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A Randomized Comparison of Patellar Tendon and Hamstring Tendon Anterior Cruciate Ligament Reconstruction*

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Background: Patellar and hamstring tendon autografts are the most frequently used graft types for anterior cruciate ligament reconstruction, but few direct comparisons of outcomes have been published.
Hypothesis: There is no difference in outcome between the two types of reconstruction.
Study Design: Prospective randomized clinical trial.
Methods: After isolated anterior cruciate ligament rupture, 65 patients were randomized to receive either a patellar tendon or a four-strand hamstring tendon graft reconstruction, and results were reviewed at 4, 8, 12, 24, and 36 months.
Results: Pain on kneeling was more common and extension deficits were greater in the patellar tendon group. There were greater quadriceps peak torque deficits in the patellar tendon group at 4 and 8 months but not thereafter. In the hamstring tendon group, active flexion deficits were greater from 8 to 24 months, and KT-1000 arthrometer side-to-side differences in anterior knee laxity at 134 N were greater. Cincinnati knee scores, International Knee Documentation Committee ratings, and rates of return to preinjury activity levels were not significantly different between the two groups.
Conclusions: Both grafts resulted in satisfactory functional outcomes but with increased morbidity in the patellar tendon group and increased knee laxity and radiographic femoral tunnel widening in the hamstring tendon group.

Central-third bone-patellar tendon-bone and combined semitendinosus and gracilis tendons are the most frequently used graft types for ACL reconstruction (J. Campbell, unpublished data, 2000). In recent years, use of hamstring tendon grafts appears to have increased,[6] perhaps related to an increased range of fixation options as well as to a perception that hamstring tendon grafts are associated with lower postoperative morbidity compared with patellar tendon grafts (Refs. 11, 16, 25, 26; P. Firer, unpublished data, 2000).

Considerable debate continues as to whether one or the other graft is preferable. Satisfactory results of function and stability have been reported for both graft types. However, in 1996, when the current study was commenced, only two published reports of direct comparisons of the two graft types were available.[1,18] The results of these studies, together with those of a subsequent randomized comparison[24] and a prospective nonrandomized comparison,[11] have been summarized in a metaanalysis.[30] The conclusion from this analysis was that stability and return to preinjury activity level were greater among patients who had undergone a patellar tendon ACL reconstruction. Recently, the results of three further randomized clinical trials have been published.[2,4,12] These studies all found no difference between the two graft types in terms of functional outcome but did report increased morbidity associated with patellar tendon grafts. We report the results of a further randomized comparison of the two graft types that complements these more recent publications.

PATIENTS AND METHODS

From May 1996 to February 1998, 65 patients who were to undergo primary ACL reconstruction were recruited from a single orthopaedic surgeon's private practice. For initial inclusion in the study, a patient had to meet the following

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criteria: age from 18 to 40 years, ACL rupture that occurred more than 3 weeks but less than 12 months previously, no previous surgery performed on the affected knee, no previous cruciate ligament damage sustained in either the affected or the contralateral knee, no concurrent or residual collateral ligament injury of greater than grade 2 severity, and no evidence of osteoarthritis on current plain radiographs. In addition, no patients could have chondral lesions of a severity greater than Noyes grade IIA or Noyes grade IIA lesions greater than 1 cm in diameter[23] seen during the arthroscopic examination performed at the commencement of the ACL reconstructive surgery. Finally, if a meniscal injury was found, its treatment had to be such that it would not alter the patient's rehabilitation. Informed consent was obtained from all patients participating in the study, and they all indicated their willingness to return for follow-up for 3 years.

Fifty-six (86%) of the patients in the study were injured while participating in sports, most commonly Australian Rules football and basketball. Five patients were injured at work and four were injured accidentally.

After the arthroscopic examination performed at the commencement of the ACL surgery confirmed their suitability for the study, patients were randomized by means of a computer-generated list of random numbers to receive either a central-third bone-patellar tendon-bone autograft or a doubled semitendinosus and gracilis tendon autograft ACL reconstruction. This randomization procedure led to a patellar tendon graft for 31 patients and a hamstring tendon graft for 34. Both groups were similar in terms of age, sex distribution, time from injury to surgery, preinjury Cincinnati sports activity level,[20] and occupational rating,[22] as well as in terms of associated chondral and meniscal pathologic conditions and treatment (Table 1). Five patients in the study were receiving workers' compensation, one in the hamstring tendon group and four in the patellar tendon group; however, two of the latter were lost to follow-up. The operating surgeon performed a total of 163 primary ACL reconstructions during the 21-month period in which patients were entered into the study.

