A 10-Year Comparison of Anterior Cruciate Ligament Reconstructions With Hamstring Tendon and Patellar Tendon Autograft

A Controlled, Prospective Trial

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Background: There are no controlled, prospective studies comparing the 10-year outcomes of anterior cruciate ligament (ACL) reconstruction using patellar tendon (PT) and 4-strand hamstring tendon (HT) autografts.

Hypothesis: Comparable results are possible with HT and PT autografts.

Study Design: Cohort study; Level of evidence, 2.

Methods: One hundred eighty ACL-deficient knees that met inclusion criteria underwent ACL reconstruction (90 HT autograft, 90 PT autograft) by one surgeon and were treated with an accelerated rehabilitation program. All knees were observed in a prospective fashion with subjective, objective, and radiographic evaluation at 2, 5, 7, and 10-year intervals.

Results: At 10 years, there were no differences in graft rupture rates (7/90 PT vs. 12/90 HT, $P = .24$). There were 20 contralateral ACL ruptures in the PT group, compared with 9 in the HT group ($P = .02$). In all patients, graft rupture was associated with instrumented laxity >2 mm at 2 years ($P = .001$). Normal or near-normal function of the knee was reported in 97% of patients in both groups. In the PT group, harvest-site symptoms ($P = .001$) and kneeling pain ($P = .01$) were more common than in the HT group. More patients reported pain with strenuous activities in PT knees than in HT knees ($P = .05$). Radiographic osteoarthritis was more common in PT knees than the HT-reconstructed knees ($P = .04$). The difference, however, was composed of patients with mild osteoarthritis. Other predictors of radiographic osteoarthritis were <90% single-legged hop test at 1 year and the need for further knee surgery. An "ideal" outcome, defined as an overall International Knee Documentation Committee grade of A or B and a radiographic grade of A at 10 years after ACL reconstruction, was associated with <3 mm of instrumented laxity at 2 years, the absence of additional surgery in the knee, and HT grafts.

Conclusions: It is possible to obtain excellent results with both HT and PT autografts. We recommend HT reconstructions to our patients because of decreased harvest-site symptoms and radiographic osteoarthritis.

Keywords: ACL reconstruction; patellar tendon; hamstring tendon; long-term; osteoarthritis; clinical

Anterior cruciate ligament (ACL) reconstructive surgery is a common elective orthopaedic procedure. In the United States, over 102 000 ACL reconstructions were performed in 1996.[26]

Despite the frequency of ACL reconstructions performed, there remain significant discrepancies in surgeon preference regarding ligament graft choice.[3,13,19,38] Common sources include bone-patellar tendon-bone (PT) autografts, 4-strand semitendinosus and gracilis hamstring (HT) autografts, quadriceps tendon autografts with or without bone plug, and allografts from a variety of sources.[17,18,30,34,35] The differences of opinion regarding graft sources indicate the lack of prospective, long-term studies comparing outcomes of different grafts. In this study, we have prospectively compared the long-term (10-year) outcomes of the 2 most commonly used autograft sources—PT autografts and HT autografts.

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There are a large number of intrinsic and extrinsic patient variables confounding the results of outcome studies for ACL reconstructions. Graft choice is only one extrinsic variable. Surgeon experience, correct graft position, choice of graft fixation, and postoperative rehabilitation confound the results of comparisons of ACL reconstruction. Factors intrinsic to the patient, such as preoperative function, concurrent intra-articular injury (meniscal and chondral injuries), and physiologic and pathologic joint laxity all affect the long-term results from ACL reconstruction.[1,8]

There are no previous prospective 10-year comparison studies to determine the effects of graft choice on the clinical outcome of ACL reconstruction. This study represents a report on the long-term outcomes of ACL reconstruction on knee function using an endoscopic technique, as well as a prospective comparison of the isolated effects of one extrinsic variable (graft choice).

MATERIALS AND METHODS

Patient Selection

Inclusion and exclusion criteria for this study[29] have been previously reported and are listed in Table 1.

An ACL reconstruction was offered to those patients fulfilling the inclusion criteria who wished to return to sports involving pivoting, cutting, or sidestepping, or those with repeated episodes of instability despite conservative treatment involving physiotherapy. All patients exhibited at least grade II Lachman and pivot shift tests on clinical examination preoperatively. The acute injury to the ACL was managed by physical therapy until a full range of movement with little swelling or pain was obtained. Subsequent repeat clinical examination confirmed ACL insufficiency, and surgical intervention was then performed during the subacute stage.

All patients agreed to participate in a research program with ethical committee approval from St Vincent's Hospital, Sydney. From January 1993 to April 1994, 333 patients were prospectively examined and underwent surgical reconstruction of the ACL using PT autograft. Of this group, 90 patients fulfilled the study inclusion criteria and included 48 men and 42 women with a median age of 25 (range, 15 to 42). In October 1993, the senior author (L.A.P.) started using the HT autograft, and after April 1994 used the HT graft exclusively. From October 1993 to November 1994, 372 patients underwent surgical reconstruction using a 4-strand HT autograft. Of these, 90 were found to fulfill the study inclusion criteria and included 47 men and 43 women with a median age of 24 (range, 13 to 52). Both groups of patients (n = 180) were reviewed annually for 5 years and then at 7 and 10 years.

Surgical Technique

All procedures were performed by the senior author and have been described previously.[28] The grafts used to reconstruct the ACL were the ipsilateral middle third patellar tendon or 4-strand gracilis and semitendinosus tendons.

