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Arthroscopic Reconstruction of the Anterior Cruciate Ligament

A Comparison of Patellar Tendon Autograft and Four-Strand Hamstring Tendon Autograft*

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ABSTRACT

We compared the outcome of anterior cruciate ligament reconstruction using hamstring tendon autograft with outcome using patellar tendon autograft at 2 years after surgery. Patients had an isolated anterior cruciate ligament injury and, apart from the grafts, the arthroscopic surgical technique was identical. Prospective assessment was performed on 90 patients with isolated anterior cruciate ligament injury undergoing reconstruction with a patellar tendon autograft; 82 were available for follow-up. The hamstring tendon autograft group consisted of the next 90 consecutive patients fulfilling the same criteria; 85 were available for follow-up. Clinical review included the Lysholm and International Knee Documentation Committee scores, instrumented testing, thigh atrophy, and kneeling pain. These methods revealed no difference between the groups in terms of ligament stability, range of motion, and general symptoms. Thigh atrophy was significantly less in the hamstring tendon group at 1 year after surgery, a difference that had disappeared by 2 years. The KT-1000 arthrometer testing showed a slightly increased mean laxity in the female patients in the hamstring tendon graft group. Kneeling pain after reconstruction with the hamstring tendon autograft was significantly less common than with the patellar tendon autograft, suggesting lower donor-site morbidity with hamstring tendon harvest.

Rupture of the ACL impairs the stability of the knee, resulting in difficulty with athletic performance,[3,6,28] increased risk of subsequent meniscal injury,[3,8,24] and increased risk of early degenerative joint disease.[7,13,16,19,28,40] The outcome of repair alone is inferior to the results after reconstruction or repair with augmentation.[5,10,38]

Anterior cruciate ligament reconstruction has been advocated to improve knee stability and reduce the incidence of later meniscal tears, although the latter has not been proved by scientific experimentation. At our center, ACL reconstruction in the meniscus-retained knee compared with ACL reconstruction in the knee with meniscectomy has been shown to reduce the likelihood of radiologic deterioration at 7 years.[18]

Many techniques for ACL reconstruction have been proposed and tested, including prosthetic ligament, allograft, autograft, graft with prosthetic augmentation, and extraarticular reconstruction. Autografts of patellar tendon or hamstring tendon are now preferred by most surgeons, and extraarticular reconstruction is rarely used.[17] Furthermore, studies have shown no difference in results when an extraarticular augmentation was added to an intraarticular patellar tendon graft.[29,42] Open and arthroscopic techniques of graft substitution have been compared but have not shown significant differences in outcome, although open and arthroscopic reconstruction with hamstring tendons has not been compared.[9,33] Suspensory methods (that is, fixation outside the tunnel) and aperture methods (by interference screw close to the origin and insertion) of fixation have been described, with aperture

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fixation resulting in increased stiffness of the construction compared with the suspensory method.[15,21,26,41]

Outcome studies on ACL reconstruction have included simple assessment of a particular technique and comparison of one surgical technique with another or others. Likewise, comparisons between groups having patellar tendon or hamstring tendon grafts have been reported.[1,12,14,23,30,31] In the reports by Aglietti et al.,[1] Otero and Hutcheson,[31] and O'Neill,[30] the patellar tendon grafts were held by interference screw aperture fixation, while the hamstring tendon grafts were held by outside suspensory fixation. O'Neill also used two-strand rather than four-strand hamstring tendon grafts. The studies by Harter et al.[12] and Holmes et al.[14] compared patellar tendon and single-strand hamstring tendon, both in "over the top" positioning but with various additional extraarticular reconstructions. A study by Marder et al.[23] had both graft types held by matching fixation (suspensory) and showed little difference in outcome between groups. This and other studies mentioned included patients with other injuries such as meniscal tears, chondral lesions, or other ligament injuries, and some included patients with revision ACL surgery. Therefore, when interpreting these studies one must consider the different techniques of fixation, other differing surgical methods, and other intraarticular lesions in addition to the differing graft sources.

Our study compares the clinical outcome of ACL reconstruction using the four-strand hamstring tendon autograft with reconstruction using the patellar tendon autograft at 2 years after surgery. The study is unique for two reasons: 1) All patients had an isolated ACL injury; patients with associated injuries were excluded to control for confounding features that may have affected outcome. 2) The arthroscopic surgical technique was identical for both autograft types, including surgeon, graft placement, graft fixation, and rehabilitation program. Furthermore, the outcome assessment techniques were identical for each group, and the groups were comparable in terms of age, sex, activity level, and indications for surgery. Therefore the graft type and its harvest were the only initial differences between groups.

The main objective of the study was to evaluate any difference in outcome between the patellar and hamstring tendon autografts, controlling as far as possible all other variables. An additional objective was to show that the outcome after arthroscopic reconstruction with either graft reaches acceptable standards when the graft is placed anatomically and secured by an interference screw.

MATERIALS AND METHODS

At our center, the preferred method of ACL reconstruction from 1989 to 1993 was the arthroscopic placement of a central-third patellar tendon autograft using interference screws for aperture fixation at the femur and near-aperture fixation at the tibia. After 1994, four-strand hamstring tendon autografts were used by harvesting the ipsilateral gracilis and semitendinosus tendons and doubling each tendon. This graft was also placed with the arthroscopic method and fixed with interference screws. Accelerated early rehabilitation without bracing was used after both techniques. After 1992, outcome assessment was standardized and prospective to audit results.

Patients

Anterior cruciate ligament reconstruction with patellar tendon autograft fixation was performed on 333 patients over a 15-month period (1992 to 1993). Patients with an associated ligament injury, chondral damage, previous meniscectomy, excision of more than one-third of one meniscus, an abnormal radiograph, or an abnormal contralateral knee joint were excluded, as were those patients who did not wish to participate in a research program. No patients were involved in claims for workers' compensation. This left 90 patients, of whom 82 (91%) were available for follow-up (patellar tendon group). The hamstring tendon group consisted of 90 consecutive patients fulfilling the same criteria from the total of 372 patients assessed prospectively and treated by hamstring tendon autograft in the succeeding 13 months (1993 to 1994); 85 (94%) were available for follow-up at 2 years after surgery.