Surgical Technique

All patients underwent an arthroscopically assisted single-incision ACL reconstruction performed by the same surgeon. The patellar tendon grafts were harvested via an anterior longitudinal incision lying over the junction of the middle and lateral thirds of the patellar tendon, and the hamstring tendon grafts were harvested via an oblique anteromedial incision lying over the distal attachment of the hamstring tendons. The femoral tunnel was drilled through the tibial tunnel.

Proximal fixation was by means of an EndoButton (Smith & Nephew Endoscopy, Mansfield, Massachusetts) attached to the graft with doubled 3-mm polyester tape. In the hamstring tendon group, the distal 18 cm of each tendon was doubled, and the ends of each tendon were sutured together in a whipstitch fashion over a distance of 3 cm with No. 5 Ethibond suture (Ethicon, Inc., Somerville, New Jersey). No additional braiding of the tendons was used. The distal bone block of the patellar tendon graft was controlled with No. 5 Ticron suture (Sherwood

TABLE 1
Characteristics of Subjects at Time of ACL Reconstruction

Characteristic[a]	Hamstring tendon graft group		Patellar tendon graft group	
	Mean	(SD)	Mean	(SD)
Age (years)	26.3	(6)	25.8	(6)
Male (*N*)	24		23	
Female (*N*)	10		8	
Interval from injury to surgery (weeks)	14.2	(15)	19.8	(23)
Preinjury sports activity score (0–100)[b]	87.3	(13)	91.6	(8)
Preinjury occupational rating (0–60)[c]	22.1	(11)	23.6	(13)
Chondral lesions (*N* of patients)				
Patella	3		3	
Trochlear groove	0		0	
Medial femoral condyle	2		5	
Medial tibial plateau	0		0	
Lateral femoral condyle	0		0	
Lateral tibial plateau	0		0	
Medial meniscal treatment (*N* of patients)				
Stable tear, no treatment	4		5	
Partial meniscectomy	4		6	
Repair	4		5	
Lateral meniscal treatment (*N* of patients)				
Stable tear, no treatment	0		2	
Partial meniscectomy	6		6	
Repair	0		1	

[a] No significant differences were found between groups for any of the variables.
[b] Noyes et al.[20]
[c] Noyes et al.[22]

Medical, St. Louis, Missouri). The graft constructs were statically pretensioned at 89 N (20 pounds) for at least 5 minutes before insertion. A mark was made on the patellar tendon grafts 35 mm proximal to the upper end of the distal bone block, and the femoral tunnel was drilled and the graft construct was adjusted to align this mark with the aperture of the femoral tunnel. For the hamstring tendon grafts, a mark was made 30 mm distal to the proximal end of the graft, and this mark was aligned with the articular margin of the femoral tunnel. Thus, there was a constant 30 mm of hamstring tendon graft in the femoral tunnel but a variable length of patellar tendon graft. Tunnels were drilled to the same diameter as the respective end of the graft.

The grafts were inserted through the tibial tunnel. After proximal fixation had been secured, manual tension was applied to the distal end of the graft, and the knee was taken through a full range of movement to ensure that the graft did not impinge in the intercondylar notch in terminal extension as well as to further pretension the construct. The distal end of both graft types was fixed with the knee in 70° of flexion with firm manual tension applied to the graft. On the tibial side, the patellar tendon grafts were fixed with a cannulated metallic interference Silk screw (Smith & Nephew Endoscopy) inserted over a guide wire to prevent divergence. The hamstring tendon grafts were fixed by tying the ends of the whipstitched suture to an Acufex fixation post (Smith & Nephew Endoscopy). In the patellar tendon group, the patellar tendon defect was loosely closed with interrupted absorbable sutures. The donor sites on the patella and tibial tubercle were not formally bone grafted, although bone fragments from trimming of the graft were loosley packed into the tibial tubercle defect. In both groups, low suction drains were inserted into the joint and into the subcutaneous layer. The patients were discharged from the hospital within 48 hours of surgery.