TABLE 1
Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Endoscopic ACL reconstruction with either patellar tendon or hamstring tendon autograft between January 1993 and November 1994	Any associated ligament injury requiring surgery
	Evidence of chondral damage or degeneration
	Previous meniscectomy
	Excision of >1/3 of one meniscus at time of reconstruction
	Abnormal radiograph
	Abnormal contralateral knee joint
	Patients seeking compensation for their injury
	Patients who did not wish to participate in a research program

Standard roundhead 7×25-mm titanium cannulated interference screws (RCI, Smith & Nephew Endoscopy, Andover, Mass) was used for both proximal and distal graft fixation in both groups. The tunnel size in the PT group was determined as 1 mm larger than the bone block size (range, 8 to 11 mm), and in the HT group the tunnel size equaled the cross-sectional diameter of the graft (range, 6 to 9 mm). This aspect of operative variability could not be controlled for. No supplementary methods of fixation were used.

Rehabilitation

Both groups of patients were treated by a similar rehabilitation program using the same group of physical therapists. Immediately after surgery, patients commenced cocontractions of quadriceps and hamstring muscles, as well as weightbearing with the aid of crutches. No brace was used, and patients were encouraged to discard crutches as soon as possible. An accelerated rehabilitation program was instituted, focusing on achieving full extension by the 14th day after surgery. Jogging was commenced after 6 weeks, but return to competitive sport was restricted until at least 6 months after surgery, and only after knee stability had been reconfirmed on clinical examination.

Assessment

All patients were assessed by an independent examiner before surgery, at 6 and 12 months after surgery, annually for 5 years, and then at 7 and 10 years using the International Knee Documentation Committee (IKDC) evaluation form.[2] Symptoms and signs of knee function were assessed to determine the IKDC grade.[2] The Lysholm Knee Score was obtained by the means of a self-administered questionnaire.[16,37] Assessment of knee stability was undertaken using the Lachman, anterior drawer, and the pivot shift tests. Instrumented laxity testing was determined

using the KT-1000 arthrometer (MEDmetric Corp, San Diego, Calif) by measuring side-to-side differences in displacement on manual maximum testing. Range of motion was measured using a goniometer. Kneeling pain on a standard carpet surface and hamstring muscle discomfort were recorded for site and severity using a visual analog scale from 0 (no pain) to 10 (most severe pain).

Before surgery and at 2, 5, 7, and 10 years after surgery, weightbearing anteroposterior (AP), 30° flexion posteroanterior (PA), lateral, and 45° Merchant view radiographs were taken. The medial, lateral, and patellofemoral compartments were examined for evidence of any joint-space narrowing and the presence of osteophytes. Radiographs were classified according to the IKDC guidelines as follows: A, normal; B, minimal changes and barely detectable joint-space narrowing; C, moderate changes and joint-space narrowing of up to 50%; and D, severe changes and more than 50% joint-space narrowing. The worst grade of the 3 compartments was used to assign the overall radiologic grade. The Blackburne-Peel index was calculated from the lateral radiograph as the perpendicular distance from the tibial plateau to the inferior margin of the patellar articular surface divided by the length of the patellar articular surface.[5] An independent experienced musculoskeletal radiologist interpreted each set of radiographs.

Statistical Method

The outcomes were compared between the two groups at 10 years using the Mann-Whitney U test for the continuous measurements (KT1000, range of motion, Lysholm score) and ordered categorical variables (such as IKDC categories). Wilcoxon signed rank test was used to assess changes over time. Linear regression analysis was used to assess relationship between selected dependent and independent variables. Statistical significance was assessed at the 5% level.

RESULTS

Operative Findings

The ACL was reconstructed less than 12 weeks after injury in 70 of 90 HT patients and in 66 of 90 PT patients ($P = .42$). Medial meniscal injury was noted at the time of reconstruction in 20 of 90 HT patients and 18 of 90 PT patients ($P = .68$). Lateral meniscal injury was seen in 43 of 90 HT patients and 34 of 90 PT patients ($P = .35$). The meniscus was sutured in 10 HT and 7 PT patients and minimal resection of less than one third of the meniscus was performed in 9 HT and 6 PT patients ($P = .52$).

ACL Graft Rupture

Over the 10-year study period, 12 patients from the HT group and 7 patients from the PT group ruptured their grafts. There was no significant difference between the HT and PT groups in the rate of ACL graft rupture ($P = .24$) (Figure 1). Anterior cruciate ligament graft rupture occurred at a mean time of 50 months in the HT group and 63 months in the PT group ($P = .52$).
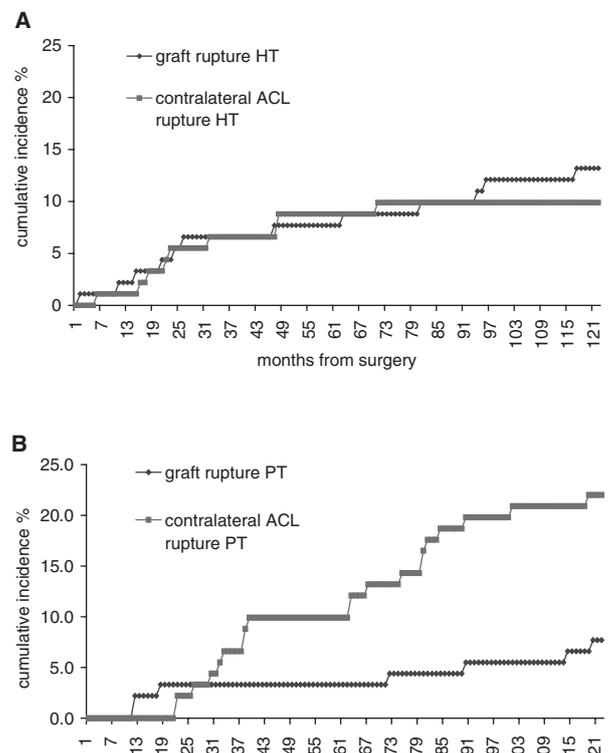