Of the eight patients who were unavailable for the 2-year follow-up in the patellar tendon group, three were overseas, four did not respond, and one could not be contacted. Also excluded from the outcome tests at 2 years were two patients with rerupture, one with atraumatic graft failure, and two with contralateral rupture, leaving 77 for outcome testing after reconstruction with a patellar tendon autograft. Of the five patients unavailable for follow-up in the hamstring tendon group, two were overseas and three did not respond. There were three patients with rerupture, one with an atraumatic graft failure, and four with contralateral ACL ruptures, leaving 77 for outcome testing after reconstruction with a hamstring tendon autograft. The outcome testing was performed at 24 months after surgery.

The patellar tendon group comprised 48 male (53%) and 42 female (47%) patients. The mean age was 25 years (range, 15 to 42). The hamstring tendon group was similar, comprising 47 male (52%) and 43 female (48%) patients with a mean age of 25 years (range, 13 to 52). (For comparison purposes, subsequent data refer to the 77 in each group followed up at 2 years unless otherwise stated.) The indication for surgery was ACL rupture confirmed by clinical diagnosis in an otherwise healthy patient who experienced instability in daily activities or wished to maintain his or her preinjury level of activity. The preinjury activity levels were comparable between groups (see Table 3). Eighty-seven percent of the patellar tendon group ($N = 67$) and 79% of the hamstring tendon group ($N = 61$) played competitive sports. To avoid potential arthrofibrosis, surgery was not performed for acute injuries unless the knee had almost a full range of movement with minimal effusion and pain.[39]

In the patellar tendon group preoperatively, all patients had a grade 1 or 2 Lachman test and 72 (93.5%) had positive pivot shift tests (5 patients had incomplete extension in which a pivot shift could not be performed). In the hamstring tendon group preoperatively, all patients had a

grade 1 or 2 Lachman test and 54 (70%) had positive pivot shift tests (23 patients had incomplete extension in which a pivot shift could not be performed).

Surgery was performed within 12 weeks after injury in 70% ($N = 54$) of the hamstring tendon group and in 66% ($N = 51$) of the patellar tendon group.

Arthroscopic Technique

All surgeries were performed by the same surgeon, using a round-headed cannulated interference fit screw (RCI, Smith & Nephew Endoscopy, Andover, Massachusetts) for both patellar tendon and hamstring tendon fixation at both the tibial and femoral attachments. No supplementary fixation was used (Fig. 1).

With the patient under general anesthesia, a single intravenous dose of 2 g cephalothin antibiotic prophylaxis was given. A tourniquet was applied high on the thigh and inflated after the leg was exsanguinated with an Esmarch bandage. High anterolateral and low anteromedial portals were used. Preliminary notch clearance included removal of the old ACL stump.

The hamstring tendon autograft was harvested from the site of the pes anserinus insertion via a 2-cm longitudinal anteromedial incision. The gracilis and semitendinosus tendons were harvested separately using a tendon stripper (Linvatec, Largo, Florida), after ensuring that accessory fascial attachments had been divided under direct vision. The tendons were left attached distally to aid tensioning in graft preparation. The tendons were cleaned of adherent muscle fibers, tensioned by attachment of a clip to the free ends, and looped over two strands of No. 5 suture, which became the leading sutures subsequently used to pull the graft through the tunnels. The quadrupled tendon graft was sutured at the looped end using No. 1 Vicryl (Ethicon Inc., Somerville, New Jersey) in a modified baseball suture for a distance of approximately 20 mm. The opposite free ends were similarly sutured to the attached tibial ends along approximately 45 mm of length. The graft was sized (usually 6.5 to 8 mm diameter), and then a mark was made 30 mm from the femoral end. The prepared graft was left attached at its tibial insertion until required. After the tunnels were reamed, the tibial attachment of the graft was divided, leaving a free graft for intraarticular placement.

The patellar tendon autograft was harvested via two 2-cm longitudinal incisions at the proximal and distal ends of the patellar tendon. A 20- to 25-mm long trapezoidal patellar tendon bone block was excised attached to the proximal end. The 10-mm wide strip of central patellar tendon was incised subcutaneously and extracted through the tibial incision. A 30-mm long rectangular tibial bone block was excised attached to the tibial end. Both ends were fashioned to pass through a gauge at 8 to 10 mm diameter. Two holes were drilled in each bone block to be used for lead threads.

The femoral tunnel position was marked with a bone awl 5 mm anterior to the posterior capsular insertion and at the 11-o'clock (right knee) or 1-o'clock (left knee) position with respect to the apex of the notch. Notchplasty of the bone was not performed.

With the knee fully flexed, the femoral tunnel was created using a 4.5-mm drill bit inserted from the anteromedial portal and aimed approximately 30° lateral and 30° anterior to the femoral axis. A 2.4-mm Beath pin was inserted in the drill hole followed by the appropriate-sized stepped router (Smith and Nephew Endoscopy) (Fig. 2), and the hole was drilled to 30 mm. The router was used to overream the articular end of the femoral tunnel to 10 mm so that the screw head could be countersunk. The tibial tunnel was created using a drill guide inserted through the anteromedial portal. The tip of the guide was placed within the remnants of the ACL stump at a position one-third of the way from the medial end of a line joining the anterior horn of the lateral meniscus and the medial tibial spine. A 4.5-mm hole was drilled entering the anterior tibia 45 mm from the intraarticular guide tip. A 2.4-mm Beath pin was inserted as a guide for the appropriate-sized stepped router, which was used to overream the subcutaneous end of the tibial tunnel to 10 mm to countersink the screw head.