Postoperative Management

Postoperatively, all patients followed a rehabilitation protocol broadly similar to the "accelerated" rehabilitation program of Shelbourne and Nitz.[27] The inpatient physiotherapy was supervised by the same physiotherapy practice for all patients. Rehabilitation after discharge was supervised by a physiotherapist selected by the patient and approved by the treating surgeon. All treating physiotherapists were supplied with a copy of the rehabilitation protocol guidelines and were familiar with their implementation. The protocol emphasized restoration of full extension and of quadriceps muscle function as soon as possible and weightbearing on an as-tolerated basis from the 1st postoperative day. No braces or splints were used. Progression through the various stages of rehabilitation was on an as-tolerated basis guided by the presence and degree of pain and swelling. Apart from isometric exercises with the knee in full extension, quadriceps muscle-strengthening exercises were restricted to closed kinetic chain exercises during the first 6 months. Emphasis was placed on restoration of vastus medialis muscle function, with EMG biofeedback and neuromuscular electrical stimulation for patients experiencing difficulties in activating the muscle. Patients were allowed to ride an exercise bicycle from 3 weeks postoperatively and were allowed to commence gymnasium exercises from 8 weeks. Recommencement of sporting activities was more conservative than in the program described by Shelbourne and Nitz.[27] Running was allowed from 10 weeks and sport-specific drills were begun at 4 months. Return to full training was allowed from 6 months and return to competitive sport from 9 months.

Evaluation

A single independent research associate reviewed patients at 4 months, 8 months, 1 year, 2 years, and 3 years postoperatively. At each review, patients were asked whether they had experienced anterior knee pain during the previous week. If they had, they were asked to rate the pain by using a 10-cm visual analog scale anchored by the descriptors "no pain" and "worst pain ever experienced." The presence and severity of pain on kneeling were recorded in a similar fashion at 4 months, 2 years, and 3 years. Visual analog scale data were scored by superimposing a 20-point grid over the line. Values were assigned in 0.5-cm increments ranging from 0 (no pain) to 10 (worst pain ever experienced).

The presence of a knee joint effusion was assessed by using the bulge test and categorized by palpation as none, small, moderate, or large. Passive and active knee flexion of both knees was recorded with the patient in the lateral decubitus position with use of a long-armed (50 cm) goniometer. For comparative purposes, the deficit (in degrees) of the operated limb was used for both active and passive flexion. Extension deficits were recorded by using the method described by Sachs et al.[26] In this technique, the patient is positioned prone, and the difference in heel height is converted to an extension deficit in degrees by using a formula based on the difference in heel height and the patient's height. This method records the deficit relative to the normal hyperextension of the contralateral limb rather than relative to an arbitrary 0°. Measurements of side-to-side differences in anterior tibial displacement on the KT-1000 arthrometer (MEDmetric Corp., San Diego, California) were recorded at 67 N (15 pound) and 134 N (30 pound). International Knee Documentation Committee (IKDC) scores,[14] Cincinnati scores,[21] and Cincinnati sports activity levels[20] were also recorded. In addition to this outcome measurement protocol, further data were obtained from the treating surgeon's records regarding the presence and grade of pivot shift and the type of end point with Lachman testing.

At 4, 8, and 12 months, a Cybex II dynamometer (Lumex, Ronkonkoma, New York) assessment of peak isokinetic torque of the quadriceps and hamstring muscle groups was performed. Measurements were made at slow (60 deg/sec) and fast (240 deg/sec) speeds. Deficits were recorded as percentage deficits relative to the contralateral limb.

Radiographs of the knee, both a flexion weightbearing

AP view and a lateral view in full extension, were also obtained at 4 months, 1 year, 2 years, and 3 years. The position of the tibial tunnel was assessed from the lateral radiograph by relating the position of the anterior margin of the tunnel to a distal extension of Blumensaat's line, as described by Muneta et al.[19] This method focuses on the issue of impingement rather than describing the position of the tibial tunnel relative to tibial anatomic landmarks. Femoral tunnel widening was recorded on both the AP and lateral radiographs. Raw measurements were corrected for magnification and then related to the diameter of the drill bit used to create the femoral tunnel. Each radiograph was examined for evidence of osteoarthritis (reduced joint space, subchondral sclerosis, and osteophyte formation).

Statistical Analysis

Data were analyzed by using the Student's t-test or the Mann-Whitney U-test to compare the two groups at each follow-up. In analyzing anterior knee pain and kneeling pain severity, we used data only from those patients who reported pain. For example, if a patient reported having no anterior knee pain, he or she was treated as a missing data point as opposed to zero pain on the visual analog scale. Contingency tables were used to calculate significant differences in the number of patients in each category based on IKDC score, presence of anterior knee pain, presence of pain on kneeling, effusion, KT-1000 arthrometer measurements, and Cincinnati sports activity levels. Significance was set at $P < 0.05$.

