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A Five-Year Comparison of Patellar Tendon Versus Four-Strand Hamstring Tendon Autograft for Arthroscopic Reconstruction of the Anterior Cruciate Ligament

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Background: The choice of graft material for anterior cruciate ligament reconstruction is believed to play a major role in outcome, but most comparisons of graft choice have not been well controlled.
Hypothesis: The choice of graft material (patellar tendon or hamstring tendon) does affect clinical outcome after anterior cruciate ligament reconstruction.
Study Design: Prospective, nonrandomized clinical trial.
Methods: Two groups of 90 patients each were followed for a minimum of 5 years.
Results: International Knee Documentation Committee assessment revealed that more than 85% of each group had an overall score of A or B at all follow-up intervals. The median Lysholm knee score was greater than 90 for both groups at 2 and 5 years. Instrumented testing revealed no significant difference between the two groups beyond 3 years. Thirty-one percent of the patellar tendon group (25) had a fixed flexion deformity and 19% of the hamstring tendon group (14) had fixed flexion deformity at 5 years. Radiologic assessment revealed early osteoarthritic changes in 4% of the hamstring tendon group (2) and in 18% of the patellar tendon group (11) at 5 years.
Conclusions: Arthroscopic reconstruction with either graft results in a similar surgical outcome, reliably restoring knee stability over a 5-year period; however, patients with patellar tendon grafts are at greater risk of developing early signs of osteoarthritis.

It is widely believed that knee injury with associated ACL rupture may lead to functional instability. Repeated episodes of instability impair function. In the active sporting population, such instability has been found to be associated with meniscal and chondral injuries as well as with the development of degenerative disease within the joint.[33,42] An increased incidence of osteoarthritic change has been found both after surgical reconstruction[27] and in association with untreated ACL rupture.[13,42] Successful treatment of ACL instability, whether nonoperative or operative, is linked to the presence of intact meniscal and chondral structures.[2,41] This has led the authors to support the concept of early ACL reconstruction in the active population, before the onset of joint damage. Despite an enormous amount of current literature on the ACL, there are no studies on arthroscopic ACL reconstruction to date that clearly document the results of successful surgery in the medium term (3 to 5 years postoperatively) in a manner that would allow for comparison between surgical techniques.

The use of arthroscopic techniques has revolutionized surgical reconstruction of the ACL. Clinical outcome, however, depends on preoperative, operative, and postoperative variables. In any study these variables must be clearly defined so that valid comparisons can be made. Graft choice is believed to play a role in surgical outcome.[15] Currently, the majority of primary procedures are performed by using either the ipsilateral bone-patellar tendon-bone or hamstring tendon construct. These graft types have been compared both in vitro and in vivo (Refs.

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28, 31, 34, 46; T. Northrup et al., unpublished data, 1997). However, the interpretation of in vivo comparisons has been significantly hampered by lack of scientific control of extraneous variables. These comparisons have included different methods of graft fixation, patient selection, timing of surgery, preexisting meniscal/chondral injury, use of bracing, and varying rehabilitation programs.[2,31,36]

This prospective study, with a minimum 5-year follow-up, was designed to provide a baseline clinical record of the effects of arthroscopic ACL surgery on the knee joint and also to document the influence of graft choice alone on the clinical result.

MATERIALS AND METHODS

Patient Selection

In this study, the key indication for early surgical reconstruction was a clinical diagnosis of ACL rupture in a patient desiring to return to an International Knee Documentation Committee (IKDC) competitive level of I or II on a regular basis. On preoperative clinical examination, all patients exhibited at least a grade 2 Lachman test and a positive pivot shift test. Surgery was performed in patients with chronic instability in whom nonoperative treatment had failed, preventing the patient from returning to his or her desired functional level. Surgical intervention after acute injury was deferred until after the patient had followed a physical therapy program to regain a pain-free range of motion and knee swelling had diminished. Subsequent repeat clinical examinations confirmed ACL insufficiency before surgical treatment. Patients with associated ligament injury, chondral damage, previous meniscectomy, excision of more than one-third of one meniscus, an abnormality seen radiographically, or an abnormal contralateral knee joint were excluded from the study.

All patients considered for inclusion in the study signed an informed consent form. Ethical committee approval was obtained from the Australian Institute of Musculoskeletal Research and The Sydney University. On January 29, 1993, a database was established of all patients undergoing ACL reconstruction with bone-patellar tendon-bone autograft. By April 29, 1994, 333 patients had been prospectively examined. Of this group, 90 patients fulfilled the study inclusion criteria. On October 20, 1993, a database was established to document the results of a novel technique for four-strand hamstring tendon ACL reconstruction. By November 9, 1994, 372 patients had been prospectively examined. Of these, 90 were found to fulfill the study inclusion criteria. Until October 28, 1993, only patellar tendon reconstructions were performed. On October 28, 1993, we began a prospective randomized study of consenting patients who met the required criteria. However, by April 10, 1994, although 52 patients had been randomized, no further patients agreed to participate in randomization. This was because the patients were noticing, through comments from the physical therapist, that the use of hamstring tendon graft led to a more rapid recovery from surgery. On questioning, patients gave the following reasons for refusing randomization to the patellar tendon group. First, patients with hamstring tendon grafts were being discharged from the hospital earlier (70% outpatient surgery compared with 1% outpatient surgery in the patellar tendon group). Second, patients with a patellar tendon graft were on crutches for a period of 10 to 14 days before walking comfortably, whereas the patients with hamstring tendon grafts were able to walk comfortably within 5 to 7 days. Finally, patients with hamstring tendon grafts cited an earlier return to sedentary work. Both groups of patients ($N = 180$) were treated with a similar rehabilitation program by the same group of physical therapists, and had the same criteria for pain relief during the postoperative period. After April 10, 1994, almost only hamstring tendon ACL reconstructions were performed until the end of the study period on November 9, 1994.

Surgical Technique

All procedures were performed by the senior author (LAP). The patellar tendon reconstructions comprised the last 333 ACL reconstructions of a personal series of 1800 procedures performed over a 5-year period. The hamstring tendon patients comprised the first 372 ACL reconstructions using what was at the time a novel fixation technique. In all cases, both proximal and distal fixation of the graft was achieved using a round-head, 7 × 25 mm, cannulated interference screw (RCI, Smith & Nephew Endoscopy, Andover, Massachusetts) with an 8-mm spherical head. No further methods of graft fixation were used, regardless of bone quality, thereby minimizing operative variables. A single-incision endoscopic technique was used with anteromedial and anterolateral arthroscopy portals and a gravity saline insufflation of the joint. The femoral tunnel was drilled through the anteromedial portal prior to tibial tunnel drilling. A bony notchplasty was not performed.

The patellar tendon was harvested through two 2-cm vertical incisions centered over the inferior pole of the patella and one centered over, but just medial to, the tibial tubercle. A 9- to 10-mm wide midthird patellar tendon graft was obtained with a 25-mm boat-shaped patellar block and a trapezoidal 30-mm long tibial block. The defects in the patella and tibia were bone grafted with bone scavenged from the drillings of the tibial tunnel. The bursae were closed over the bone graft, but the subcutaneous harvest of the patellar tendon itself did not allow closure of the tendon defect.

The gracilis and semitendinosus tendons were harvested through a 2.5-cm long incision centered 1 cm medial and 1 cm distal to the medial margin of the tibial tubercle. A Linvatec tendon harvester (Linvatec, Largo, Florida) was used to obtain a 22-cm long gracilis and semitendinosus tendon graft. The tendon grafts were then doubled over two pull-out lead sutures. The proximal 25 mm of the graft was sutured with No. 1 Vicryl suture (Ethicon, Edinburgh, United Kingdom) into a plug. The distal 40 mm of the graft was equally tensioned and sutured with a No. 2 Vicryl suture. The tendons were de-

tached from the tibia before insertion into the joint. The defect in the sartorius tendon was not closed.

Both patellar tendon and hamstring tendon grafts were inserted retrograde via the tibial tunnel into a blind femoral tunnel. A single 7 × 25 mm RCI soft-threaded titanium screw was used to fix all grafts proximally and distally, regardless of graft size. Tunnel size in the patellar tendon group was determined at 1 mm larger than the bone block size, and in the hamstring tendon group tunnel size equaled the cross-sectional size of the graft.

All femoral tunnels were located in the posterior third of Blumensaat's line. All tibial tunnels entered the joint in the anterior half of the middle third of the tibial plateau as seen on the lateral radiograph (Fig. 1A). On the AP view, the lateral margin of the tibial tunnel was at the center of the intercondylar notch, which is the highest point of the intercondylar notch (Fig. 1B). This placement was obtained by using the following intraoperative landmarks. The center for femoral placement was 5 mm anterior to the posterior capsular insertion into the intercondylar notch, at approximately 10 to 11 o'clock in a right knee. The tibial entry hole corresponded to a line from the anterior horn of the lateral meniscus to the medial tibial spine. The tibial drill hole diameter was known and movement laterally and anteriorly along this imaginary line was to a distance such that the drill hole would remove the posterior footprint of the ACL insertion and was adjacent to but not removing the apex of the medial tibial spine. Tourniquet was routinely applied before surgical preparation of the limb and released after skin closure. The mean tourniquet time was 69 minutes (range, 40 to 114) for the patellar tendon group and 64 minutes (range, 45 to 95) for the hamstring tendon group.