Figure 1. Incidence of ACL graft and contralateral ACL rupture in the (A) hamstring tendon (HT) group and the (B) patellar tendon (PT) group.

Regression analysis revealed that ACL graft rupture was associated with laxity at 2 years ($P = .001$). There was no significant relationship between ACL graft rupture and the variables of age less than 21 years ($P = .60$), graft source ($P = .83$), activity level at 2 years ($P = .25$), or gender ($P = .11$).

Although this group of 19 patients has been excluded from the principal analysis, summaries of their results are shown in Table 2.

Survivorship

Kaplan-Meier analysis of the 90 HT patients revealed a 10-year survival rate of 86% (95% confidence interval [CI], 79% to 94%) with graft rupture as the end point. For the PT patients, the 10-year survival rate was 92% (95% CI, 86% to 98%). The combined incidence of either ACL graft rupture or contralateral ACL injury is shown in Figure 2.

Contralateral ACL Injury

Over the 10-year study period, 9 patients from the HT group and 20 patients from the PT group ruptured their contralateral ACL (Figure 1). There was a significant difference between the HT and PT groups in the rate of contralateral ACL rupture ($P = .02$). Contralateral ACL injury occurred at a mean of 32 months in the HT group and 59 months in the PT group ($P = .02$).

TABLE 2
Summary of 10-Year Results of the 19 Patients
Who Sustained a Graft Rupture

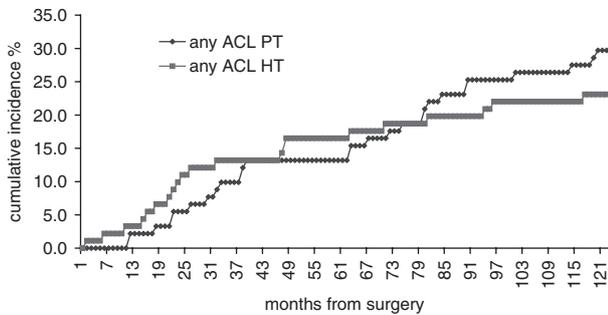|	
No. of ACL graft ruptures	19
No. of patients proceeding to revision ACL surgery	14
No. of patients sustaining a rupture of revised graft	5
No. of patients reviewed	17
Subjective knee function (normal or nearly normal)	69%
Lysholm score (mean)	78
Overall IKDC evaluation (normal or nearly normal)	23%
Lachman grade	
0	31%
1	15%
2	54%
Pivot grade	
0	38%
1	15%
2	46%
KT-1000 mean (mm)	4
Radiographs	
Grade A	85%
Grade B	15%
Grade C	8%

Figure 2. Combined incidence of ACL graft or contralateral ACL injury in the patellar tendon (PT) and hamstring tendon (HT) groups.

Regression analysis revealed that contralateral ACL rupture was associated with the PT graft ($P = .01$) and age less than 21 years at the time of reconstruction ($P = .02$). There was no significant relationship between contralateral ACL rupture and the variables of laxity at 2 years ($P = .63$), activity level at 2 years ($P = .19$), or gender ($P = .88$).

Follow-up

Of the remaining 78 patients from the HT group with intact ACL grafts, 74 patients (95%) were reviewed at 10 years. Of the 4 patients not reviewed, 2 had moved overseas, 1 patient was recovering from a serious illness, and 1 patient could not be located. One patient from the PT group died of unrelated causes, leaving 82 patients in the PT group with intact ACL grafts. Seventy-five patients (91%) were reviewed at 10 years. Of the 7 patients not reviewed, 1 patient refused to attend and 6 patients could not be located.

The objective components of the IKDC knee ligament evaluation are designed to compare the reconstructed knee to a normal contralateral knee. A total of 29 patients suffered a contralateral ACL injury during the follow-up period. To avoid creating a bias in our results by excluding such a large number of patients, those patients with a contralateral ACL injury have been included in the subjective analysis sections but removed from the objective components of the analysis that require comparison with a normal knee. A further 8 patients from the HT graft group and 8 patients from the PT group were unable to attend our clinic for review due to geographical reasons and completed subjective review only.

The results of this patient cohort have been previously published.[28,29] However, subtle differences in the patient cohort have occurred. At all reviews, patients who had suffered an ACL graft rupture were excluded. At the 5-year review, patients who had a contralateral ACL rupture were included in both the subjective and objective results. At the 7-year review, all patients who had suffered a contralateral ACL graft rupture were excluded from subjective and objective results. At the 10-year review, it was decided that excluding all the results of the 29 patients who had suffered a contralateral ACL rupture would bias the results. The objective components of the assessments require comparison with a normal contralateral limb; therefore, in the current study we have included the subjective components of those patients but excluded their objective results.