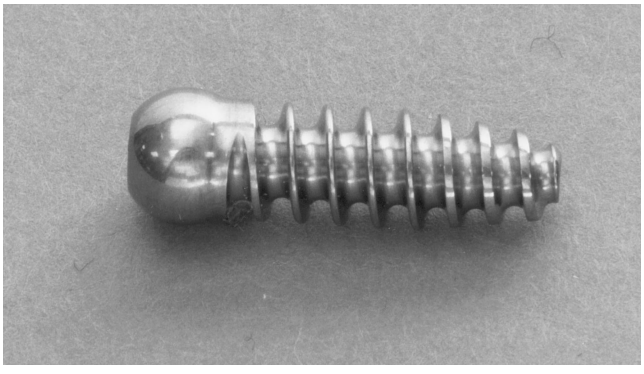

Figure 1. Round-headed, soft-threaded, cannulated, interference screw.

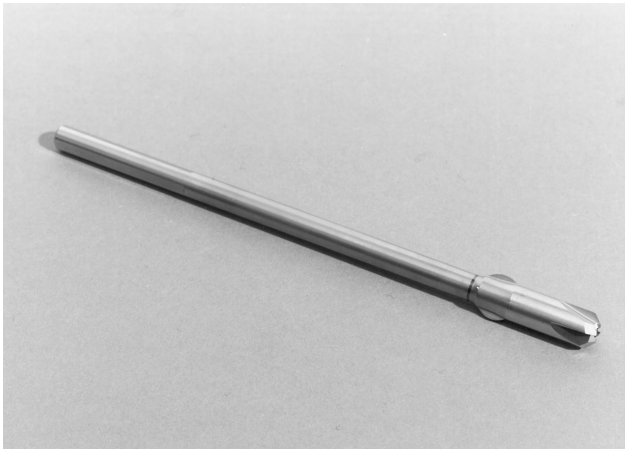

Figure 2. Stepped router.

The graft was then passed into the knee using a nylon pull-through suture to place the lead threads. The hamstring tendon graft was positioned such that the mark at 30 mm on the femoral end was flush with the femoral tunnel, ensuring that the graft was fully seated. The patellar tendon graft was positioned so that the bony attachment was entirely within the femoral tunnel with the cancellous side facing anteroinferiorly. With the knee fully flexed, a guide pin was inserted via the anteromedial portal along the anterior surface of the graft and the round-headed, soft-threaded, cannulated interference screw was driven home until the head was engaged in the aperture created by the stepped router. The direction of the initial femoral drill hole and the direction of screw insertion (both via the anteromedial portal) eliminated potential screw-graft divergence. Firm traction was then applied to the tibial end while the knee was taken through a full range of motion to pretension the graft and to observe that full extension could be achieved without impingement. A guide pin was then inserted along the posterior aspect of the tibial tunnel and the screw was inserted. This screw was initially advanced two to three turns with the knee flexed. When a firm grip was obtained, the leg was straightened to ensure full extension and then the screw was fully seated. Laxity was checked with the Lachman and anterior drawer tests.

The knee joint was then irrigated, 10 ml of 0.25% bupivacaine hydrochloride was inserted into the joint and around the portals, and routine closure was performed.

The tourniquet was applied before skin preparation and draping and removed after wound dressing. The mean tourniquet time for the patellar tendon procedure was 69 minutes (range, 40 to 114) and for the hamstring tendon procedure, 64 minutes (range, 45 to 95).

Rehabilitation

Surgery was performed on an outpatient basis when postoperative pain permitted. The median length of hospital stay was 2 nights (range, 1 to 5) for the patellar tendon group and 1 night (range, 0 to 3) for the hamstring tendon group ($P < 0.001$, t-test). Immediate weightbearing using crutches was encouraged, and patients did not wear a brace. The median time on crutches was 10 days (range, 2 to 21) for the patellar tendon group and 7 days (range, 0 to 21) for the hamstring tendon group ($P < 0.001$, t-test). Simple analgesics were given for pain control, and daily physical therapy was initiated to reduce postoperative swelling. Active range of motion exercises were commenced aiming for full extension by 14 days. The usual clinical follow-up included review at 10 to 14 days for wound inspection and suture removal, then at 6 weeks, 6 months, 1 year, and 2 years. An accelerated rehabilitation program was undertaken using closed chain exercises and proprioceptive training. By 6 weeks, jogging in straight lines, swimming, and cycling were permitted. After 12 weeks, general strengthening exercises were continued and agility work and sport-specific activities were encouraged. Return to competitive sport involving jumping, pivoting, or sidestepping was prohibited until 9 months after reconstruction, but with variable patient compliance.

Outcome

Clinical review at 1 year and 2 years included the International Knee Documentation Committee's (IKDC) Knee Ligament Standard Evaluation.[2] Clinical assessment was used for grading in the IKDC ligament evaluation category. Instrumented testing was performed by one experienced technician for both groups using the KT-1000 arthrometer (MEDmetric Corporation, San Diego, California), and the side-to-side difference at 89 N was reported for comparison. Thigh atrophy was defined as the difference in thigh circumference between the involved and contralateral knee 10 cm proximal to the superior pole of the patella. Kneeling pain and hamstring area pain were subjectively assessed by the patients in addition to the IKDC category of graft-site tenderness. Patients completed the Lysholm knee score to document subjective symptoms.[43]

Statistics

Statistical comparison was by the chi-square test for categorical data, using A and B against C and D (normal or nearly normal versus abnormal or severely abnormal) in IKDC data. The Mann-Whitney U-test was used for ranked continuous data (thigh atrophy and Lysholm score), and the unpaired Student's t-test for continuous data (KT-1000 arthrometer comparison). Multiple regression analysis was used to assess the outcomes in different subgroups.

RESULTS

These patients with isolated ACL injuries were extracted from larger groups. The 90 in the patellar tendon group represented 27% of the 333 patients with patellar tendon graft reconstructions, and the 90 in the hamstring tendon group represented 24% of the 372 patients with hamstring tendon grafts. Thus, the ACL injuries that were not isolated was on the order of 70% to 75% of cases.