Rehabilitation

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. A brace was not used in any case. Immediate weightbearing with the aid of crutches was encouraged. The median time for the use of crutches before full weightbearing was 10 days (range, 2 to 21) for the patellar tendon group and 7 days (range, 0 to 21) for the hamstring tendon group. An accelerated rehabilitation program was instituted immediately. Range of motion exercises were directed toward achieving full active extension by the 14th day after surgery. The wound was reviewed at this point. Jogging on a rebounder was commenced at 6 weeks after surgery. Closed kinetic chain (axial load-bearing) exercises with proprioceptive training were performed. Return to competitive sport was not permitted until at least 6 months after surgery and then only after knee stability was reconfirmed on clinical examination.

Outcome

All patients were assessed by an independent examiner before surgery and at 2 weeks, 6 weeks, and 3, 6, and 12 months after surgery and annually thereafter. Symptoms

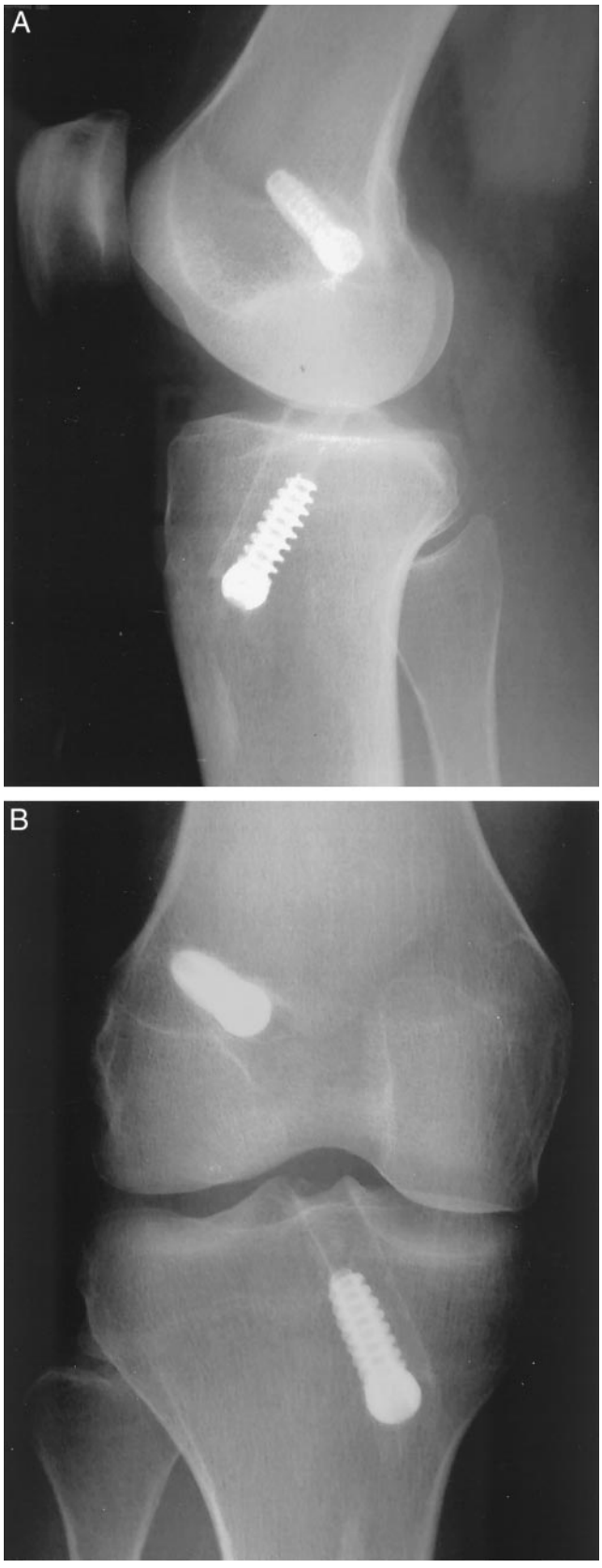

Figure 1. Postoperative lateral (A) and AP (B) radiographs showing the locations of the tibial and femoral tunnels.

and signs of knee function were assessed to determine the IKDC knee grade.[3,20] The Lysholm knee score was obtained by means of a self-administered questionnaire.[21,45] Range of motion was measured by using a goniometer and bony landmarks at the lateral malleolus of the ankle, knee joint line, and greater trochanter of the hip. Clinical ligament testing was performed by means of the Lachman test, anterior drawer test, and pivot shift test, with side-to-side differences recorded.[16,47] Instrumented laxity testing was determined with the KT-1000 arthrometer (MEDmetric Corp., San Diego, California) by recording side-to-side differences in displacement at 9.1 kg (20 pounds) and on manual maximum testing.[5,18] Thigh atrophy was measured as the difference between the two sides at a point 10 cm above the superior pole of the patella. Kneeling pain on a standard carpet surface was recorded for site and severity by using an analog score from 0 (no pain) to 10 (most severe pain). Before surgery, and at 2 and 5 years after surgery, weightbearing AP and posteroanterior radiographs at 30° of flexion, lateral radiographs, and patellofemoral and tunnel view radiographs were taken. Each set of films was interpreted on two separate occasions by two independent surgeons. Discrepancies in reporting were examined by a third surgeon to obtain consensus.

Statistical Analyses

For the purposes of analysis all data were assumed to be nonparametric. The Mann-Whitney *U* test was used for independent ordinal or interval data. The Wilcoxon signed rank test was used for related ordinal or interval data. Data were considered statistically significant at $P < 0.05$.

RESULTS

In the patellar tendon group, there were 48 (53%) men with 19 left and 29 right involved knees and 42 (47%) women with 17 left and 25 right involved knees. The median age of the patellar tendon group was 25 years (range, 15 to 42). In the hamstring tendon group, there were 47 (52%) men with 25 left and 22 right involved knees, and 43 (48%) women with 27 left and 16 right involved knees. The median age of the hamstring tendon group was 24 years (range, 13 to 52).

Of the original 90 patients in the patellar tendon group 3 patients had ruptured their grafts (3%) and 11 patients (12%) had ruptured their contralateral ACL. Of the remaining 87 patients with intact grafts, 80 (92%) returned for follow-up at 5 years. In the hamstring tendon group there were 7 cases of graft rupture (8%) and 8 patients (9%) had ruptured their contralateral ACL. Of the remaining 83 patients with intact grafts, 75 (90%) were followed up at 5 years. The number of patients followed up each year is depicted in Table 1. Those patients who suffered a graft rupture were excluded from further study whether or not they went on to have revision ACL surgery. Those patients who suffered contralateral ACL rupture were included in further study whether or not they went on to have contralateral ACL surgery.

TABLE 1
Percentage of Patients Reviewed Annually

Follow-up year	Patients	
	Hamstring tendon group	Patellar tendon group
1	87 of 88 (99%)	83 of 89 (93%)
2	77 of 85 (91%)	77 of 87 (89%)
3	71 of 84 (85%)	71 of 87 (82%)
4	52 of 83 (63%)	68 of 87 (78%)
5	75 of 83 (90%)	80 of 87 (92%)

Complications and Further Surgery

Among the three cases of graft failure in the patellar tendon group, one was an atraumatic rupture (no history of injury) noted at 12 months. This patient underwent arthroscopic lateral meniscectomy for a new injury at 14 months postoperatively. He declined revision ACL surgery. Two were traumatic ruptures incurred while playing rugby at 11 and 18 months, respectively. One of these patients underwent revision ACL reconstruction at 12 months but suffered a further traumatic graft failure at 42 months, and the other patient underwent revision surgery at 18 months and suffered no further injury. Two patients underwent arthroscopic debridement for a cyclops lesion at 6 and 24 months, respectively, after surgery. Two patients required partial ipsilateral meniscectomy (one medial and one lateral) within 2 years of reconstruction. Two patients developed ipsilateral patellar tendinitis, which was managed nonoperatively with oral analgesics and a further rehabilitation program. One patient required excision of a patellar tendon cyst at 24 months, which eliminated anterior knee symptoms. One patient underwent arthroscopic arthrolysis (3 months), and one required arthroscopic chondroplasty (21 months). Over the same period, there were 10 cases of traumatic contralateral ACL disruption at a median time of 31 months (range, 23 to 57).

In the hamstring tendon group, there were seven cases of graft rupture. Two grafts failed without any history of trauma. Five grafts failed during sports activities. The injuries occurred while twisting in four cases and when landing from a jump in two cases. Five patients underwent arthroscopic partial medial meniscectomy on the reconstructed joint. There was one case of wound hematoma at the donor site due to bleeding from the inferior medial genicular artery that required the patient to be readmitted to the hospital and the bleeding artery cauterized. One patient required arthroscopic debridement of a cyclops lesion to regain full extension. One patient underwent arthroscopic arthrolysis. There were eight cases of contralateral ACL rupture over the same time period. No infections occurred in this series.