Complications and Further Surgery at 10 Years

Complications and further surgery are shown in Table 3. There was no significant difference between the HT and PT groups with respect to other complications.

SUBJECTIVE RESULTS

Subjective results were obtained on 74 patients from the HT group and 75 patients from the PT group. The number of patients reviewed at each year is shown in Table 4.

Subjective Functional Assessment (IKDC)

Over 96% of patients reviewed reported normal or nearly normal knee function at all review periods (Figure 3). There was no significant difference between the HT and PT groups at any time point. There was no significant change in either group over time.

Subjective Symptoms With Activity

At 10 years after surgery, 57 of 74 HT patients and 45 of 75 PT patients were able to participate in strenuous activities without pain ($P = .05$). At 10 years, strenuous activity was able to be performed without swelling in 63 of 74 HT

TABLE 3
Complications and Further Surgery at 10 Years

	Hamstring Tendon Group			Patellar Tendon Group		
	No. of patients	Mean duration (months)	Range (months)	No. of patients	Mean duration (months)	Range (months)
Meniscectomy	8	24.5	7-120	5	52.4	14-99
Contralateral meniscectomy	1	34		2	72	44-99
Excision of patellar tendinitis				1	24	
Removal of tibial screw	2	70	68-72	2	74	60-87
Arthroscopy & arthrolysis				1	3	
Arthroscopy & chondroplasty				1	21	
Fracture of lateral tibial plateau	1	119				
Fracture of spiral tibia & fibula	1	28				
Removal of cyclops lesion	2	12	9-15	1	6	

TABLE 4
Patients Reviewed With Subjective Results
(Graft Ruptures and Deaths Excluded)

	Patients	
Follow-up year	Hamstring Tendon Group	Patellar Tendon Group
2	78 of 85 (92%)	79 of 87 (91%)
5	76 of 83 (92%)	79 of 87 (91%)
7	73 of 82 (89%)	77 of 85 (91%)
10	74 of 78 (95%)	75 of 82 (91%)

Figure 4. Percentage of patients from hamstring tendon (HT) and patellar tendon (PT) groups with good or excellent Lysholm scores at each review.
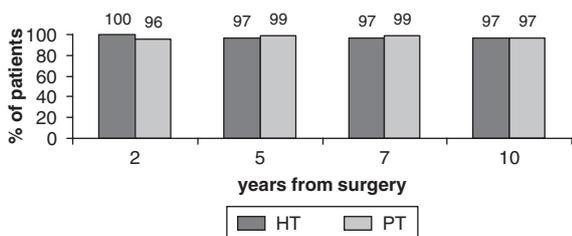

Figure 3. Percentage of patients from hamstring tendon (HT) and patellar tendon (PT) groups with knee function grade A or B at each review.

patients and 64 of 75 PT patients (P = .94) and without giving way in 67 of 74 HT patients and 65 of 75 PT patients (P = .39). The worst grade from each of the above components determines the overall symptom grade. No symptoms with strenuous activity was reported by 43 of 75 patients (57%) in the PT group and 53 of 74 patients (72%) in the HT group (P = .07).

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 maximum score is 100. The percentage
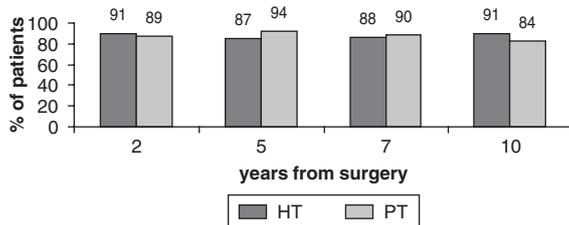
of patients with a good to excellent Lysholm knee score at each review is shown in Figure 4. There was no significant difference between the HT and PT groups at any time point and no significant change in either group over time.

Activity Level

By 10 years after surgery, 42 of 74 HT patients and 34 of 75 PT patients were participating in level-1 or -2 sports (P = .17). However, only 8 HT patients and 9 PT patients (P = .84) reported that the decrease in activity was related to their knee. The decrease in the activity level between 2 and 10 years was significant in both the HT (P = .01) and PT groups (P = .001), and is shown in Figure 5.

Harvest-Site Symptoms

Patients were asked to note tenderness, irritation, or numbness at the autograft harvest site and grade these symptoms as A (none), B (mild), C (moderate), or D (severe). In the HT group at 10 years, 70 patients graded them A, and 4 patients graded them B. In the PT group, 49 patients were grade A, 22 patients grade B, 3 patients grade C, and 1 patient grade D. The PT group reported a significantly higher incidence of symptoms arising from their graft harvest site at 10 years compared with the HT group (P = .001).
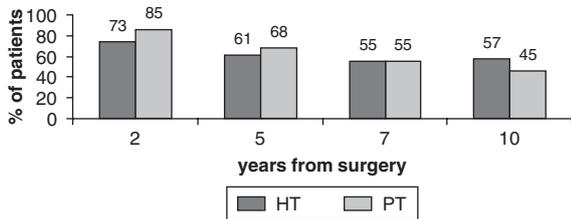
Figure 5. Percentage of patients from hamstring tendon (HT) and patellar tendon (PT) groups participating in level-1 or -2 sport activities at each review.
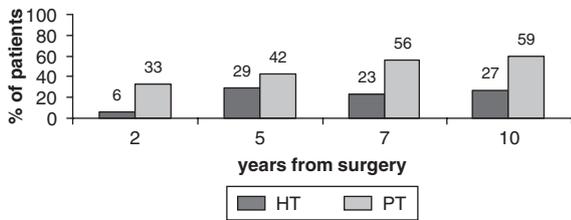

Figure 6. Percentage of patients from hamstring tendon (HT) and patellar tendon (PT) groups with kneeling pain at each review.