The results of clinical assessment were based on the patients with grafts and contralateral ACLs apparently intact at 2 years. Those with reruptures, atraumatic failures, or contralateral ACL rupture were not suitable for formal testing and were recorded separately.

To illustrate the overall results of surgery rather than simply the results of those with apparently intact grafts, we included adjusted figures with the assumption that reruptures score grade D on the IKDC scale and "poor" on the Lysholm score. The patients with reruptures could not have been included in formal testing because all reconstructions had been revised by the time of the 2-year follow-up. Patients with contralateral ruptures could not be included because all assessment assumes a "normal" contralateral knee.

Of the eight patients not responding at 2 years in the patellar tendon group, four had stable knees at 6 months'

follow-up and were then lost to follow-up. The remaining four patients had stable knees at 12 months and had returned to moderate or strenuous activity. Of the five patients lost to follow-up from the hamstring tendon group, three had stable knees at 12 months and had returned to moderate or strenuous activity, and one had a stable knee at 6 months and was asymptomatic at 2 years but not examined.

Lysholm Knee Score

The Lysholm knee score is designed to evaluate symptoms (limp, support, locking, instability, pain, swelling, stair-climbing, squatting). In the patellar tendon group, 90% ($N = 69$) of patients had good or excellent results, as did 91% ($N = 70$) of patients in the hamstring tendon group (Table 1). There were two patients who had poor results in the hamstring tendon group. One was a 24-year-old woman who scored 42 and continued to have pain and swelling, despite a grading of 0 for the Lachman and pivot shift tests and a KT-1000 arthrometer side-to-side difference of 1 mm. The other was a 52-year-old woman who scored 55 and who had intermittent pain, swelling, and giving way. She had grade 0 Lachman and pivot shift tests with a KT-1000 arthrometer difference of 3 mm. One patient in the patellar tendon group was described as having a poor result. She was a 23-year-old woman who had pain, swelling, partial giving way, and 1.5 cm thigh atrophy with a KT-1000 arthrometer difference of 3 mm and grade 1 Lachman and pivot shift tests. If patients with graft rerupture or atraumatic failure are assumed to be in the "poor" category, the total of good or excellent results was 86% (70 of 81) for the patellar tendon group and 86% (69 or 80) for the hamstring tendon group.

IKDC Scores

The IKDC assessment combines symptoms and signs. Each category is given an overall grade of A (normal), B (nearly normal), C (abnormal), or D (severely abnormal). The final evaluation of A, B, C, or D is determined by the worst score in the following categories: 1) subjective functional assessment, 2) symptoms, 3) range of motion, and 4) ligament evaluation. Overall, 86% of patients (66 of 77) in the patellar tendon group were assessed as normal or nearly normal (grade A or B), as were 93% (72 of 77) in the hamstring tendon group (Table 2). If patients with reruptures or atraumatic failures were assumed to have scored grade D, then there were 82% (66 of 80) in the patellar tendon group and 89% (72 of 81) in the hamstring tendon group scoring grade A or B. Further analysis of the subcategories is given below with IKDC grades in parentheses.

Category 1 (Subjective Functional Assessment). In the patellar tendon group, 95% of patients (73 of 77), and in the hamstring tendon group 100% of patients (77) graded their knee function as normal (A) or nearly normal (B).

Category 2 (Symptoms). Ninety percent (69 of 77) of the patellar tendon group and 95% (73 of 77) of the hamstring tendon group reported no pain during moderate (B) or strenuous (A) activities. Ninety-six percent (74 of 77) of the patellar tendon group and 97% (75 of 77) of the hamstring tendon group reported no swelling during moderate or strenuous activities. For partial giving way, there were 99% (76) of the patellar tendon group and 97% (75) of the hamstring tendon group without symptoms during moderate or strenuous activities. All patients in the patellar tendon group and 99% (76) in the hamstring tendon group reported no full giving way during moderate or strenuous activities.

Category 3 (Range of Motion). Full extension or a 3° or less difference from the opposite limb (A) was recorded in 97% (75) of the patellar tendon group and 95% (73) of the hamstring tendon group. Loss of extension of 3° to 5° (B) was present in 3% (2) of patellar tendon patients and 5% (4) of hamstring tendon patients. Full flexion or a 5° or less difference (A) was present in 99% (76) of each group. The remaining patient in each group lacked 6° to 15° (B) of flexion.

Category 4 (Ligament Evaluation). Lachman testing demonstrated 81% (62) of the patellar tendon group and 75% (58) of the hamstring tendon group had grade 0 laxity (A). Twenty percent (15) of the patients in the patellar tendon group and 22% (17) in the hamstring tendon group had grade 1 laxity (B). Two patients with hamstring tendon grafts had grade 2 laxity (C). Pivot shift testing showed 91% (70) of the patellar tendon patients and 82% (63) of the hamstring tendon patients had a negative, or grade 0, result (A). The remaining 9% (7) of patients in the patellar tendon group and 18% (14) in the hamstring

TABLE 1
Lysholm Knee Scores for Patients with Patellar or Hamstring Tendon Autografts

Score (points)	Patellar tendon[a]				Hamstring tendon[a]			
	Tested		Total		Tested		Total	
	N	(%)	*N*	(%)	*N*	(%)	*N*	(%)
Excellent (95–100)	50	(65)	50	(62)	48	(62)	48	(59)
Good (84–94)	19	(25)	19	(24)	22	(29)	22	(27)
Fair (65–83)	7	(9)	7	(9)	5	(6)	5	(6)
Poor (<65)	1	(1)	4	(5)	2	(3)	6	(7)
Median Lysholm score	95				95			
Interquartile range	10				10			

[a] "Tested" refers to 77 patients in each group with follow-up evaluation at 2 years after surgery. "Total" equals 80 in the patellar tendon group and 81 in the hamstring tendon group and includes patients with graft failures.