There was no statistically significant difference between the two groups regarding complications in the involved limb or the contralateral limb ($P > 0.05$). There was no statistically significant difference in rate of graft rupture ($P = 0.20$). However, the power of this study for detecting a difference of this magnitude was only 0.33. In fact, we

would have needed 450 patients in each group to be able to draw a conclusion free of the risk of type II error.

Operative Findings

Of the patients whose results are presented, surgery was performed within 12 weeks of injury in 58 patients in the patellar tendon group and in 56 patients in the hamstring tendon group. The site of ACL rupture in the patellar tendon group was the midsubstance in 77% of patients (62) and the proximal ACL in 15% (12). The site was ill-defined in 8% (6). In the hamstring tendon group, the site of ACL rupture was the midsubstance in 71% of patients (53), the proximal ACL in 28% (21), and ill-defined in 1% (1). Eighty-six percent of patients (69) in the patellar tendon group and 82% (61) of the hamstring tendon group had intact menisci at surgery. Eight percent (6) of patients in the patellar tendon group required meniscal suture at the time of reconstruction and 6% (5) required excision of less than one-third of one meniscus. In the hamstring tendon group, 9% of patients (7) required meniscal suture and 9% (7) required excision of less than one-third of one meniscus.

Subjective Functional Assessment

More than 95% of patients graded their knee as normal (grade A) or nearly normal (grade B) for both groups from the 1st postoperative year onward. These percentages remained similar for all time points up to 5 years after surgery (Fig. 2).

Symptoms

Patients were asked to report the presence of pain, knee swelling, and giving way at varying levels of activity. At 2 years, 90% of the patellar tendon group (69) and 95% of the hamstring tendon group (73) reported no pain with strenuous (I) or moderate (II) activity. At 5 years, these figures were 91% (73) for the patellar tendon group and 91% (74) for the hamstring tendon group. At 2 years, 96% of the patellar tendon group (74) and 97% of the hamstring tendon group (75) reported no knee swelling with strenuous or moderate activity. These figures were 99% (79) and 95% (71), respectively, at 5 years. At 2 years, all patients in the patellar tendon group and 99% (76) of the hamstring tendon group reported no partial or full giving way during strenuous or moderate activity. At 5 years, 99% (79) of the patellar tendon group and 97% (73) of the hamstring tendon group again reported the absence of such symptoms with strenuous or moderate activity. There were no significant differences between the two groups for any time point.

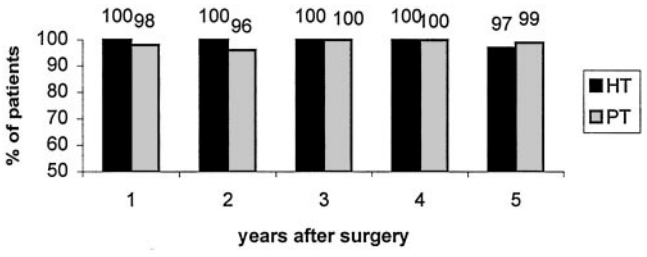

Figure 2. Subjective knee function was grade A or B in more than 95% of patients. At 5 years, there was no significant difference between the hamstring tendon (HT) and patellar tendon (PT) groups ($P = 0.72$, Mann-Whitney U test), nor were there any significant differences between the two groups for any other time point. Percentages based on number of patients at follow-up (See Table 1).

Range of Motion

Extension deficit was determined as the loss of extension in the involved limb in comparison with the passively hyperextended posture of the contralateral uninjured limb. At 2 years, 92% (71) of the patellar tendon group and 86% (62) of the hamstring tendon group had no extension deficit and no patient in either group was found to have an extension deficit greater than 5°. The percentages of the two groups with no extension deficit for each time point are detailed in Figure 3. An increasing percentage of the patellar tendon group developed a loss of normal extension/hyperextension between 1 and 5 years ($P = 0.001$). This was not apparent at the 2-year follow-up.

Full flexion, or a less than 5° loss of flexion, was found in 99% of patients (76) in both groups at 2 years. This figure did not change significantly over the 5-year period. At 5 years, 100% (75) of the patellar tendon group and 99% (79) of the hamstring tendon group had full flexion.

Clinical Ligament Evaluation

Figure 4 outlines the percentages of patients in the two groups with grade 0 laxity for each time point. In the hamstring tendon group, the number of patients with a grade 0 Lachman test significantly increased between 1

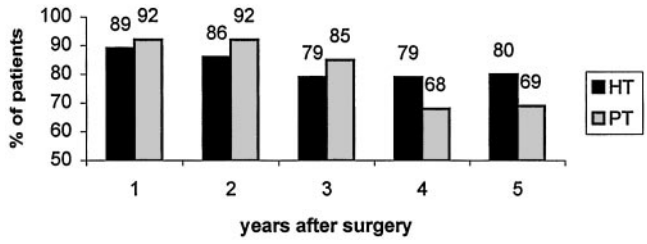

Figure 3. Percentage of patients with no extension deficit at each time point. There were no significant differences between the hamstring (HT) and patellar tendon (PT) groups at 5 years ($P = 0.11$, Mann-Whitney U test). Within the hamstring tendon group, there was no significant difference between 1 and 5 years ($P = 0.47$, Wilcoxon signed rank test). Within the patellar tendon group, there was a significant increase in the percentage of patients with a fixed flexion deformity between 1 and 5 years ($P = 0.001$, Wilcoxon signed rank test). Percentages based on number of patients at follow-up (See Table 1).

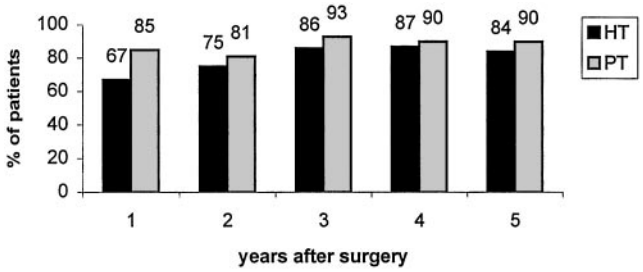

Figure 4. Percentage of patients with grade 0 Lachman test at each time point. There were no significant differences between the hamstring (HT) and patellar tendon (PT) groups at 5 years ($P = 0.27$, Mann-Whitney U test). Within the hamstring tendon group, there was a significant increase in the percentage of patients with a grade 0 Lachman test between 1 and 5 years ($P = 0.01$, Wilcoxon signed rank test). Within the patellar tendon group, there was no significant change in the percentage of patients with a grade 0 Lachman between 1 and 5 years ($P = 0.80$, Wilcoxon signed rank test). Percentages based on number of patients at follow-up (See Table 1).

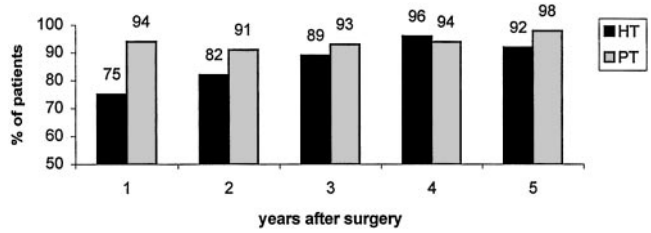

Figure 5. Percentage of patients with a grade 0 pivot shift test at each time point. There were no significant differences between the hamstring (HT) and patellar tendon (PT) groups at 5 years ($P = 0.12$, Mann-Whitney U test). Within the hamstring tendon group, there was a significant increase in the percentage of patients with a grade 0 pivot shift test between 1 and 5 years ($P = 0.002$, Wilcoxon signed rank test). Within the patellar tendon group, there was no significant change in the percentage of patients with a grade 0 pivot shift test between 1 and 5 years ($P = 0.32$, Wilcoxon signed rank test). Percentages based on number of patients at follow-up (See Table 1).

and 5 years after surgery ($P = 0.006$). The percentage of patients in the two groups with a grade 0 pivot shift result for each review point is shown in Figure 5.

Radiologic Assessment

The medial, lateral, and patellofemoral compartments were scrutinized for evidence of joint space narrowing at 2 and 5-year review. The IKDC system was used for grading (A, normal; B, minimal changes and barely detectable joint space narrowing; C, minimal changes and joint space narrowing of up to 50%; and D, more than 50% joint space narrowing). At 2 years, standardized radiographs of the involved knee for 72 patients in the patellar tendon group and 70 patients in the hamstring tendon group were obtained. At 5 years, radiographs were obtained for 60 patients in the patellar tendon group and 45 patients in the hamstring tendon group. The results are shown in Table 2. At 2 years there were no significant differences between the two groups ($P = 0.98$). However, by 5 years, more patients in the patellar tendon group displayed evidence of early osteoarthritic change ($P = 0.04$) (Fig. 6). The incidence of osteoarthritic change significantly increased in the patellar tendon group from 1% (1 of 67) at 2 years to 18% (11 of 60) at 5 years ($P = 0.003$). There was no significant increase in the hamstring tendon group between 2 and 5 years ($P = 0.41$).

Compartment Loading

Table 3 shows the percentage of patients with no crepitus or pain, by compartment, at 2 and 5 years postoperatively. No significant differences were noted between the two time points or between the groups. Nine percent (7) of the patellar tendon group and 9% (7) of the hamstring group demonstrated patellofemoral crepitus at 5 years.