Kneeling Pain

Kneeling pain was reported if it was present after patients kneeled on a carpeted floor. The severity was recorded on a visual analog scale from 0 to 10. The incidence of kneeling pain at each review point is shown in Figure 6. At all review periods the PT group had greater incidence of kneeling pain than the HT group ($P < .01$).

OBJECTIVE RESULTS

Because the objective results assume comparison with a normal contralateral limb, all patients with contralateral ACL injury were excluded from the analysis of objective results. Objective results were obtained on 58 patients from the HT group and 53 patients from the PT group at 10 years. The number of patients reviewed at each year is shown in Table 5.

Clinical Ligament Evaluation

Ligament laxity was assessed with the Lachman, pivot-shift, and KT-1000 arthrometer instrumented tests.

Lachman Testing. In the HT group at 10 years, 46 patients had a grade 0 Lachman test, 11 patients had a grade 1 test, and 1 patient had a grade 2 test. In the PT group at 10 years, 43 patients had a grade 0 test and 10 patients had a grade 1 test. There was no significant difference between the groups at 10 years ($P = .78$). There was no significant change in the Lachman test between 2 and 10 years in either the PT ($P = .62$) or HT groups ($P = .76$) (Figure 7).

TABLE 5
Patients Reviewed With Objective Results (Contralateral ACL-Deficient and Graft Ruptures Excluded)

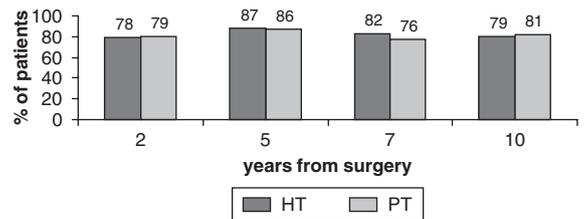| Follow-up year	Patients	
	Hamstring Tendon Group	Patellar Tendon Group
2	76 of 80 (95%)	77 or 85 (91%)
5	69 of 75 (92%)	69 of 78 (88%)
7	62 of 73 (85%)	59 of 68 (87%)
10	58 of 70 (82%)	53 of 65 (82%)

Figure 7. Percentage of patients from hamstring tendon (HT) and patellar tendon (PT) groups with grade 0 Lachman at each review.

Pivot Shift Testing. In the HT group at 10 years, 50 patients had a grade 0 pivot shift test, and 8 patients had a grade 1 test. In the PT group at 10 years, 48 patients had a grade 0 test and 5 patients had a grade 1 test. There was no significant difference between the groups at 10 years ($P = .48$). There was no significant change in the pivot shift test between 2 and 10 years in either the PT ($P = .74$) or HT groups ($P = .13$) (Figure 8).

Instrumented Testing. The percentage of patients in each group with a side-to-side difference of <3 mm on manual maximum testing for years 2 to 10 is shown in Figure 9. There was a significant difference between the groups at 2 years ($P = .004$), but no significant difference at 5 ($P = .19$), 7 ($P = .42$), or 10 years ($P = .53$). The number of patients over 2 mm in the PT group was 13 of 54 and in the HT, 17 of 58. No patients in either group had a manual maximum test of >5 mm. There was a significant decrease in the number of patients with <3 mm side-to-side difference in the PT group ($P = .03$) between 2 and 10 years; no corresponding change was seen in the HT group ($P = .68$). The mean side-to-side difference on manual maximum testing did not significantly change between 2 and 10 years for the PT ($P = .08$) or the HT group ($P = 0.50$) and is shown in Table 6.

Regression analysis revealed that manual maximum testing at 10 years was not significantly related to gender ($P = .63$), graft ($P = .86$), or extension loss ($P = .66$). There was a significant relationship between laxity at 10 years and the variables of laxity at 2 years ($P = .02$) on manual maximum testing.
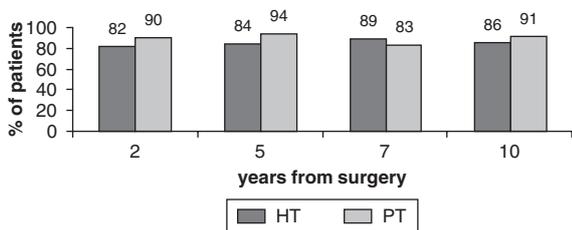
Figure 8. Percentage of patients from hamstring tendon (HT) and patellar tendon (PT) groups with grade 0 pivot shift at each review.
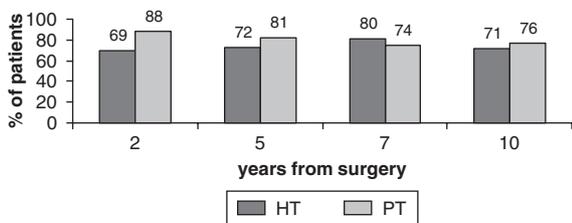

Figure 9. Percentage of patients from hamstring tendon (HT) and patellar tendon (PT) groups with <3 mm on side-to-side manual maximum testing at each review.