TABLE 2
Overall IKDC Grades for Patients with Patellar or Hamstring Tendon Autografts

Rating	Patellar tendon[a]				Hamstring tendon[a]			
	Tested		Total		Tested		Total	
	N	(%)	*N*	(%)	*N*	(%)	*N*	(%)
A (normal)	37	(48)	37	(46)	31	(40)	31	(38)
B (nearly normal)	29	(38)	29	(36)	41	(53)	41	(51)
C (abnormal)	7	(9)	7	(9)	4	(5)	4	(5)
D (severely abnormal)	4	(5)	7	(9)	1	(2)	5	(6)

[a] See footnote at Table 1.

tendon group demonstrated a grade 1 pivot shift (B). There was no significant difference in these results between the two groups.

The other four IKDC categories, although not included in the overall grade, are considered important in outcome assessment of ACL reconstruction. "Patellofemoral crepitus" was graded A in 92% (71) of patients in the patellar tendon group and 99% (76) in the hamstring tendon group. "Harvest site tenderness, numbness, or irritation" were absent in 56% (43) of the patellar tendon group and 75% (58) of the hamstring tendon group (A); however, mild symptoms (B) were noted in 34% (26) of the patellar tendon group and 23% (18) of the hamstring tendon group.

Normal radiologic reports (A) were given for 66 of 67 patients in the patellar tendon group and 61 of 62 patients in the hamstring tendon group. One patient from each group was noted as having minimal radiologic changes (B) over the 24-month period.

The functional test of "single-legged hop" was scored A or B in 97% (74 of 76, 1 missing value) of patients in the patellar tendon group and 99% (71 of 72, 5 missing values) in the hamstring tendon group. The percentages in category A for the single-legged hop test (that is, 90% or more distance compared with the opposite side) were 92% (70 of 76) in the patellar tendon group and 94% (68 of 72) in the hamstring tendon group.

The activity level category is shown in Table 3. At the time of first examination the patients reported their preinjury activity level; there was no difference between groups, with over 90% involved in strenuous activities. Before surgery, 70% ($N = 54$) of the patellar tendon group and 82% ($N = 63$) of the hamstring group could participate only at the light or sedentary level of activity, that is, levels III or IV. At 1 year 73% (56 of 77) in the patellar tendon group and 70% (54 of 77) in the hamstring tendon group were already participating at activity level I or II, that is, moderate to strenuous activity, with about 50% in each group back to strenuous activity. By 2 years, 84% ($N = 65$) of the patellar tendon group and 74% ($N = 57$) of the hamstring tendon group reached level I or II (chi-square, $P = 0.1$, not significant). However, if the focus of analysis is applied to attainment of level I sport against attainment of levels II, III, or IV, then a chi-square analysis of these numbers gives a significance of $P = 0.01$, that is, significantly more of the patellar tendon group reached level I. Of the 11 patients in the patellar tendon group and 18 in the hamstring tendon group who were originally participating in level I or II activities and had not returned to this level at 2 years, 7 in the patellar tendon group and only 2 in the hamstring tendon group stated that this was because of their knees.

There was no significant difference between the patellar tendon and hamstring tendon groups in any of the other IKDC subcategories at 2 years.

Thigh Atrophy

Table 4 shows there was significantly greater thigh atrophy in the patellar tendon group than in the hamstring tendon group at 1 year, although, with a high percentage in each group at 10 mm or less, the actual difference is small. By 2 years the difference between groups was no longer significant, with 62 (81%) of the patellar tendon group and 58 (75%) of the hamstring tendon group having less than 10-mm difference in thigh circumference.

Instrumented Testing

The KT-1000 arthrometer data at 89 N were available for 61 patients in the patellar tendon group and for 75 patients in the hamstring tendon group (Table 5). The reason for incomplete data was the inconsistent KT-1000

TABLE 3
Activity Levels for 77 Patients With Patellar Tendon (PT) or Hamstring Tendon (HT) Autograft and 2-Year Follow-up Results

Level	Preinjury *N* (%)		Presurgery *N* (%)		1-year follow-up *N* (%)		2-year follow-up *N* (%)	
	PT	HT	PT	HT	PT	HT	PT	HT
I. Strenuous	72 (94)	70 (91)	17 (22)	8 (10)	42 (55)	38 (49)	54 (70)[a]	39 (51)
II. Moderate	4 (5)	5 (6)	6 (8)	6 (8)	14 (18)	16 (21)	11 (14)	18 (23)
III. Light	0 (0)	0 (0)	5 (6)	6 (8)	17 (22)	16 (21)	7 (9)	11 (14)
IV. Sedentary	1 (1)	2 (3)	49 (64)	57 (74)	4 (5)	7 (9)	5 (7)	9 (12)

[a] Significantly more patients in the patellar tendon group reached level I activity when compared with levels II, III, and IV ($P = 0.01$, chi-square test).

TABLE 4
Thigh Atrophy Difference at 1-Year Follow-up for Patients with Patellar and Hamstring Tendon Grafts

Difference	Patellar tendon[a]		Hamstring tendon	
	N	(%)	*N*	(%)
<10 mm	41	(53)	56	(73)
10–20 mm	35	(46)	18	(23)
>20 mm	1	(1)	3	(4)

[a] Significantly greater thigh atrophy was seen in the patellar tendon group ($P = 0.002$, Mann-Whitney U test).

TABLE 5
Mean and 95% Confidence Limits of KT-1000 Arthrometer Findings (Side-to-Side Difference in Millimeters) at 89 N of Force[a]

Patients	Patellar tendon group	Hamstring tendon group
Overall	1 (0.8–1.2)	1.7 (1.5–1.9)
Male	0.9 (0.6–1.2)	0.9 (0.7–1.1)
Female	1.0 (0.7–1.3)	2.5 (2.2–2.8)

[a] There was a significant difference between patellar tendon and hamstring tendon groups overall ($P = 0.02$, *t*-test). The female patients in the hamstring tendon group differed significantly from the male patients in that group and from both male and female patients in the patellar tendon group.