Activity

The IKDC form grades *level of activity*, with level I being strenuous activity, level II being moderate activity, level III being light activity, and level IV being sedentary. Before injury, 99% (89 of 90) of patients in the patellar tendon group and 97% (87 of 90) of patients in the hamstring tendon group participated in level I or II activities. Among patients who received initial nonoperative treatment of their injury, 30% (27 of 90) of the patellar tendon group and 18% (16 of 90) of the hamstring tendon group were able to achieve level I or II activities before surgical reconstruction, but they experienced symptoms of instability. The remaining patients in both groups were not

TABLE 2
Radiologic Assessment after Surgery

Radiologic grade	Year 2				Year 5			
	Patellar tendon group		Hamstring tendon group		Patellar tendon group		Hamstring tendon group	
	N	%	*N*	%	*N*	%	*N*	%
A	71	99	69	99	49	82	43	96
B	1	1	1	1	9	15	1	2
C	0	0	0	0	2	3	1	2

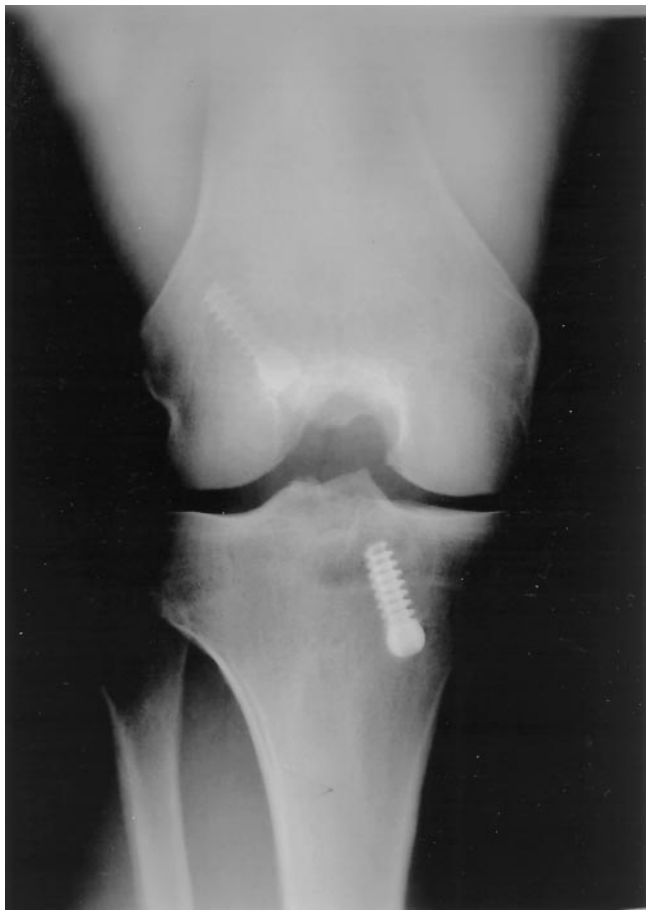

Figure 6. Five-year postoperative radiograph showing early osteoarthritic changes.

TABLE 3
Percentage of Patients with No Crepitus or Pain on Testing by Compartment

Compartment	Patellar tendon group		Hamstring tendon group	
	2 years	5 years	2 years	5 years
Patellofemoral	92	91	99	91
Medial	99	100	92	90
Lateral	97	98	98	97

participating in level I or level II activities. Figure 7 illustrates the percentage of patients in each group who participated in level I or II activities at each review point. There was a trend toward a reduction with time in the percentage of patients in each group participating at level I or II activities. Both intragroup and intergroup comparisons failed to identify any significant differences.

Although there was no significant difference between the two groups at each review point, both groups displayed a significant decrease in the percentage of patients participating in level I and II activities between 1 and 5 years after surgery (patellar tendon group, $P = 0.04$; hamstring tendon group, $P = 0.03$).

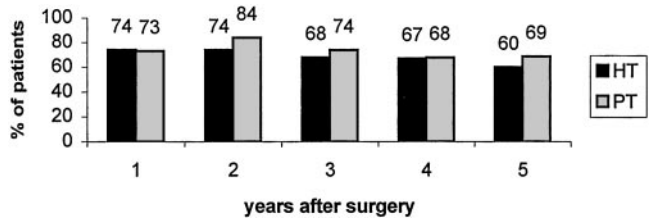

Figure 7. Patients participating in level I or II activities. There were no significant differences between the hamstring (HT) and patellar tendon (PT) groups at 5 years ($P = 0.19$, Mann-Whitney U test). Within the hamstring tendon group, there was a significant decrease in the percentage of patients participating in level I or II activities between 1 and 5 years ($P = 0.03$, Wilcoxon signed rank test). Within the patellar tendon group, there was a significant decrease in the percentage of patients participating in level I or II activities between 1 and 5 years ($P = 0.04$, Wilcoxon signed rank test). Percentages based on number of patients at follow-up (See Table 1).

Single-Legged Hop Test

The single-legged hop test of knee function determines the ratio of distance achieved by hopping on the involved limb compared with the contralateral normal limb. A grade A hop on the involved side is a distance equal to or greater than 90% of that achieved with the contralateral limb. At 2 years, 92% (70) of the patellar tendon group and 94% (68) of the hamstring tendon group had achieved a grade A hop. At 5 years, these figures were 89% (71) and 97% (73), respectively. There was no significant difference between either group at either time point or between years 2 and 5 within the groups.

Overall IKDC Score

Figure 8 shows the percentage of patients in each group with an overall IKDC grade A or B for all review points. No significant differences were noted for any time point. More than 87% of patients in both groups had either grade A or B scores throughout the review period.

Lysholm Knee Score

The Lysholm knee score is designed to evaluate specific symptoms relating to knee function (limp, need for support, locking, instability, pain, swelling, and impairment of stair-climbing or squatting ability). The highest obtainable score is 100. The median knee score for the patellar tendon group was 95 (range, 42 to 100) at 2 years and 96 (range, 64 to 100) at 5 years. For the hamstring tendon group, the median scores were 95 (range, 56 to 100) at 2 years and 95 (range, 55 to 100) at 5 years. The maximum Lysholm knee score was achieved by the 1st year after reconstruction; this score remained unaltered up to 5

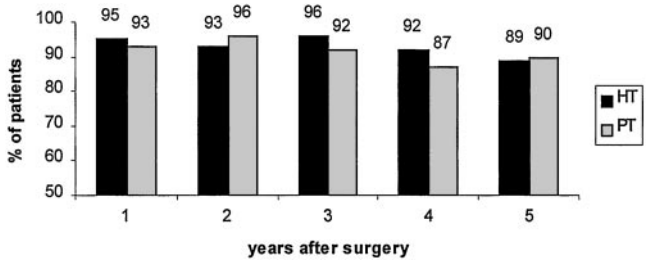

Figure 8. Percentage of patients with an overall IKDC score of A or B at each time point. There were no significant differences between the hamstring (HT) and patellar tendon (PT) groups at 5 years ($P = 0.69$, Mann-Whitney *U* test). There were no significant changes between 1 and 5 years in either the patellar tendon ($P = 0.16$, Wilcoxon signed rank test) or the hamstring tendon group ($P = 0.41$, Wilcoxon signed rank test). Percentages based on number of patients at follow-up (See Table 1).

years after surgery. There were no significant differences between the two groups at any time point.

Thigh Atrophy

At 2 years, 81% (62 of 77) of the patellar tendon group and 75% (58 of 77) of the hamstring tendon group had less than 10 mm side-to-side difference in thigh circumference. At 5 years, these figures were 65% (52 of 80) for the patellar tendon group and 64% (48 of 75) for the hamstring tendon group. Figure 9 shows the percentage of patients in the two groups with a side-to-side thigh circumference of less than 10 mm at each review point. The percentage of patients with less than 10 mm of side-to-side thigh circumference peaked at 3 years in the patellar tendon group and at 4 years in the hamstring tendon group. No patient had greater than 10 mm of side-to-side difference in thigh circumference at any time point. It appears that less than 1 cm of quadriceps muscle atrophy

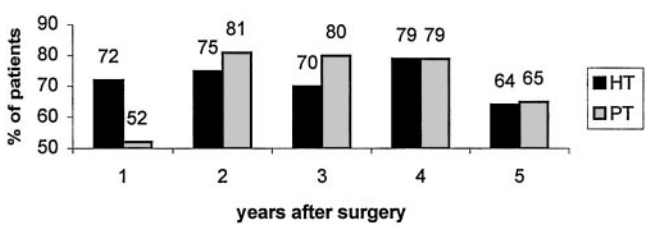

Figure 9. Percentage of patients with <10 mm of thigh atrophy at each time point. There were no significant differences between the hamstring (HT) and patellar tendon (PT) groups at 5 years ($P = 0.92$, Mann-Whitney *U* test). There were no significant changes between 1 and 5 years in either the patellar tendon group ($P = 0.49$, Wilcoxon signed rank test) or the hamstring tendon group ($P = 0.57$, Wilcoxon signed rank test). Percentages based on number of patients at follow-up (See Table 1).