TABLE 6
The Mean and 95% Confidence Intervals (CI) for the
Manual Maximum Laxity Tests in the
Hamstring and Patellar Tendon Groups

		Hamstring Tendon Group	Patellar Tendon Group	*P*
2 years	Mean	1.8	0.8	.001
	95% CI	1.4-2.3	0.4-1.2	
5 years	Mean	1.4	1.5	.85
	95% CI	1.0-1.8	1.1-1.8	
7 years	Mean	1.2	1.5	.25
	95% CI	1.2-1.6	1.1-1.8	
10 years	Mean	1.6	1.2	.18
	95% CI	1.2-2.0	0.7-1.6	

The breakdown of male and female differences in instrumented laxity assessment is shown in Table 7.

Overall IKDC Grade

Figure 10 demonstrates the percentage of patients with each overall IKDC grade at 10 years. There was no significant change between 2 and 10 years in the overall IKDC grade in either the PT or the HT group ($P > .05$). There was no significant difference between the PT or HT groups at any time point. Figure 11 demonstrates the percentage of patients with grade A or B ratings in the IKDC subgroups at 10 years.

TABLE 7
The Results of Instrumented Laxity Testing in Men and
Women in the Hamstring and Patellar Tendon Groups

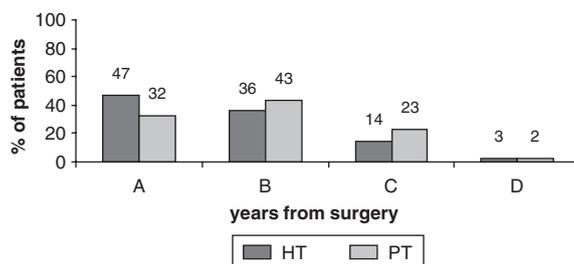|		Hamstring Tendon Group		Patellar Tendon Group	
		Women	Men	Women	Men
2 years	Mean	2.4	1.2	0.8	0.9
	% <3 mm	54%	84%	94%	83%
5 years	Mean	1.7	1.6	1.2	1.4
	% <3 mm	72%	72%	79%	84%
7 years	Mean	1.4	1.1	1.3	1.6
	% <3 mm	76%	84%	69%	79%
10 years	Mean	1.7	1.5	1.2	1.2
	% <3 mm	66%	76%	71%	81%

Figure 10. Overall IKDC grade at 10 years in the hamstring tendon (HT) and patellar tendon (PT) groups.

Single-Legged Hop Test

The single-legged hop test of knee function determines the percentage of the distance achieved by hopping on the involved limb compared with the contralateral normal limb. There was no significant difference between the HT and PT groups at any time and no significant change in either group over time. The percentage of patients able to hop >90% of the contralateral knee at each review point is shown in Figure 12.

Range of Motion

Extension deficit was determined as the loss of passive extension in the involved limb as compared with the uninjured contralateral limb. The percentages of the 2 groups with no extension deficit for each time point are detailed in Figure 13. There was no significant difference in the percentage of patients with an extension deficit between the HT and PT groups at 10-year review ($P = .35$).

Radiographic Assessment

Of the 149 patients reviewed subjectively at 10 years, radiographs were performed on 59 of 75 PT and 69 of 74 HT
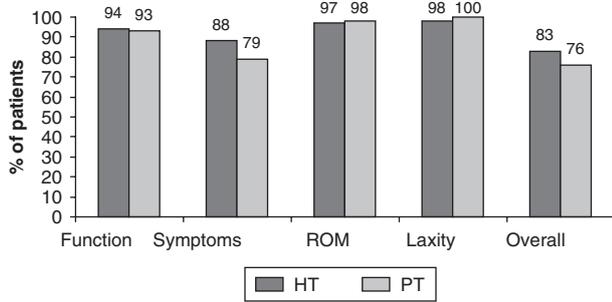
Figure 11. Percentage of patients in the hamstring tendon (HT) and patellar tendon (PT) groups with 10-year IKDC subgroups and overall IKDC Grade A or B.
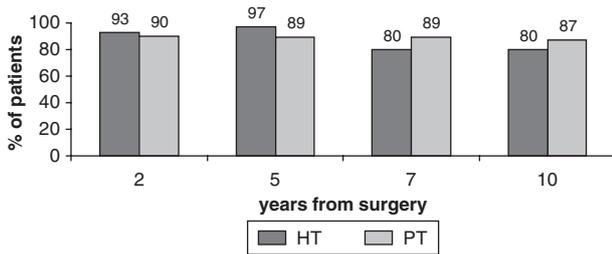

Figure 12. Percentage of patients from hamstring tendon (HT) and patellar tendon (PT) groups able to hop >90% of contralateral limb at 10 years.
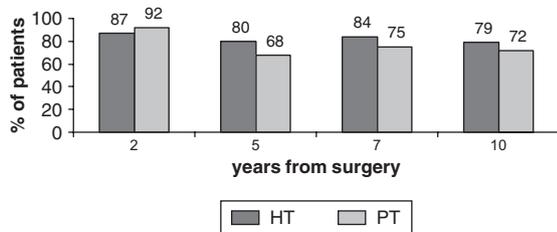

Figure 13. Percentage of patients from hamstring tendon (HT) and patellar tendon (PT) groups with no extension deficit at each review.

patients. Of the 21 patients without radiographic follow-up, 3 were pregnant and the remainder were reviewed at peripheral clinics without access to radiographic facilities. The medial, lateral, and patellofemoral compartments were scrutinized for evidence of joint-space narrowing at 2, 5, 7, and 10 years. 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 up to 50%; and D, >50% joint-space narrowing). The results are shown in Table 8.