RESULTS

Fifty-seven of the 65 patients (88%) were available for follow-up examination at 3 years. Of the five patients in the patellar tendon group who were not available for follow-up, one sustained a graft rupture at 6 months in the setting of significant trauma and we lost contact with four who could not be traced. Two of these four had a good result at 1 year with Cincinnati scores of 100 and an IKDC rating of normal. Of the remaining two, one had a Cincinnati score of 86 and an IKDC rating of abnormal at 2 years, and the other patient was last reviewed at 8 months, at which time he had an IKDC rating of nearly normal. Two patients in the hamstring tendon group could not be contacted. One of these patients had a Cincinnati score of 92 and an IKDC rating of nearly normal at 1 year. The other patient was last reviewed at 8 months, at which time he had an IKDC rating of severely abnormal. A third patient in the hamstring tendon group declined to be followed up beyond 2 years, but at that time she had a Cincinnati score of 100 and an IKDC rating of nearly normal.

Pain

Data for the recorded pain variables is presented in Table 2. Anterior knee pain was significantly more common in the patellar tendon group at 8 months and again at 2 years, but not at other times. There was no difference in severity of anterior knee pain between the two groups. The incidence but not the severity of pain on kneeling was significantly greater in the patellar tendon group at all follow-up times at which this variable was recorded.

Range of Motion and Effusion

Table 3 shows the data for range of motion and effusion. Extension deficits were significantly greater in the patellar tendon group at 8 months, and this difference persisted through subsequent follow-up. There was no correlation between extension deficit and anterior knee pain. Active flexion deficits were significantly greater in the hamstring tendon group at 8 months, 1 year, and 2 years, but not at 3 years. Passive flexion deficits were not significantly different between the groups. There was a significantly greater incidence of effusion in the patellar tendon group at 8 months but not at other follow-up times.

Anterior Knee Laxity

Table 4 shows the KT-1000 arthrometer side-to-side differences in anterior tibial displacement. At 67 N, side-to-side differences were significantly greater in the hamstring tendon group at all follow-up times through 2 years. The difference persisted at 3 years but did not reach

TABLE 2
Subjective Pain Measurements at Follow-up[a]

Pain measurement	4 months		8 months		1 year		2 years		3 years	
	HS ($N = 34$)	PT ($N = 31$)	HS ($N = 34$)	PT ($N = 30$)	HS ($N = 33$)	PT ($N = 29$)	HS ($N = 29$)	PT ($N = 23$)	HS ($N = 31$)	PT ($N = 26$)
Anterior knee pain										
Incidence (%)	70	81	35	73[c]	33	55	17	52[b]	33	43
Severity (Mean [SD])	2.8 (2.2)	3.5 (2.0)	3.1 (2.2)	3.3 (2.3)	2.6 (2.4)	2.3 (1.4)	3.6 (2.1)	2.4 (2.1)	3.2 (1.9)	3.2 (1.5)
Pain on kneeling										
Incidence (%)	62	90[b]					35	65[c]	26	67[c]
Severity (Mean [SD])	3.3 (2.2)	4.5 (2.1)					2.9 (2.1)	4.0 (2.6)	1.6 (1.2)	3.5 (2.6)

[a] Severity was assessed as 0 (no pain) to 10 (severe pain) on a visual analog scale. HS, hamstring tendon group; PT, patellar tendon group.
[b] $P < 0.05$ compared with the hamstring tendon group.
[c] $P < 0.01$ compared with the hamstring tendon group.

TABLE 3
Range of Motion and Effusion at Follow-up[a]

Variable	4 months		8 months		1 year		2 years		3 years	
	HS (*N* = 34)	PT (*N* = 31)	HS (*N* = 34)	PT (*N* = 30)	HS (*N* = 33)	PT (*N* = 29)	HS (*N* = 29)	PT (*N* = 23)	HS (*N* = 27)	PT (*N* = 21)
Extension deficit										
Mean (SD)	1.8 (1.7)	2.7 (3.4)	1.4 (1.6)	2.8 (3.4)[b]	1.4 (2.0)	2.8 (3.1)[b]	1.4 (1.9)	3.0 (2.7)[b]	1.2 (1.5)	2.7 (2.3)[b]
Range	0–6	0–14	0–5	0–12	0–9	0–10	0–7	0–9	0–4	0–8
Active flexion deficit										
Mean (SD)	10.2 (7.3)	7.5 (7.0)	6.3 (4.8)	4.8 (7.5)[b]	5.1 (4.0)	3.1 (4.4)[b]	6.7 (5.0)	1.5 (2.3)[c]	3.3 (3.9)	2.6 (3.0)
Range	0–35	0–20	0–20	0–30	0–15	0–20	0–15	0–5	0–10	0–10
Passive flexion deficit										
Mean (SD)	13.5 (8.7)	15.6 (9.9)	7.8 (6.8)	9.8 (9.9)	6.6 (5.8)	7.0 (7.6)	5.4 (5.0)	7.0 (7.3)	2.2 (3.5)	4.0 (5.4)
Range	0–40	0–40	0–30	0–45	0–25	0–35	0–15	0–25	0–10	0–20
Effusion (% of patients)										
None	62	68	97	77[b,d]	94	86	97	87	96	100
Mild	35	29	3	20	3	10	3	13	4	0
Moderate	3	3	0	3	3	4	0	0	0	0
Severe	0	0	0	0	0	0	0	0	0	0