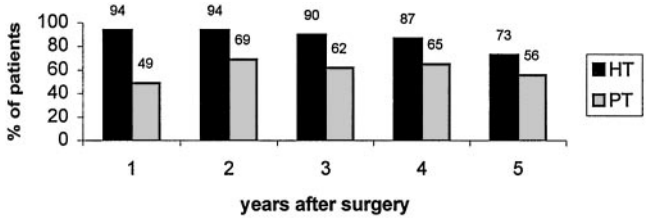

Figure 10. Percentage of patients with no kneeling pain. There was a significantly higher incidence of kneeling pain in the patellar tendon (PT) group compared with the hamstring tendon (HT) group at 5 years ($P = 0.03$, Mann-Whitney *U* test). There were no significant changes between 1 and 5 years in either the patellar tendon group ($P = 0.34$, Wilcoxon signed rank test) or the hamstring tendon group ($P = 0.83$, Wilcoxon signed rank test). Percentages based on number of patients at follow-up (See Table 1).

does not affect the result of the single-legged hop test of function.

Kneeling Pain

Figure 10 illustrates the percentage of patients in each group who reported no kneeling pain at each time point. There was a significant difference between the two groups at all time points. At 2 years, 31% (24) of the patellar tendon group and 6% (5) of the hamstring tendon group reported kneeling pain ($P = 0.002$). At 5 years after surgery, these percentages had increased for both groups, with 44% (35) of the patellar tendon group and 27% (20) of the hamstring tendon group reporting some kneeling pain ($P = 0.03$).

Donor Site Symptoms at Rest

Patients were asked to report both the presence and severity of donor site symptoms while at rest. At 2 years, 34% (26 of 77) of the patellar tendon group and 23% (18 of 77) of the hamstring tendon group reported mild symptoms. At 5 years, 41% (33 of 80) of the patellar tendon group and 12% (9 of 75) in the hamstring tendon group reported the presence of residual donor site symptoms ($P = 0.004$). No patient reported greater than mild symptoms. Unfortunately the required wording of the IKDC evaluation does not differentiate between type of symptoms experienced.

Instrumented Testing

At 2 years, KT-1000 arthrometer data were available for 61 patients in the patellar tendon group and 75 patients in the hamstring tendon group. At 5 years, 70 patients in the patellar tendon group and 67 patients in the hamstring tendon group were available for instrumented testing. Data were obtained in subsequent years on patients absent at the 2-year review. The absence of significant discrepancies in laxity measurements at these time points suggests that the available data are reliable.

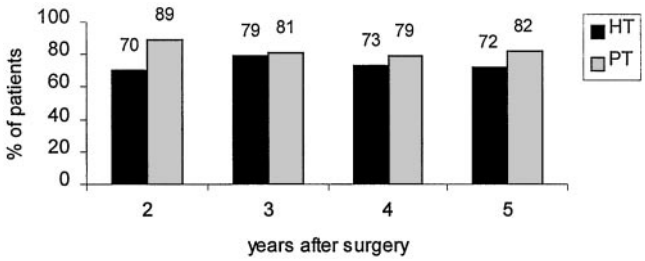

Figure 11. Percentage of patients with a side-to-side difference of less than 3 mm on manual maximum testing. There was a significant difference between the patellar tendon (PT) and hamstring tendon (HT) groups at 2 years ($P = 0.001$). There was no significant difference between the hamstring and patellar tendon groups at 5 years ($P = 0.37$, Mann-Whitney U test). There was no significant change in the percentage of patients between 1 and 5 years in either the patellar tendon group ($P = 0.37$, Wilcoxon signed rank test) or the hamstring tendon group ($P = 0.43$, Wilcoxon signed rank test). Percentages based on number of patients at follow-up (See Table 1).

The percentage of patients in each group with a side-to-side difference of less than 3 mm on manual maximum testing for years 2 to 5 is shown in Figure 11.

Figure 12 illustrates the mean laxity on manual maximum testing at years 2 through 5. At 2 years, mean laxity was 0.8 mm for the patellar tendon group and 1.8 mm for the hamstring tendon group ($P = 0.001$). This discrepancy in mean laxity has previously been examined through subgroup analysis. Female patients with hamstring tendon grafts have statistically increased laxity on KT-1000 arthrometer testing, thus the statistically increased laxity in the hamstring tendon group is due to the increased

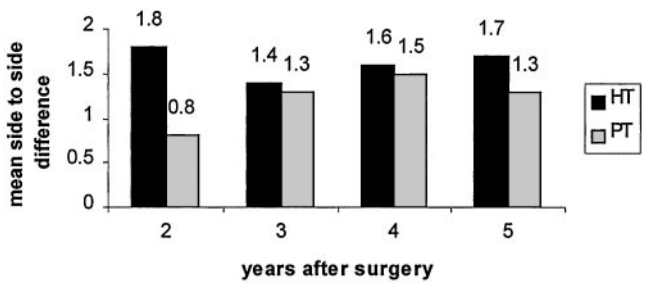

Figure 12. Mean manual maximum testing results. There was a significant difference between the patellar tendon (PT) and hamstring tendon (HT) groups at 2 years ($P = 0.01$). There was no significant difference in the mean side-to-side difference on maximum manual testing between the two groups at 5 years ($P = 0.17$, Mann-Whitney U test). Within the hamstring tendon group, there was no significant change in the mean manual maximum between 2 and 5 years ($P = 0.28$, Wilcoxon signed rank test). Within the patellar tendon group, there was a significant increase in the mean manual maximum between 2 and 5 years ($P = 0.01$, Wilcoxon signed rank test). Percentages based on number of patients at follow-up (See Table 1).

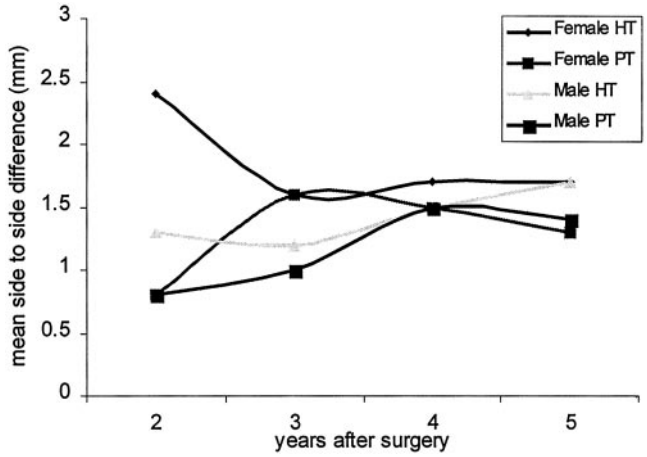

Figure 13. Sex differences on mean manual maximum testing. A significant difference between the female hamstring and female patellar tendon groups was present at 2 years ($P = 0.001$, unpaired t-test). No significant difference was seen between men and women at years 3 through 5. Graft choice did not significantly affect mean laxity measurements in either men ($P > 0.49$) or women ($P > 0.20$) from 3 to 5 years. HT, hamstring tendon; PT, patellar tendon.

laxity in the female patients.[12] The difference could not be explained by timing of surgery or weight or age of the patient groups. It did result in an increased number of hamstring tendon patients with grade 1 laxity on pivot shift and Lachman testing at 2 years. Figure 13 shows that the sex discrepancy seen at 2 years normalized between the groups by 3 years after surgery.

By 5 years after surgery, the mean laxity had significantly increased in the patellar tendon group to 1.5 mm ($P = 0.01$). However, the percentage of patients with a side-to-side difference of less than 3 mm on manual maximum testing was not significantly different from the 2-year results ($P = 0.37$). Both the mean laxity and the percentage of patients with a side-to-side difference of less than 3 mm on manual maximum testing remained unchanged in the hamstring tendon group between 2 and 5 years ($P = 0.30$ and $P = 0.37$, respectively). Analysis of 5-year results did not show any significant differences between the patellar tendon and hamstring tendon groups or between the men and women in either group.

DISCUSSION

The ACL acts as both a proprioceptive and a mechanical organ within the knee,[49] regulating anterior translation of the tibia on the femur and controlling tibial rotation and abduction in the flexed knee.[9] Such control is achieved through the process of fiber recruitment.[10] The ACL appears to carry loads well below its failure capacity during activities of daily living. Therefore, traumatic rupture of the normal ligament will occur only during peak torsional forces generated with high-demand activities.[30] In vivo and in vitro analyses have identified the key movements that are most likely to jeopardize the integrity of the

ACL.[6] These include quadriceps muscle-controlled extension of the knee from 40° of flexion, knee hyperextension, excessive internal tibial rotation, and excessive varus or valgus stress in association with a torn collateral ligament. As a viscoelastic structure, the ACL is believed to have the capability of responding to differences in load distribution, dissipating energy, and altering its length as a function of the strains placed on it.[29] Graft material appears incapable of such behavior, because it is composed of avascular collagen, is devoid of a nerve supply, and effectively acts as a tether within the joint. The shape of this tether differs between patellar tendon and hamstring tendon and that of the native ACL.