The PT group displayed a significantly higher incidence of radiographic osteoarthritis at 5 (P = .02), 7 (P = .005), and 10 years after surgery (P = .04). Regression analysis revealed that the overall radiographic grade was not associated with

increased laxity on instrumented testing at 2 years, or loss of extension at 1 or 10 years. Poorer radiographic findings were significantly associated with the PT graft (p=0.05), and performance of the single-legged hop test at 1 year (P = .001).

"Ideal" Outcome

We defined ideal outcome at 10 years after surgery as patients who received an overall IKDC grade of A or B and a radiographic grade of A. In the PT group, 47% of patients reviewed met this criteria, compared with 69% of the HT group (P = .03). On regression analysis, the ideal outcome was associated with the HT graft (P = .01), 2-year instrumented laxity testing of <3 mm (P = .005), and no subsequent surgery to the index knee (P = .02). Ideal outcome was not significantly associated with age (P = .63), sex (P = .89), or 1-year hop test (P = .17).

DISCUSSION

The current study shows that at 10-year follow-up, both HT and PT graft reconstructions produce excellent subjective results, stability, and range of motion. With both grafts, the majority of patients report normal or near normal knee function. There was a significantly higher incidence of radiographic osteoarthritic change in knees reconstructed with PT autografts compared with HT grafts, although the difference was composed largely of knees with mild radiographic changes. Kneeling pain was statistically increased in PT graft reconstructed knees, and there was a trend toward a lower overall IKDC score in knees reconstructed with PT grafts compared with HT grafts.

We have previously reported the 7-year outcomes from this patient group.[29] The present study adds the perspective of longer follow-up and, with that, more accurate assessment of long-term outcomes. We have continued to assess risk factors for osteoarthritis and graft failure, and regression analysis was used to determine which, if any, measurable factors in our study correlated with the best outcomes. In the current study, we have subjective follow-up data on 95% of knees with intact HT grafts and 91% of knees with PT grafts, and objective follow-up data on 82% of HT and 82% of PT-reconstructed knees.

This controlled, prospective, cohort study used inclusion/exclusion criteria that allowed for control of variables that have made similar comparisons difficult to interpret.[10,12,19] In the current study, one surgeon performed all of the operations in succession for each cohort. Identical fixation methods (aperture screw fixation) were used for both graft types. Only knees that had minimal if any associated chondral or meniscal injuries were included. In addition, all knees with abnormal radiographs, a history of meniscectomy, contralateral knee abnormality, or a compensable injury were excluded. While the knees studied are considered ideal for long-term results, this allowed us to isolate any effects directly related to the graft choice. Since we have previously reported on these patient cohorts with shorter follow-up, the benefits and limitations of this study design have been previously described.[28,29]

TABLE 8
IKDC Radiologic Grade at 2, 5, 7, and 10 Years From Surgery in Patellar and Hamstring Tendon Groups

		2 Yrs		5 Yrs		7 Yrs		10 Yrs	
Patellar	N	68		61		44		59	
Tendon	Grade A	68	96%	45	74%	29	66%	36	61%
Group	Grade B	4	4%	16	26%	14	32%	21	36%
	Grade C					1	2%	2	3%
Hamstring	N	69		48		46		69	
Tendon	Grade A	68	99%	44	92%	42	91%	56	81%
Group	Grade B	1	1%	4	8%	3	7%	12	17%
	Grade C					1	2%	1	1%
	P value	.19		.02		.005		.04	

There was no statistical difference in the 10-year survivorship between HT and PT grafts (86% vs. 92%). However, there was an association between graft failure and 2-year side-to-side instrumented laxity >2 mm (*P* < .0001). This finding is consistent with literature describing increased forces on ACL grafts with increased laxity.[4] At 2 years, there was a significantly higher number of HT knees with KT-1000 arthrometer scores >2 mm, compared with PT knees. By 5 years, KT-1000 arthrometer scores between the 2 cohorts were equal. One possible explanation may have been that excessively lax HT grafts failed earlier, leaving knees with more stable grafts with better long-term survival in the study. Unfortunately, the study construct did not have adequate power to detect whether the early HT failures significantly affected overall mean laxity.

There was a statistically higher incidence of contralateral ACL injury in those patients receiving PT grafts (10% vs. 22%, *P* = .02). The reasons for the increase in contralateral ACL ruptures in PT-reconstructed knees are not obvious from our data, as there were no differences in activity or knee function between the 2 groups. The 10-year ACL reinjury rate, including graft ruptures and contralateral ACL injuries, was 22% for HT graft reconstructed knees and 30% for PT-reconstructed knees.