TABLE 6
Percentage of Patients with Kneeling Pain in the Patellar Tendon and Hamstring Tendon Groups at 1- and 2-Year Follow-up[a]

Location of Pain	Patellar tendon group		Hamstring tendon group	
	1 year	2 years	1 year	2 years
Anterior	55	31	6	6
Other	1	1	1	0
None	44	68	93	94

[a] Significant difference between groups at 2-year follow-up ($P < 0.0002$, chi-square test).

arthrometer availability in the early stages of the study. Of the 16 patients with missing values in the patellar tendon group, data for 13 were available at 3 years; the mean value was 1.1-mm side-to-side difference and only 2 patients had more than a 3-mm difference (both 4 mm). Of the two patients with missing values in the hamstring tendon group, data for one were available at 3 years and measured 1-mm side-to-side difference. These extra data suggest that our conclusions would not have been substantially altered had the data been complete at 2 years.

If it is assumed that the patients with reruptures or atraumatic failed grafts scored more than 5-mm side-to-side difference on KT-1000 arthrometer testing, then, in the patellar tendon group, 91% (58 of 64) scored 3 mm or less difference, as did 79% (62 of 79) of the hamstring tendon group. Eight percent of the patellar tendon group (5 of 64) and 6% of the hamstring tendon group (5 of 79) scored more than 5 mm. For those tested at 2 years (that is, excluding patients with reruptures or atraumatic failures), the patellar tendon group scores were significantly lower ($P = 0.02$), although the mean result in each group was low at 1 mm (patellar tendon group) and 1.7 mm (hamstring tendon group). The increased laxity in the hamstring tendon group was associated with the patient's sex. Women in the hamstring tendon group had a mean difference of 2.5 mm, which was significantly different from female patients in the patellar tendon group ($P = 0.001$), male patients in the patellar tendon group ($P = 0.0003$), and male patients in the hamstring tendon group ($P < 0.0001$). The side-to-side difference for men in the patellar tendon group was not significantly different from that of the men in the hamstring tendon group ($P = 0.99$). Multiple regression analysis showed that this sex difference in the hamstring tendon group could not be explained by age or weight of the patient or timing of surgery. The KT-1000 arthrometer results were poorly correlated with the IKDC scores ($r^2 = 0.2$) or Lysholm score ($r^2 = -0.1$).

Because of the difference in KT-1000 arthrometer scores, subgroup analysis of the Lachman test in the hamstring tendon graft patients was performed. Comparison of grade 0 and grade 1 or 2 showed a significant increase in laxity in the female patients compared with the male patients ($P = 0.0002$, chi-square). There was also a significant difference between women in the hamstring tendon group and those in the patellar tendon group ($P = 0.049$). This was consistent with the increased KT-1000 arthrometer difference in the women in the hamstring tendon group. A similar analysis of grade 0 and grade 1 or 2 pivot shift test showed a significant difference between male and female patients in the hamstring tendon group ($P = 0.003$, chi-square); however, this sex difference was also seen in the patellar tendon group ($P = 0.025$, chi-square). The hamstring tendon and patellar tendon groups did not differ from each other overall in terms of pivot shift grade. Therefore, this simply represents a tendency for more female patients to score grade 1 than grade 0, irrespective of the graft source. (There were no grade 2 pivot shift results in either group.)

Kneeling Pain

Table 6 shows the most unambiguous difference between the two groups. The percentage of patients with anterior kneeling pain in the patellar tendon group decreased from 55% ($N = 42$) at 1 year to 31% ($N = 24$) at 2 years. In the hamstring tendon group anterior kneeling pain was present in 6% (5) at both 1 and 2 years ($P < 0.0002$).

Hamstring Pain

In the patellar tendon group, 96% (74 patients) reported no hamstring area pain; two patients reported pain in the lower region and one reported pain in the midhamstring muscle region. In the hamstring tendon group, 92% (71 patients) had no hamstring area pain. In the remaining patients, pain was felt in the lower third of the hamstring muscles (four patients) or in the middle third (two patients). There was no significant difference between groups.

Complications

In the original patellar tendon group, and not included in the formal assessments, two patients ruptured their grafts playing football at 11 months and 18 months after reconstruction. One graft failed without any history of trauma. Two patients ruptured their contralateral ACLs during sport; these injuries occurred 23 and 24 months after reconstruction. Revisions of the traumatic graft ruptures were performed at 12 and 18 months after the initial reconstruction.

There were two superficial wound infections treated with oral antibiotics for complete resolution. There were three late arthroscopic procedures, one for an arthrolysis and two for excision of cyclops lesions to allow full extension. One case of patellar tendinitis developed, requiring antiinflammatory medication and a further rehabilitation program for resolution, and a patellar tendon cyst was excised at 24 months at the time of a contralateral ACL reconstruction.

In the hamstring tendon group, one patient ruptured the graft while dancing (at 7 weeks after surgery), one while playing basketball (10 months after surgery), and one while playing soccer (18 months after surgery). One graft failed without any history of trauma. Four patients ruptured their contralateral ACLs during sport, these injuries occurred at 9, 19, 22, and 23 months after reconstruction. Revisions of traumatic graft ruptures were performed at 10, 11, and 22 months after the initial reconstructions.

One 27-year-old man developed a popliteal vein thrombosis. There was one wound hematoma and one wound hemorrhage. One patient required a notchplasty for a cyclops lesion 10 months after reconstruction. Five patients (three male, two female) underwent partial medial meniscectomy at 7, 10, 14, 14, and 23 months after ACL reconstruction. Of these patients, two had an intact meniscus at the time of reconstruction, one had a healed tear, and two had had the meniscus sutured. At the 2-year review, two of these patients had grade 0 and two had grade 1 Lachman and pivot shift results. Their KT-1000 arthrometer values were 1, 3, 4, and 5 mm. The fifth patient who had a meniscectomy underwent a medial meniscal suture at 12 months, before undergoing medial meniscectomy at 14 months. His medial meniscus had been intact at the time of reconstruction. He subsequently ruptured his contralateral ACL 19 months after reconstruction and was not included in the formal 2-year assessment.