[a] HS, hamstring tendon group; PT, patellar tendon group.
[b] $P < 0.05$ compared with hamstring tendon group.
[c] $P < 0.01$ compared with hamstring tendon group.
[d] Fisher's exact test comparing no effusion and effusion (mild, moderate, and large categories combined).

statistical significance ($P = 0.07$). Side-to-side differences at 134 N were significantly greater in the hamstring tendon group at all follow-up times from 8 months onward. At 3 years, 15% (4 of 27) of the hamstring tendon group patients had a side-to-side difference of more than 3 mm at 134 N compared with 5% (1 of 21) of patellar tendon group patients. Excluding the patient who had a graft rupture, at final follow-up, five patients in the hamstring tendon group had a trace positive pivot shift and no patients in the patellar tendon group had a positive pivot shift test. One patient in the hamstring tendon group had an equivocal end point on Lachman testing, and all other patients in both groups had a firm end point. Although extension deficits were greater in the patellar tendon group, there was no correlation between extension deficit and side-to-side difference in anterior knee laxity in either group.

Strength

Peak isokinetic torque deficit results are shown in Table 5. There were significantly greater quadriceps muscle peak torque deficits in the patellar tendon group at 240 deg/sec at 4 months and 8 months and at 60 deg/sec at 8 months. Although there was a trend toward increased quadriceps muscle peak torque deficits in the patellar tendon group at 12 months, the differences were not significant. Ham-

TABLE 4
Relative Frequency Distribution and Mean KT-1000 Side-to-Side Differences in Anterior Knee Laxity at Follow-up[a]

KT-1000 arthrometer result	4 months		8 months		1 year		2 years		3 years	
	HS (*N* = 34)	PT (*N* = 31)	HS (*N* = 34)	PT (*N* = 30)	HS (*N* = 33)	PT (*N* = 29)	HS (*N* = 29)	PT (*N* = 23)	HS (*N* = 27)	PT (*N* = 21)
67 N (% of patients)										
0–2 mm	94	100	97	100	94	96	97	100	96	100
3–5 mm	6	0	9	0	6	4	3	0	4	0
6–10 mm	0	0	0	0	0	0	0	0	0	0
Mean (SD)	1.2 (1.1)	0.5 (1.1)[b]	1.0 (0.9)	0.4 (0.7)[c]	1.4 (0.9)	0.6 (0.7)[c]	1.4 (0.9)	0.7 (0.8)[c]	1.1 (1.2)	0.5 (1.0)
134 N (% of patients)										
0–2 mm	82	90	74	100[c,d]	79	89	86	96	85	95
3–5 mm	15	10	26	0	21	11	14	4	15	5
6–10 mm	3	0	0	0	0	0	0	0	0	0
Mean (SD)	1.7 (1.1)	1.0 (1.7)	1.7 (1.3)	0.8 (0.9)[c]	1.9 (1.1)	1.2 (0.9)[b]	1.7 (1.0)	1.1 (1.1)[b]	1.6 (1.3)	0.5 (1.5)[b]

[a] HS, hamstring tendon group; PT, patellar tendon group.
[b] $P < 0.05$ compared with hamstring tendon group.
[c] $P < 0.01$ compared with hamstring tendon group.
[d] Fisher's exact test comparing 0–2 mm (normal) with 3–5 mm (nearly normal).