The expressed aim of surgical reconstruction of the ACL is to restore normal joint kinematics, thereby eliminating instability and the potential for associated damage to the menisci and chondral surfaces. After a 2-year follow-up, surgical reconstruction has been found to lower the rate of meniscal tear and subsequent surgery from 27% to 0.3%.[4] Repeated instability may ultimately lead to osteoarthritic change. However, quantification of the relationship between instability and degenerative change within the joint is yet to be accurately defined. Longitudinal studies have revealed a high incidence of osteoarthritic change in both the ACL-deficient and ACL-reconstructed knee.[27,33] Radiologic analyses have shown the incidence to be anywhere between 15% and 100%, depending on the presence of meniscal or chondral abnormalities and the duration of the instability before surgery.[27] The high number of patients who underwent surgery in the subacute phase in this study may include patients who could have reduced their activity level so as to minimize their knee instability, but who chose not to do so. It may also be that this study included true "copers," who can function at a high level without a clinically stable ACL. It is conceded that the patients included in this study were among the least severely injured and so would have the best prognosis. Our contention is that this group of patients, with their absence of associated meniscal or chondral injury, offers the optimal chance to study the effects of our surgical procedure, particularly regarding osteoarthritic change.

Surgery was performed after a period of physical therapy aimed at restoring full knee motion, allowing for resolution of the acute hemarthrosis. This had the added advantage of making the operative procedure easier, allowing for more accurate placement of the critical femoral tunnel. Such a delay also appears to minimize the risk of arthrofibrosis.[41] In our series, less than 10% of patients in both groups underwent surgery earlier than 3 weeks after injury.

Two years after surgery more than 85% of patients in both groups had full extension and 95% had full flexion. Despite this, there was a disturbing increase in the percentage of patients in the patellar tendon group who developed a fixed flexion deformity more than 2 years after surgery. This may herald the onset of osteoarthritic change.

Despite the plethora of literature on ACL reconstruction, there are only three other scientifically valid reports that compare autograft patellar tendon with hamstring tendon graft constructs.[2,31,36] The findings of these studies are shown in Table 4. It would be inappropriate to extrapolate the results of one report to those of another unless account is taken of patient activity level, sex, age, timing of surgery, surgical technique, the rehabilitation program followed, and specific outcome measures.

Our study is unique in that we followed the patient cohort annually to 5 years using the IKDC evaluation and recruited patients with isolated ACL injury, thereby minimizing the bias from short-term review and from the presence of associated joint, ligament, meniscal, or chondral injury. Longitudinal medium-term follow-up has allowed us to identify new trends in clinical measurements both within and between the two groups of patients, thus defining the joint's response to our surgical intervention. The fact that these patterns are not seen at the 2-year review highlights the need to redefine short-term follow-up at 3 years rather than 2 years for ACL reconstruction. We believe that the principal surgical determinants for outcome of ACL reconstruction are tunnel placement, graft choice, fixation choice, and type of postoperative rehabilitation program. In comparisons of one technique against another, ideally only one component of these determinants should be varied. In this study, there was a uniform observational technique with a randomized subgroup. As has been observed in previous studies, the greatest threat to completion of a randomized trial is the inability to recruit adequate numbers of participants, because of perceived advantages of one intervention over another. Indeed, this is what transpired in this study, wherein patients favored reconstruction with the hamstring tendon construct over the patellar tendon autograft based on the shorter hospital stay, perceived speedier rehabilitation, and decreased morbidity after the hamstring tendon graft harvest. Thus, it was decided to expand the study in a consecutive rather than an alternating pattern.

A bias is present in any study in which a change is made to a current treatment regimen. In this study, this bias favors the patellar tendon group, because the hamstring tendon procedure was a new method of graft harvest for the surgical team and a novel fixation method. We attempted, in the design of our study, to minimize the influence of other biases. Susceptibility bias was reduced because the two groups of patients had a similar prognosis because of the strict selection criteria. Performance bias was minimized because each study group had the same surgeon, similar fixation technique, similar postoperative management, similar postoperative activity level, and similar follow-up. Detection bias was substantially reduced by having a single independent examiner for 4 years of the study and one other independent examiner for the 4th and 5th year, with overlap at 4 years. This minimized the variation in follow-up methods, minimized the definition of subjective results, and minimized variation in clinical testing, functional evaluation, and laxity testing. Transfer bias was reduced by a high level of follow-up in each group of patients.

Graft fixation on the femoral side may be achieved either through suspensory or aperture methods. With both

TABLE 4
Comparison with Other Studies Assessing Hamstring Versus Patellar Tendon Autograft

Variable	Marder et al.[31]	Aglietti et al.[2]	O'Neill[37]	Pinczewski et al.
Months of follow-up (minimum/average)	24/29	22/28	24/42	60/60
Study design	Prospective randomized (alternating)	Prospective randomized (alternating)	Prospective randomized (by month of birth)	Prospective sequential (isolated ACL injury only)
Number of patients (initial/final)	80/72	63/60	129/125	180/170
Timing of surgery	Chronic	Chronic	Acute and chronic	Acute and chronic
Rehabilitation equal	Yes	Yes	Yes	Yes
Full weightbearing without aids (weeks)	6	8	1	1–1.5
Use of brace support	Hinged ROM[a] 0–6 weeks	Hinged ROM	No	No
Closed chain exercises	No	Yes	Yes	Yes
IKDC level I activity	Not tested	Not tested	Not tested	Not significant
Lysholm	Not tested	Not tested	Not significant	Not significant
Overall IKDC	Not tested	Not tested	Not significant	Not significant
IKDC symptoms	Not tested	Not tested	Not significant	Not significant
Range of motion	Not significant	Hamstring ($P < 0.001$)	Not significant	Significant incidence of fixed flexion in patellar tendon group
Ligament evaluation	Not significant	Not significant	Not significant	Not significant
Anterior knee pain	Not significant	Not significant	Not significant	Not significant but of tenderness significantly higher incidence in patellar tendon group
Single-legged hop test	Not tested	Not tested	Not tested	Not significant
Thigh atrophy	Not tested	Not tested	Not tested	Significantly higher incidence in patellar tendon group
KT-1000 arthrometer	Not significant (20 lbs)	Not significant (manual maximum)	Not significant (manual maximum)	Not significant (manual maximum)

[a] Range of motion.

methods, the assumption is that the graft will ultimately integrate with the host femoral bone. In vitro work has shown that both methods support strength-to-failure loads of 400 N.[7,32,36,44] More recent work has focused on the stiffness of the graft construct, related to both its composition and also the mode of fixation. Aperture fixation with an interference screw results in a stiffer graft construct than suspensory fixation methods with the same graft material.[28,44] Grafts fixed to bone at the intraarticular apertures undergo less stretching and are thus stiffer than either suspensory-fixed grafts or grafts fixed external to the drilled tunnels. Our results are in keeping with those of other work in which aperture fixation was found to perform better than suspensory methods with the patellar tendon graft, especially under cyclic loading conditions similar to early active rehabilitation protocols.[24]

Interference screw fixation was popularized in conjunction with patellar tendon graft reconstruction. Hamstring tendon graft fixation has been previously obtained by suspensory or external methods. The results of this study reveal that with a modified screw, aperture interference fixation may be used successfully for both graft types. Most researchers agree that donor patellar bone incorporates quite successfully into host cancellous femoral bone. We have previously shown that four-strand hamstring tendon graft material will similarly form collagenous crosslinks with the host femoral bone.[38] We have not, to date, identified any cases of failure caused by complete pullout (although graft slippage cannot be excluded). This study suggests that the mechanical strength afforded by interference screw fixation of both patellar tendon and hamstring tendon grafts reasonably permits early rehabilitation of the reconstructed knee during the period of graft integration, thus allowing an early return to normal activity.

Much has been written on fixation techniques performed in cadaveric and animal models. These reports give time-zero measurements, reporting pull-out strengths of interference screw fixation for hamstring tendon constructs varying around 300 N for the femoral side and slightly less on the tibial side.[8] The clinical results reported in this study suggest that such pull-out strengths are adequate. This further suggests that improved clinical results should be shown before it can be validated that higher fixation strengths are clinically advantageous.

No significant differences were identified between the percentages of patellar tendon or hamstring tendon patients who subjectively rated their knee function as either normal or nearly normal. For all time points, in both groups, this figure reassuringly remained above 95%. This figure correlated with the high Lysholm knee scores seen in both groups at 2 and 5 years after surgery and attests

to the high level of patient acceptance of both these procedures. Lachman testing revealed that only 75% of patients in the hamstring tendon group had a grade 0 result at 2 years, compared with 81% in the patellar tendon group. At 3 years, a significant increase was seen in the hamstring tendon group, with 86% having a grade 0 Lachman test ($P = 0.02$). This increase in knee stability was also found with pivot shift testing. At 1 year after surgery, only 75% of the hamstring tendon group had a grade 0 pivot shift test result; 94% of the patellar tendon group had a grade 0 result. However, the percentage of patients in both groups with grade 0 laxity increased with time, so that 5 years after surgical reconstruction, 92% of the hamstring tendon group and 98% of the patellar tendon group had a grade 0 result. Over the 5-year review period, no significant change in the percentage of patients with less than 3 mm of manual maximum laxity was seen in the hamstring tendon group or in the patellar tendon group. The mean manual maximum side-to-side difference recorded for the hamstring tendon group remained unchanged between 2 and 5 years; however, the difference in the patellar tendon group increased significantly, from 0.8 at 2 years to 1.3 at 5 years ($P = 0.01$). After 2 years there was no significant difference from that of the hamstring tendon group (1.7 mm). The increase in KT-1000 arthrometer measurements in the patellar tendon group at 3 years, compared with that of the hamstring tendon group, may reflect the effects of graft remodeling on this examination. The clinical laxity testing and instrumented laxity testing suggest that although there are early detectable differences between the patellar tendon and hamstring tendon groups, after 3 years, regardless of the graft choice, the results are similar. The authors believe that the physical differences seen are due to graft remodeling and that after 3 years, both grafts are the same.

