 1998:26: 181-188.
27. Sgaglione NA, Del Pizzo W, Fox JM, Friedman MJ, Snyder SJ, Ferkel RD. Arthroscopic-assisted anterior cruciate ligament reconstruction with the semitendinosus tendon: Comparison of results with and without braided polypropylene augmentation. *Arthroscopy* 1992;8:65-77.
28. Siegel MG, Barber-Westin SD. Arthroscopic-assisted outpatient anterior cruciate ligament reconstruction using the semitendinosus and gracilis tendons. *Arthroscopy* 1998;14: 268-277.
29. Corry IS, Webb JM, Clingeleffer AJ, Pinczewski LA. Arthroscopic reconstruction of the anterior cruciate ligament: A comparison of patellar tendon autograft and four-strand hamstring tendon autograft. *Am J Sports Med* 1999;27:444-454.
30. Khalfayan EE, Sharkey PF, Alexander AH, Bruckner JD, Bynum EB. The relationship between tunnel placement and clinical results after anterior cruciate ligament reconstruction. *Am J Sports Med* 1996;24:335-341.
31. Muneta T, Sekiya I, Ogiuchi T, Yagishita K, Yamamoto H, Shinomiya K. Effects of aggressive early rehabilitation on the

outcome of anterior cruciate ligament reconstruction with multi-strand semitendinosus tendon. *Int Orthop* 1998;22:352-356.
32. Rodeo SA, Arnoczky SP, Torzilli PA, Hidaka C, Warren RF. Tendon-healing in a bone tunnel: A biomechanical and histological study in the dog. *J Bone Joint Surg Am* 1993;75: 1795-1803.
33. To JT, Howell SM, Hull ML. Contributions of femoral fixation methods to the stiffness of anterior cruciate ligament replacements at implantation. *Arthroscopy* 1999;15:379-387.
34. Tyler TF, McHugh MP, Gleim GW, Nicholas SJ. Association of KT-1000 measurements with clinical tests of knee stability 1 year following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther* 1999;29:540-545.
35. Snyder-Mackler L, Fitzgerald GK, Bartolozzi AR III, Ciccotti MG. The relationship between passive joint laxity and functional outcome after anterior cruciate ligament injury. *Am J Sports Med* 1997;25:191-195.
36. Noojin FK, Voor MJ, Smith MG, Tillett ED. Point of femoral fixation in hamstring ACL reconstruction: A biomechanical study. *Arthroscopy* 2000;16:420-421.
37. Magen HE, Howell SM, Hull ML. Structural properties of six tibial fixation methods for anterior cruciate ligament soft tissue grafts. *Am J Sports Med* 1999;27:35-43.