TABLE 5
Mean (SD) Peak Isokinetic Torque Deficits (% of normal side) at Follow-up[a]

Strength deficit	4 months		8 months		1 year	
	HS (N = 34)	PT (N = 28)	HS (N = 33)	PT (N = 24)	HS (N = 18)	PT (N = 21)
Quadriceps muscles						
60 deg/sec	27.2 (20.1)	36.3 (16.4)	12.1 (13.7)	25.5 (11.3)[c]	11.1 (16.5)	22.7 (26.9)
240 deg/sec	21.6 (23.3)	33.1 (16.8)[b]	9.3 (28.2)	25.0 (21.3)[b]	9.0 (20.8)	14.8 (25.1)
Hamstring muscles						
60 deg/sec	8.8 (37.7)	9.7 (20.7)	8.8 (17.6)	3.4 (13.7)	8.7 (17.1)	1.7 (28.4)[b]
240 deg/sec	20.9 (36.9)	15.3 (27.8)	14.6 (29.4)	2.3 (11.6)	−5.5 (31.9)	0.6 (36.5)

[a] HS, hamstring tendon group; PT, patellar tendon group.
[b] $P < 0.05$ compared with the hamstring tendon group.
[c] $P < 0.01$ compared with the hamstring tendon group.

string muscle peak torque deficits at 60 deg/sec were greater in the hamstring tendon group at 1 year.

Radiographs

There was no radiographic evidence of osteoarthritis at any follow-up. On the lateral radiograph with the knee in full extension, the anterior margin of the tibial tunnel was in line with or posterior to Blumensaat's line for all patients except for one patient in the patellar tendon group. The femoral tunnel widening data have previously been reported.[29] The femoral tunnel appeared to be obliterated from 4 months onward on the radiographs of 32% (9 of 28) of the patellar tendon group patients. Among the remaining patients, there was a significantly greater increase in femoral tunnel width in the hamstring tendon group at each follow-up, but there was no significant change with time. Ninety-four percent (31 of 33) of hamstring tendon group patients had greater than 25% femoral tunnel widening, compared with only 11% (3 of 28) of the patellar tendon group patients.

Cincinnati Knee and IKDC Scores and Sports Activity Levels

There were no differences between the two groups in terms of Cincinnati scores or IKDC ratings (Table 6). Analysis of the individual IKDC categories at 3 years did not identify any difference between the two graft types (Table 7). Sports activity levels (which are based on frequency of participation) were significantly greater in the patellar tendon group at 4 months but not at other times, although at 3 years only 68% (21 of 31) of hamstring tendon group patients reported level I or II activity levels compared with 88% (23 of 26) of patellar tendon group patients ($P = 0.1$) (Table 6). At 3 years, 54% of patients (14 of 26) in the patellar tendon group returned to their pre-

TABLE 6
Mean Cincinnati Knee Scores and Relative Frequency Distributions for Sports Activity Level and Overall IKDC Rating at Follow-up[a]

Scoring system	4 months		8 months		1 year		2 years		3 years	
	HS (N = 34)	PT (N = 31)	HS (N = 34)	PT (N = 30)	HS (N = 33)	PT (N = 29)	HS (N = 29)	PT (N = 23)	HS (N = 31)	PT (N = 26)
Cincinnati knee score										
Mean (SD)					87.7 (12.0)	84.4 (12.3)	91.9 (9.3)	90.9 (10.3)	93.7 (9.0)	92.7 (8.2)
Sports activity level (% of patients)										
I	24	42[b,c]	21	33	33	38	21	35	36	27
II	35	45	36	37	40	38	48	48	32	61
III	9	3	0	3	3	0	14	4	19	4
IV	32	10	43	27	24	24	17	13	13	8
IKDC score										
Median	75	80	75	80	80	85	80	85	80	85
Overall IKDC rating (% of patients)[d]										
A (normal)	0	0	3	0	3	14	28	26	37	33
B (nearly normal)	15	3	21	27	52	31	38	39	56	38
C (abnormal)	35	19	41	33	33	41	28	26	7	24
D (severely abnormal)	50	78	35	40	12	14	6	9	0	5

[a] HS, hamstring tendon group; PT, patellar tendon group.
[b] $P < 0.05$ compared with hamstring tendon group.
[c] Fisher's exact test comparing sports activity levels I and II with levels III and IV.
[d] At 3 years only 27 in the HS group and 21 in the PT group had IKDC ratings.

TABLE 7
Individual Category IKDC Results at 3 Years (Percentage of Patients with Each Rating)

Category	Hamstring tendon group	Patellar tendon group
Subjective assessment		
A	74	50
B	26	42
C	0	8
D	0	0
Symptoms		
A	58	73
B	26	11.5
C	6	4
D	10	11.5
Range of motion		
A	70	57
B	30	29
C	0	14
D	0	0
Ligament examination		
A	85	95
B	15	5
C	0	0
D	0	0

injury activity level, compared with 52% (16 of 31) of hamstring tendon group patients. However, at 3 years, 69% (18 of 26) of patellar tendon group patients and 55% (17 of 31) of hamstring tendon group patients returned to their preinjury sport. There was no difference in the sports activity level reported by patients who did and did not report anterior knee pain.