DISCUSSION

Four types of bias are often encountered in orthopaedic clinical research: susceptibility, performance, detection, and transfer.[36] This study has minimized *susceptibility bias* by matching the groups; *performance bias* by matching the surgeon, graft placement, graft fixation, rehabilitation, and follow-up; *detection bias* by using identical outcome assessment; and *transfer bias* by a high rate of follow-up. Therefore, the outcome comparison can reasonably be described as a true assessment of the difference associated with the graft and its harvest.

The proportion of patients with ACL reconstruction having an isolated ACL injury (27% in the patellar tendon group and 24% in the hamstring tendon group) is slightly less than the 30.6% (22 of 72) in the report by Sgaglione et al.,[38] although their patients all had acute reconstructions. (If reconstructions are all done in the acute phase of injury, there may be more isolated ACL injuries since some of these may subsequently not require reconstruction if left to become subacute or chronic injuries.)

The outcome results after both hamstring tendon and patellar tendon graft reconstruction in our series are consistent with other reports, suggesting that each technique reached the accepted contemporary standards.

General Comparison

The IKDC and Lysholm scores showed satisfactory recovery and patient subjective assessment. Including the patients with graft failures, 86% of patients had good or excellent results on the Lysholm score, and 82% of the patellar tendon group and 89% of the hamstring tendon group had normal or nearly normal scores on IKDC assessment. In particular, the activity level scores were promising. In a patient population in which 92% to 94% indulged in strenuous activity before injury, it was encouraging to have about 50% return to strenuous activity by 1 year after surgery. The small number of "poor" results on Lysholm score were not linked to objective graft laxity.

Otero and Hutcheson[31] found that the hamstring tendon graft was inferior to the patellar tendon graft in terms of laxity by Lachman and KT-1000 arthrometer testing. However, their patellar tendon graft was fixed anatomically by an interference screw, while their hamstring tendon graft was held by suspensory fixation using a femoral post and suture and a tibial screw and washer outside the tunnel. This presents the previously mentioned limitation of different grafts *and* different fixation techniques. Despite the demonstrated laxity in their study, Lysholm scores were not significantly different. Our study eliminated the variation in fixation technique, but we confirmed a similar small increase in KT-1000 arthrometer results.

We recognize that our KT-1000 arthrometer data are incomplete, although it would appear from the data at 3 years' follow-up that the missing values were similar to those recorded for the overall study at 2 years. We also recognize that subgroup analysis should be treated with caution and should be confirmed by trial. However, the apparent increase in laxity among the female patients in our hamstring tendon group may be a real difference and may be associated with the clinical observation of poorer interference screw tibial fixation in diminished bone stock, although there was no correlation with the age of the patient within this subgroup. A randomized trial of supplementary tibial fixation is underway to test this hypothesis.

The comparable Lysholm and IKDC scores and a low correlation of KT-1000 arthrometer scores with IKDC or

Lysholm scores confirm that laxity of this small magnitude was not directly linked to clinical outcome (that is, in the 92% of patellar tendon patients and 94% of hamstring tendon patients who had 5 mm or less side-to-side difference). The importance of small differences in KT-1000 arthrometer scores is uncertain since the scores correlated very poorly with activity level, IKDC score, and Lysholm score. With respect to the attainment of sporting levels, the mean KT-1000 arthrometer finding for patients at level I was 1.2 mm difference; for level II, 1.8 mm; for level III, 1.2 mm; and for level IV, 1.3 mm.

Marder et al.[23] evaluated alternating patients with patellar tendon or four-strand hamstring tendon reconstruction. Their patients had chronic ACL tears and included patients with meniscectomy and chondral damage. Suspensory fixation was used for both types of grafts. Similar results between groups were demonstrated at a mean follow-up of 29 months.

Aglietti et al.[1] used a study group similar to that of Marder et al., with suspensory fixation in the hamstring tendon group but with a combination of suspensory and interference screw in the patellar tendon group. They showed little difference in outcome between the two groups at a mean follow-up of 28 months except that a greater number of patients in the patellar tendon group had returned to sports at the IKDC functional level of grade I or II. Our 2-year results do not confirm this difference. However, there was a significant trend if level I alone was compared with levels II, III, and IV collectively. A 1° to 3° extension loss was noted in 47% of their patellar tendon group compared with 3% in their hamstring tendon group—a significant difference also unconfirmed in our series. A nonsignificant trend toward anterior knee symptoms was noted (see "Donor Site Pain").

Holmes et al.[14] report that hamstring tendon grafts are inferior in cases of chronic injury reconstruction compared with acute injury reconstruction. However, these authors used single-strand semitendinosus graft plus one of three extraarticular augmentations and many patient variables with respect to injuries and previous procedures. These results were not confirmed by Karlson et al.[20] and O'Neill[30] using two-strand hamstring tendon grafts.

Cumulative meniscal injury has been implicated in poorer results reported after reconstruction of chronic ligament ruptures as compared with those after reconstruction of acute ruptures.[37] In our study, only isolated ACL injuries were included, thereby eliminating those cases of chronic injury in which recurrent instability had already led to further injury.