There was a significant increase in the donor-site symptoms and kneeling pain in knees reconstructed with PT grafts compared with HT grafts. At 10 years, 27% of HT patients and 41% of PT patients (*P* < .01) reported pain with kneeling in the operative knee. Kartus et al[22] reported a much higher incidence of anterior knee discomfort with PT reconstructions, but they used a specific "knee-walking" test to judge discomfort. Donor-site morbidity and kneeling pain are frequently reported as having a higher incidence in PT reconstructions compared with HT reconstructions,[9,11,32] and these differences have been theorized to be due to injury to the infrapatellar branch(es) of the saphenous nerve. The smaller, more medial incision used for hamstring tendon harvests is less likely to damage the infrapatellar branch, and this may be responsible for the decrease in anterior knee discomfort with HT ACL reconstructions.[21]

There was a significantly higher incidence of arthritic changes on radiographs in PT compared with HT-reconstructed knees, a finding that has been consistent with earlier studies in this patient cohort.[28,29] Arthritic changes occur predominantly in the medial compartment. One possible explanation for the increase in medial compartment osteoarthritis in ipsilateral PT reconstructions is that altered knee kinematics in gait result in decreased external knee flexion moment and increased loading of the medial compartment.[39] In our study, the only physical examination finding associated with subsequent osteoarthritis was the single-legged hop test at 1 year (*P* = .001), a measure of short-term external knee flexion moment. Further studies evaluating long-term gait alterations are necessary to determine whether graft source plays a significant functional role in long-term knee function.

Not surprisingly, there is a trend toward increasing osteoarthritic changes in both the PT and HT cohorts between 2 and 10 years, with the percentage of patients with IKDC grade A radiographs decreasing by 19% in the HT group and 34% in the PT group. This rate and degree of arthritic change after ACL reconstruction compares favorably with studies treating ACL-deficient knees nonoperatively, or including knees with injured menisci. Daniel et al[7] reported 79% of knees having osteophytes at a mean of 64 months after ACL injury, and degenerative changes were more frequent in ACL-reconstructed knees. Other studies have reported radiographic degenerative changes as high as 44% to 59% at 9 to 16 years after injury in young active patients.[25,36] Alternatively, this rate of degenerative change is consistent with studies including ACL-reconstructed knees with intact menisci. Shelbourne and Gray[33] reported 97% normal or near-normal radiographs in ACL-reconstructed patients 5 to 15 years after reconstruction, provided both menisci were intact and articular surfaces were normal at the time of surgery. Other studies have supported low rates of radiographic osteoarthritis 7 to 10 years after ACL reconstruction.[14,20]

In terms of clinical signs of osteoarthritis, significantly more PT than HT patients reported pain with strenuous activities (*P* = .05). However, there were no differences between the 2 cohorts in extension deficit, swelling with activity, or activity levels. In both cohorts, 97% of patients reported overall normal or near-normal subjective knee function at 10 years. Furthermore, while only 57% of the HT-reconstructed group and 45% of the PT-reconstructed group participated in level-1 or -2 sports 10 years after

ACL injury, only a small minority of patients in each group were restricted by the function of the operative knee. The subjective results in both groups suggest that the arthritis detected on radiographs in both groups is largely subclinical at 10-year follow-up.

We arbitrarily chose that an "ideal" outcome at 10 years after an ACL reconstruction would be a knee with no evidence of radiographic arthritis and an overall IKDC grade of A or B. Our rationale for choosing these criteria were that many people with "normal," uninjured knees report IKDC grades of A or B, and otherwise healthy knees in young adults should have a very low incidence of radiographic osteoarthritis.[27] In this study, factors associated with an ideal outcome were knees that received HT graft versus PT graft (*P* = .013), with 2-year KT-1000 arthrometer scores <2 mm compared with the contralateral side (*P* = .005), and not requiring any subsequent surgery (*P* = .016).

We have previously reported on the gender differences in laxity and graft failures at a minimum of 7 year's follow-up.[31] Our current study echoes these findings. In this cohort of patients, there were no gender differences in outcomes in terms of failures, radiographic osteoarthritis, or overall IKDC scores at 10-year follow-up.

The results of this study reflect the senior author's earliest experience with HT ACL reconstruction. Since that time, there have been several improvements in the technique used. At the time, standard sized 7 × 25-mm RCI interference screws were used for graft fixation. The strength of several types of fixation have recently been measured in fresh-frozen cadaveric bone, and the strength of this type of interference screw was determined to be less than that of other types of fixation for soft tissue grafts.[23,24] We contend that the quality of cancellous bone in our younger, more active patient cohort is significantly better than that in fresh-frozen cadaveric bone, and this difference accounts for much greater fixation strength.[6] However, as graft failures were correlated with 2-year KT-1000 arthrometer scores > 3 mm, it is possible that some graft slippage occurred before failure. We have since addressed this by oversizing the tibial screw in female patients and those male patients who are judged at the time of surgery to have soft tibial metaphyseal bone.

Criticisms of this study were that the patients were not randomized, and that blinding patients and examiners was not possible. The PT cohort of patients were collected after the surgeon had significant experience with this procedure, while the HT cohort was collected at the beginning of the surgeon's experience with this technique. Significant advances, particularly with respect to fixation of the graft in the tibial tunnel, have resulted in decreased laxity in HT grafts compared with the outcomes of this study.[15] We anticipate lower failure rates and more frequent ideal outcomes in patients with HT ACL reconstructions with more contemporary fixation. Even longer term follow-up will be needed to determine the eventual outcomes of ACL reconstruction in otherwise normal knees.

SUMMARY

Both HT and PT autograft ACL reconstructions have excellent 10-year results in knees without significant chondral or meniscal injury. The incidence of mild radiographic osteoarthritis in PT-reconstructed knees is greater at 10 years and appears to be gradually increasing in knees with both graft types. Kneeling pain is greater in PT-reconstructed knees. Ten-year survivorship and subjective function is no different between graft types. Factors associated with the best outcomes in this study were the use of HT grafts, 2-year KT-1000 arthrometer scores <3 mm, and no need for subsequent surgery on the operative knee.

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