Complications

During the follow-up period, one patient in the patellar tendon group suffered a graft rupture at 6 months when he fell while skateboarding down a flight of stairs. A further six patients in the patellar tendon group required an additional operative procedure on their affected knee. One patient required debridement for a superficial wound infection. Two patients required arthroscopic debridement for notch impingement, and one had an arthroscopic partial medial meniscectomy. Two diagnostic arthroscopic examinations were performed: one for a persistent effusion that subsequently resolved and one for lateral knee pain that remained undiagnosed but eventually resolved. In the hamstring tendon group, four patients required further surgery on the affected knee: one removal of a prominent fixation post, one arthroscopic resection of a medial meniscal tear, one arthroscopic debridement of the intercondylar notch, and one manipulation performed for a lack of flexion with the patient under general anesthesia.

DISCUSSION

The findings of this study are generally consistent with those of similar trials that have been published recently.[2,4,11,12] We were unable to detect a significant difference between bone-patellar tendon-bone and combined semitendinosus and gracilis hamstring tendon grafts in terms of functional outcome at 3 years. The principal differences between the two graft types were in terms of morbidity. Patellar tendon grafts were associated with increased pain on kneeling and increased extension deficits compared with hamstring tendon grafts. The principal disadvantage of hamstring tendon grafts among patients in this study was increased anterior knee laxity, although it did not appear to be associated with any functional deficit. In a previous report on the same group of patients,[29] we documented an increased incidence and severity of radiographic widening of the femoral tunnel in association with hamstring tendon grafts. The clinical significance of this radiographic phenomenon remains unclear, but in our study it did not correlate with graft laxity or functional outcome.

Although difficult to complete, randomized clinical trials provide the best level of evidence regarding a particular surgical technique. The sample size of the current study was planned to be sufficient to identify differences between the two groups with a large effect size (0.8). Although a greater sample size would have allowed for identification of differences with smaller effect sizes, such differences may not, by the very nature of their small effect size, be clinically relevant. Given the difficulties of recruitment for a randomized trial and the logistics of follow-up, it may not be practicable to work with larger numbers of subjects.

To maximize the strength of our study we used strict inclusion criteria to reduce the number of potentially confounding variables. A single surgeon performed all procedures to reduce variability in surgical technique. Apart from graft harvest and tibial graft fixation, the surgical technique was identical in both groups. Ideally, the same tibial fixation would have been used for both graft types. However, at the time the study was commenced, interference screw fixation of hamstring tendon grafts was a relatively new concept and was not supported in the published literature.[28] With use of a tibial fixation post in the hamstring tendon group, suspensory fixation was used at both ends of the graft, as compared with only one end in the patellar tendon group. Whether the increased graft laxity seen in the hamstring tendon group was related to the fixation method or the intrinsic properties of the hamstring tendons is unclear. However, the values of side-to-side differences in anterior tibial displacement seen in the hamstring tendon group compare favorably with those reported with interference screw fixation of hamstring tendon grafts,[11] suggesting that fixation was not the sole cause of the increased laxity. Pretensioning of hamstring tendon grafts has also been suggested to reduce subsequent laxity.[9] We used static rather than dynamic pretensioning. Whether one or the other is preferable is not clear, but both could be expected to reduce the effects of creep of the graft and suture complex in a suspensory fixation construct.

The angle of knee flexion at the time of graft fixation has been shown to affect graft tension and anterior knee laxity.[3,10,13] Fixation with the knee in 30° of flexion results in decreased laxity compared with fixation in 0° of flexion[3,10] but has also been associated with an increased incidence of extension deficits.[3] Fleming et al.[13] used a goat model in which grafts were fixed in various combinations of flexion angles of 30°, 60°, and 90° and tensions of 30, 60, and 90 N. They demonstrated that a number of different combinations of flexion angle and tension at graft fixation could produce satisfactory patterns of graft behavior.