It has been suggested that a narrow intercondylar notch may be associated with a higher incidence of ACL rupture.[17] Routine widening of the roof of the intercondylar notch has been advocated so as to minimize both graft rupture and loss of full extension.[22,23] In this series, notchplasty was not performed in any case. We consider that there are three reasons for performing notchplasty; first, to obtain visualization; second, to correct impingement; and third, to remove osteophytes. We had no need for notchplasty because our arthroscopic technique allowed for adequate visualization, patients with osteophytes were excluded from this study, and we followed the principle of anatomic graft placement, thereby avoiding impingement. Jackson and Jennings[25] reported that perioperative removal of residual tibial cruciate stump debris minimized the risk of a cyclops lesion.

A radiologic study was performed with use of the Insall-Salvati index to examine patellar tendon length at a minimum of 2 years after surgery in our two groups of patients (unpublished data). The mean patellar tendon length in the patellar tendon group at 2 years was 91.0% (range, 88.9% to 93.2%, 95% confidence interval) of the preoperative length, compared with 99.0% (range, 97.5% to 100.5%, 95% confidence interval) for the hamstring tendon group. At 5 years, patellar tendon length was 90% of the preoperative length in the patellar tendon group and 99% in the hamstring tendon group. The difference in means between the two groups was significant ($P < 0.001$, unpaired t-tests). However, there was no significant correlation between change in patellar tendon length and the presence of anterior knee pain or range of motion. Removal of the patellar tendon alone results in late shortening of the patellar tendon; this does not occur after the use of hamstring tendons for ACL reconstruction (T. Pollard et al., unpublished data, 2002). In a retrospective clinical and radiographic study of 100 patients, Jarvela et al.[26] reported the incidence of patellofemoral osteoarthritis 7 years after ACL reconstruction with bone-patellar tendon-bone autograft. They found that shortening of the patellar tendon correlated with the severity of the patellofemoral osteoarthritis. The greatest shortening was seen among patients with the most severe osteoarthritic changes.

Instrumented testing is often used by investigators in an attempt to minimize the variance that can occur due to the subjective nature of the Lachman and pivot shift tests. In this study we obtained both manual maximum force measurements and instrumented displacement measurements at 9.1-kg (20-N) force. Differences were noted between instrumented 20 N and manual maximum measurements in this series. There was a marked concordance between the findings for both groups for these two measurements. Although a greater percentage of patients in the patellar tendon group exhibited less laxity compared with the hamstring tendon group, these differences did not reach statistical significance after 3 years. The significance of this early difference in the face of an excellent subjective result remains unclear. Our results concur with those of Otero and Hutcheson,[37] who found that hamstring tendon grafts were more lax on both instrumented and Lachman testing, but Otero and Hutcheson used different modes of fixation for patellar tendon and hamstring tendon. Subgroup analysis of our results at 2 years revealed that the difference between the hamstring and patellar tendon groups was due to increased laxity in the female patients with hamstring tendon grafts. It has been proposed that interference screw fixation of the hamstring tendon graft on the tibial side may be prejudiced by weaker cancellous bone in women. The difference may be on the femoral side or there may be an error in measurement. Further study is needed to identify the nature of this between-sex discrepancy. At 3 years postoperatively, no significant difference in laxity measurements was seen between the patellar tendon and hamstring tendon groups or between men and women, and this was maintained up to the last follow-up at 5 years. Weiler et al.[48] recently reported the presence of myofibroblasts in sheep ACL tendon grafts after reconstruction. These structures may explain the paradoxical tightening of the hamstring tendon graft seen in this series.

After 2 years, an increase was seen in the presence of flexion contracture (loss of full extension) among patients in the patellar tendon group. This trend was not mirrored in the hamstring tendon group, even at 5 years. The flexion contracture was accompanied by an increase in radiographic evidence of early osteoarthritic changes. In the

patellar tendon group, these changes were observed between 2 and 5 years postoperatively. The hamstring tendon group displayed no significant changes between 2 and 5 years. By 5 years, mild changes were evident in 18% of the patellar tendon group, compared with 4% of the hamstring tendon group ($P = 0.003$).

Knee instability preventing participation in higher levels of activity is one of the key indications for surgical reconstruction. Functional ability may deteriorate with time in ACL-deficient knees, requiring these patients to substantially modify their lifestyle to maintain a safe level of function.[14,40] Only 14% of ACL-deficient patients in one study were able to return to unlimited athletic activities.[19] Noyes et al.[35] found that only 11% of patients treated nonoperatively were able to participate in strenuous sports without limitations. This current study supports the contention that ACL reconstruction affords a higher level of function than nonoperative treatment. Other studies have consistently shown that up to 2 years after surgery, the activity level remains significantly higher in patients with patellar tendon grafts than in patients with hamstring tendon grafts.[31,36] At 2 years postoperatively in our study, 74% of the hamstring tendon group and 84% of the patellar tendon group were participating regularly in level I or II activities. This figure declined marginally over the next 3 years. At the 5-year follow-up, 60% of the hamstring tendon group and 69% of the patellar tendon group continued to perform at level I or II. This is not a significant difference between the two groups and again reinforces the impression that the two grafts are equivalent at 3 years after surgical reconstruction.

Patellofemoral tenderness after ACL reconstruction remains an unresolved problem for patients with patellar tendon grafts.[1] Discomfort at rest must be differentiated from kneeling pain. Anterior knee pain at rest may be present before surgical reconstruction for ACL deficiency.[11] An incidence of anterior knee pain of up to 50% has been documented in patients after surgical reconstruction using patellar tendon autograft.[31,39] Studies that have compared anterior knee pain in patients with patellar tendon versus hamstring tendon autografts have failed to identify significant differences in patellofemoral pain between the two groups.[2,31,36] Our study identified persistent levels of discomfort in the patellar tendon group beyond 2 years after surgery. However, this was not reflected in the hamstring tendon group. Patients may feel discomfort in a number of sites around the knee, which suggests that there is more than one etiologic factor. Proposed mechanisms include a limited range of movement before surgery, concurrent patellar chondromalacia, poor rehabilitation, graft harvest site pain, the presence of a fixed flexion contracture, and the development of patella baja subsequent to patellar tendon fibrosis.[2,43] We found donor-site pain at rest in 23% of the hamstring tendon group and 34% of the patellar tendon group at 2 years. However, by 5 years after surgery, only 12% of patients in the hamstring tendon group had residual thigh pain, whereas 41% of the patellar tendon group continued to report at least mild donor-site symptoms.

Kneeling pain caused by the weight of the body on the tibial tubercle is more easily tested for than anterior knee discomfort that occurs during general activity. Kneeling pain may also be an important factor for patients who have to kneel because of their occupation. At 2 years, 31% of the patellar tendon group and only 6% of the hamstring tendon group reported the presence of at least mild pain on kneeling. In both groups, there was an increase in the percentage of patients who reported kneeling pain with time, but for all time points the figure was significantly worse for the patellar tendon group. It appears that both groups of patients are at risk for such discomfort but that the group with a harvested patellar tendon is at significantly more risk. We found only a low incidence of patellofemoral crepitus on clinical examination in both groups (9% for both groups at 5 years). This confirms the impression that abnormalities of patellofemoral articulation do not account for the residual anterior knee pain or kneeling pain after reconstruction.

CONCLUSIONS

This study confirms the clinical impression that surgical reconstruction with either patellar or hamstring tendon graft reliably restores knee stability, allowing for return to a high level of functional activity. In the medium term, 3 to 5 years, the reconstructed knees were indistinguishable regarding stability examination. There was an increase in the incidence of early radiographic osteoarthritic change and fixed flexion deformity in the patellar tendon group, and this may herald the onset of degenerative change in this group. There was no significant difference in the clinical outcomes of these two groups of patients. Analysis of the results of the randomized subgroup of 52 patients did not show any new findings over and above those seen in the cohort study. Both groups of patients remain the subject of an ongoing study. Unfortunately, the number of patients in this study is too small to draw any conclusions from statistically insignificant results. However, this study does show the knee joint's response to our current techniques for surgical treatment of ACL rupture, demonstrating that these techniques do not cause the gross osteoarthritic changes that were seen with our open technique.