Graft Fixation and Strength

Taking account of necrosis and revascularization, Marder et al.[23] estimated that four-strand hamstring grafts, 14-mm patellar tendon grafts, and normal ACLs should have comparable tensile strengths, provided there was equal tension applied along each arm of the hamstring tendon graft. Steiner et al.,[41] in cadaver studies, found comparable strength of four-strand hamstring grafts, 10-mm patellar tendon grafts, and normal ACLs. The failure load of an evenly tensioned four-strand hamstring tendon graft has been reported to be on the order of 4500 N.[11] This exceeds that reported for a 10-mm patellar tendon graft (2646 N)[25] and an intact ACL (1725 N).[27]

Recent reports, however, have implied that it may be more important to match the *stiffness* of a graft construction (rather than the failure load) to that of the intact ACL.[44] The stiffness of the graft construction is determined not only by the choice of graft but also the fixation method. Northrup et al.[26] reported comparable values of stiffness for a 10-mm patellar tendon graft and four-strand hamstring tendon graft when both were secured by interference screw fixation.

The screw method described for the patients in our study uses aperture fixation at the femoral end and near-aperture fixation at the tibial end both for patellar tendon and hamstring tendon grafts. Aperture rather than suspensory fixation was preferred by Steiner et al.[41] as the strongest method of patellar tendon fixation, although they did not test this fixation on hamstring tendon grafts. Ishibashi et al.[15] reported that aperture fixation minimized anterior tibial displacement, with greater instability for the more distant fixation methods. Kurosaka et al.[21] also showed for the patellar tendon that interference screw fixation was superior to suspensory fixation in terms of graft stiffness, and they attributed this both to the stronger fixation and the relatively shorter length of the graft.

The difference between the effects of aperture versus suspensory fixation has been perceived as one of the disadvantages of hamstring tendon grafting because surgeons have been reluctant to use the interference screw method and therefore have assumed that hamstring tendon grafting and suspensory fixation are essentially linked. Reconstruction using interference screw fixation ultimately requires osteointegration of the tendon graft. We have examined the histologic appearance at the bone-tendon junction of two specimens retrieved from patients undergoing revision surgery at 12 and 15 weeks after reconstruction for traumatic midsubstance hamstring tendon graft rupture at 6 and 10 weeks.[32] Integration of the hamstring tendon ACL autograft was demonstrated by observation of collagen fiber continuity between bone and tendon. The histologic evidence plus the low overall incidence of early graft failure imply that the strength of the bone-tendon junction, supported by the interference screw, is adequate for rehabilitation forces below the threshold for provocation of midsubstance rupture. In the 372 reconstructions using hamstring tendon grafts from which the 90 patients in this study were extracted, we are unaware of any early failures by graft pullout, suggesting that in vivo the interference screw method is adequate for fixation until osteointegration occurs.

For biomechanical testing in the dog, Rodeo et al.[35] used a snug-fit tendon in a tibial tunnel secured with stainless steel sutures and allowed postoperative exercise ad libitum. They noted failure by tendon pullout from the tunnel at up to 8 weeks after surgery. By 12 weeks, all failure tests resulted in graft slippage from the clamp or graft

rupture, implying that the tunnel-graft interface was no longer the weakest link.

There is biomechanical, clinical, and histologic evidence supporting the choice of aperture fixation for either four-strand hamstring or patellar tendon graft.

Hamstring Recovery and Thigh Atrophy

The slight but significantly better results in terms of less thigh atrophy in the hamstring tendon group suggest that quadriceps muscle rehabilitation may be more advanced after hamstring tendon reconstruction than after patellar tendon reconstruction at 1 year. Equal or greater thigh circumference was associated with the best results in *untreated* ACL injuries reported by McDaniel and Dameron.[24] Earlier quadriceps muscle recovery after hamstring tendon reconstruction was suggested by Brown et al.,[4] and several reports have noted no decrease in hamstring muscle strength after rehabilitation.[20,22,45] A study by Yasuda et al.[45] showed that recovery of isometric hamstring muscle strength after graft harvest from the uninjured limb averaged 100% by 3 months.

Donor Site Pain

O'Brien et al.[29] reported patellar pain in 37% (30 of 80) of knees after ACL reconstruction with patellar tendon graft. They stated that this remained an unsolved problem. Re et al.[34] found a significant increase in knee pain after reconstruction using patellar tendon compared with hamstring tendon graft. Aglietti et al.,[1] comparing the two graft techniques in a prospective, alternate patient study and using a combined pain and crepitation patellofemoral score, found that 17% (5 of 30) in the patellar tendon group had moderate symptoms compared with 3% (1 of 30) in their hamstring tendon group, but the difference did not reach significance. Marder et al.[23] (despite noting 11% of their patellar tendon patients had lower-pole patellar tenderness, compared with none in the hamstring tendon group) showed no difference between patellar tendon and hamstring tendon groups for knee pain as a symptom, and indeed our groups were similar in this respect. However, the specific question of *kneeling* pain revealed a significant difference. In the patellar tendon group of our series 56% of patients had some form of anterior knee pain on kneeling at 1 year after surgery, and 31% had kneeling pain at 2 years. This finding confirms the unsolved problem described by O'Brien et al.[29] The presence of similar general outcome results in the hamstring tendon group but only 6% having kneeling pain and 8% having hamstring area pain show that use of hamstring tendon autograft may be a solution to the problem. The initial postoperative patellar pain may also explain the significantly greater time both in the hospital and on crutches for the patellar tendon group, although, in recognizing that our study is sequential, we realize that reduced hospital stay is a general trend irrespective of surgical procedure.

CONCLUSIONS

The outcome for patients in this study undergoing ACL reconstruction with a hamstring tendon graft did not differ from that of patients with a patellar tendon graft in terms of clinical stability, range of motion, and general symptoms. There was no difference in the return to level I or II sports, although more of the patellar tendon group reached level I. The female patients in the hamstring tendon group had a trend toward increased laxity measured by KT-1000 arthrometer and Lachman tests. The hamstring tendon group had less thigh atrophy in the 1st year, suggesting earlier quadriceps muscle recovery, but this difference was insignificant by 2 years. The hamstring tendon group also had lower graft harvest site morbidity, as demonstrated by less kneeling pain at 1 and 2 years.

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