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REFERENCES

1. Aglietti P, Buzzi R, D'Andria S, et al: Patellofemoral problems after intra-articular anterior cruciate ligament reconstruction. *Clin Orthop 288:* 195–203, 1993
2. Aglietti P, Buzzi R, Zaccherotti G, et al: Patellar tendon versus doubled semitendinosus and gracilis tendons for anterior cruciate ligament reconstruction. *Am J Sports Med 22:* 211–218, 1994
3. Anderson AF: Rating scales, in Fu F, Harner C, Vince K (eds): *Knee Surgery.* Baltimore, Williams & Wilkins, 1994, pp 275–296
4. Andersson C, Odensten M, Good L, et al: Surgical or non-surgical treatment of acute rupture of the anterior cruciate ligament: A randomized study with long-term follow-up. *J Bone Joint Surg 71A:* 965–974, 1989

5. Bach BR Jr, Warren RF, Flynn WM, et al: Arthrometric evaluation of knees that have a torn anterior cruciate ligament. *J Bone Joint Surg 72A:* 1299–1306, 1990
6. Beynnon-Fleming B, Pope M, Johnson R: The measurement of anterior cruciate ligament strain in vivo, in Jackson DW, Arnoczky SP, Woo S, et al. (eds): *The Anterior Cruciate Ligament. Current and Future Concepts.* New York, Raven Press, 1993, pp 101–111
7. Brown CH Jr, Hecker AT, Hipp JA, et al: The biomechanics of interference screw fixation of patellar tendon anterior cruciate ligament grafts. *Am J Sports Med 21:* 880–886, 1993
8. Brown CH Jr, Steiner ME, Carson EW: The use of hamstring tendons for anterior cruciate ligament reconstruction. Technique and results. *Clin Sports Med 12:* 723–756, 1993
9. Butler DL: Anterior cruciate ligament: Its normal response and replacement. *J Orthop Res 7:* 910–921, 1989
10. Butler DL, Guan Y, Kay MD, et al: Location-dependent variations in the material properties of the anterior cruciate ligament. *J Biomech 25:* 511–518, 1992
11. Bynum EB, Barrack RL, Alexander AH: Open versus closed chain kinetic exercises after anterior cruciate ligament reconstruction: A prospective randomized study. *Am J Sports Med 23:* 401–406, 1995
12. Corry IS, Webb JM, Clingeleffer AJ, et al: Arthroscopic reconstruction of the anterior cruciate ligament. A comparison of patellar tendon autograft and four-strand hamstring tendon autograft. *Am J Sports Med 27:* 444–454, 1999
13. Daniel DM, Stone ML, Dobson BE, et al: Fate of the ACL-injured patient: A prospective outcome study. *Am J Sports Med 22:* 632–644, 1994
14. Fowler PJ, Regan WD: The patient with symptomatic chronic anterior cruciate ligament insufficiency: Results of minimal arthroscopic surgery and rehabilitation. *Am J Sports Med 15:* 321–325, 1987
15. Frank CB, Jackson DW: The science of reconstruction of the anterior cruciate ligament. *J Bone Joint Surg 79A:* 1556–1576, 1997
16. Galway R, Beaupre A, MacIntosh D: Pivot shift: A clinical sign of symptomatic anterior cruciate ligament insufficiency. *J Bone Joint Surg 71B:* 763–764, 1972
17. Good L, Odensten M, Gillquist J: Intercondylar notch measurements with special reference to anterior cruciate ligament surgery. *Clin Orthop 263:* 185–189, 1991
18. Harter RA, Osternig LR, Singer KM: Instrumented Lachman tests for the evaluation of anterior laxity after reconstruction of the anterior cruciate ligament. *J Bone Joint Surg 71A:* 975–983, 1989
19. Hawkins RJ, Misamore GW, Merritt TR: Followup of the acute nonoperated isolated anterior cruciate ligament tear. *Am J Sports Med 14:* 205–210, 1986
20. Hefzy MS, Grood ES, Noyes FR: Factors affecting the region of most isometric femoral attachments. Part II: The anterior cruciate ligament. *Am J Sports Med 17:* 208–216, 1989
21. Hoher J, Bach T, Munster A, et al: Does the mode of data collection change results in a subjective knee score? Self-administration versus interview. *Am J Sports Med 25:* 642–647, 1997
22. Howell SM: Arthroscopic roofplasty: A method for correcting an extension deficit caused by roof impingement of an anterior cruciate ligament graft. *Arthroscopy 8:* 375–379, 1992
23. Howell SM, Taylor MA: Failure of reconstruction of the anterior cruciate ligament due to impingement by the intercondylar roof. *J Bone Joint Surg 75A:* 1044–1055, 1993
24. Ishibashi Y, Rudy TW, Livesay GA: The effect of anterior cruciate ligament graft fixation site at the tibia on knee stability: Evaluation using a robotic testing system. *Arthroscopy 13:* 177–182, 1997
25. Jackson DW, Jennings LD: Arthroscopically assisted reconstruction of the anterior cruciate ligament using a patella tendon bone autograft. *Clin Sports Med 7:* 785–800, 1988
26. Jarvela T, Paakkala T, Kannus P, et al: The incidence of patellofemoral osteoarthritis and associated findings 7 years after anterior cruciate ligament reconstruction with bone-patellar tendon-bone autograft. *Am J Sports Med 29:* 18–24, 2001
27. Jomha NM, Pinczewski LA, Clingeleffer A, et al: Arthroscopic reconstruction of the anterior cruciate ligament with patellar-tendon autograft and interference screw fixation. The results at seven years. *J Bone Joint Surg 81B:* 775–779, 1999
28. Kurosaka M, Yoshiya S, Andrish JT: A biomechanical comparison of different surgical techniques of graft fixation in anterior cruciate ligament reconstruction. *Am J Sports Med 15:* 225–229, 1987
29. Kwan MK, Lin TH, Woo SL-Y: On the viscoelastic properties of the anteromedial bundle of the anterior cruciate ligament. *J Biomech 26:* 447–452, 1993
30. Lewis J, Lew W, Markolf K: The measurement of anterior cruciate ligament loads: Direct methods, in Jackson D, Arnoczky S, Woo SL-Y, et al. (eds): *The Anterior Cruciate Ligament: Current and Future Concepts.* New York, Raven Press, 1993, pp 101–111
31. 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 19:* 478–484, 1991
32. Matthews LS, Lawrence SJ, Yahiro MA, et al: Fixation strengths of patellar tendon-bone grafts. *Arthroscopy 9:* 76–81, 1993
33. McDaniel WJ Jr, Dameron TB Jr: Untreated ruptures of the anterior cruciate ligament. A follow-up study. *J Bone Joint Surg 62A:* 696–705, 1980
34. Noyes FR, Butler DL, Grood ES, et al: Biomechanical analysis of human ligament grafts used in knee-ligament repairs and reconstructions. *J Bone Joint Surg 66A:* 344–352, 1984
35. Noyes FR, Mooar PA, Matthews DS, et al: The symptomatic anterior cruciate-deficient knee. Part I: The long-term functional disability in athletically active individuals. *J Bone Joint Surg 65A:* 154–162, 1983
36. O'Neill DB: Arthroscopically assisted reconstruction of the anterior cruciate ligament. A prospective randomized analysis of three techniques. *J Bone Joint Surg 78A:* 803–813, 1996
37. 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 9:* 143–148, 1993
38. Pinczewski LA, Clingeleffer AJ, Otto DD, et al: Integration of hamstring tendon graft with bone in reconstruction of the anterior cruciate ligament. *Arthroscopy 13:* 641–643, 1997
39. Sachs RA, Daniel DM, Stone ML, et al: Patellofemoral problems after anterior cruciate ligament reconstruction. *Am J Sports Med 17:* 760–765, 1989
40. Satku K, Kumar VP, Ngoi SS: Anterior cruciate ligament injuries. To counsel or to operate? *J Bone Joint Surg 68B:* 458–461, 1986
41. Shelbourne KD, Gray T: Results of anterior cruciate ligament reconstruction based on meniscus and articular cartilage status at the time of surgery. Five- to fifteen-year evaluations. *Am J Sports Med 28:* 446–452, 2000
42. Sherman MF, Warren RF, Marshall JL, et al: A clinical and radiographical analysis of 127 anterior cruciate insufficient knees. *Clin Orthop 227:* 229–237, 1988
43. Shino K, Inoue M, Nakagawa S, et al: Deterioration of the patellofemoral joint after anterior cruciate ligament reconstruction [abstract]. *Am J Sports Med 18:* 560, 1990
44. Steiner ME, Hecker AT, Brown CH Jr, et al: Anterior cruciate ligament graft fixation. Comparison of hamstring and patellar tendon grafts. *Am J Sports Med 22:* 240–247, 1994
45. Tegner Y, Lysholm J: Rating systems in the evaluation of knee ligament injuries. *Clin Orthop 198:* 43–49, 1985
46. To J, Howell SM, Hull ML: Contributions of femoral fixation methods to the stiffness of anterior cruciate ligament replacements at implantation. *Arthroscopy 15:* 379–387, 1999
47. Torg JS, Conrad W, Kalen V: Clinical diagnosis of anterior cruciate ligament instability in the athlete. *Am J Sports Med 4:* 84–93, 1976
48. Weiler A, Unterhauser FN, Bail HJ, et al: Alpha-smooth muscle actin is expressed by fibroblastic cells of the ovine anterior cruciate ligament and its free tendon graft during remodeling. *J Orthop Res 20:* 310–317, 2002
49. Wojtys EM, Huston LJ: Neuromuscular performance in normal and anterior cruciate ligament-deficient lower extremities. *Am J Sports Med 22:* 89–104, 1994