In the current study, grafts were fixed with the knee in 70° of flexion, in keeping with the operating surgeon's practice for hamstring tendon grafts based on his observation that this practice appeared to improve stability. Although a causal relationship between fixation angle and subsequent stability cannot be established by the results of this study, the low values of side-to-side differences in anterior tibial displacement seen in the patients of the hamstring tendon group compared with those reported in other studies are nonetheless encouraging.[1,4,11,12,18,24] The decision to fix the patellar tendon grafts with the knee at the same degree of flexion was made to eliminate a potential difference in surgical technique between the two groups. It is unclear whether this decision contributed to the increased incidence and degree of extension deficit in the patellar tendon group. Although Asahina et al.[3] reported an association between fixation at 30° of flexion and both an increased incidence of extension deficits and improved laxity measurements for hamstring tendon grafts, in the current study we found no correlation between extension deficit and anterior knee laxity. This finding suggests that, in those knees with extension deficits, the effect was not one of "capturing" by a graft that was too tight. Nor does poor tunnel placement appear to have been a factor, as analysis of the plain radiographs identified only one patient in the patellar tendon group in whom the anterior margin of the tibial tunnel lay slightly anterior to a distal extension of Blumensaat's line in a lateral view of the extended knee. Because the viscoelastic properties of the two graft types are not exactly the same, it may be appropriate to fix each graft type at different knee flexion angles and at different tensions. This issue was not addressed in the current study but is the subject of a subsequent investigation by the authors.

The incidence and severity of pain on kneeling was perhaps the most significant difference between the two groups. Only a few studies comparing hamstring and patellar tendon grafts have specifically looked at this variable.[4,11,12] Despite the difference in kneeling pain between the two groups, there was no significant difference at 3 years in terms of the more general variable of anterior knee pain, which highlights the need to be specific when analyzing pain variables. This finding was similar to that of Eriksson et al.,[12] who found no difference between patellar tendon and hamstring tendon grafts when a comprehensive patellofemoral score was used but did find a difference in the subscore for kneeling pain. The persistence of a high incidence of kneeling pain at 3 years in the patellar tendon group, albeit to a relatively mild degree, should be noted and may be an important factor in deciding which graft is most appropriate for a particular patient. For instance, patients who need to kneel as part of their work requirements would perhaps be better served by a hamstring tendon graft rather than a patellar tendon graft.

Although it has been suggested that grafting of the tibial tubercle and patellar bone defects may reduce the incidence of pain on kneeling after a bone-patellar tendon-bone graft ACL reconstruction, Boszotta and Prunner,[7] in a prospective study, found that there was no difference in the incidence of kneeling pain associated with grafting of bone defects. In a randomized comparison, Brandsson et al.[8] also did not demonstrate any benefit of bone grafting the patellar defect in terms of donor-site morbidity, although they did not specifically report the results for kneeling pain. Kohn and Sander-Beuermann[17] have also reported a 36% incidence of painful spurs at the inferior pole of the patella after grafting of the patellar defect. The origin of kneeling pain may in part relate to disruption of or damage to the infrapatellar branch of the saphenous nerve caused by the skin incision.[5,15] This cause might also explain the lesser but nonetheless definite incidence of pain on kneeling in the hamstring tendon group. However, this pain could also be attributed to prominence of the fixation post, as Corry et al.[11] found only a 6% incidence of kneeling pain in patients in whom the hamstring tendon graft had been fixed by means of interference screws at each end.

The rates of return to preinjury levels of activity appear modest and are in contrast to the high Cincinnati knee rating scores, suggesting that factors other than those measured in this study may contribute to the decision to return to previous levels of activity. It is important to note that the level of the Cincinnati Sports Activity Scale is determined by frequency of participation and that the score is based on both sport type and frequency of participation. Thus, after surgery, a patient could return to the same sport type but less frequently and would therefore be graded at a lower level. It is also important to recognize that we used preinjury rather than preoperative levels of activity as a baseline for the postoperative comparison. Data regarding activity levels is frequently reported, but few researchers have specifically looked at return to preinjury levels of sport.

Aglietti et al.[1] reported that 66% (20 of 30) of bone-patellar tendon-bone graft patients returned to their preinjury sport, compared with 50% (15 of 30) of hamstring tendon patients. This finding is consistent with ours that 69% of patellar tendon group patients and 55% of hamstring tendon group patients returned to their preinjury type of sport. Marder et al.[18] reported that 64% (46 of 72) of all patients returned to their preinjury level of activity and that there was no difference between graft types.

O'Neill[24] also reported higher levels of return to preinjury levels, but only 65% (81 of 125) of his patients played sports that involved cutting and pivoting. Recent randomized trials comparing patellar and hamstring tendon grafts for ACL reconstruction have either compared postoperative levels of activity with preoperative rather than preinjury levels[2,12] or have not addressed the issue.[4] We believe that use of preinjury levels is a more relevant, albeit more rigorous, standard, because preoperative levels have previously been shown to be lower than preinjury levels.[11]

CONCLUSIONS

The results of this study confirm those of similar randomized studies that show that there is little or no difference between bone-patellar tendon-bone and combined semitendinosus and gracilis hamstring tendon grafts in terms of the functional outcome after ACL reconstruction, despite greater laxity measurements in the hamstring tendon group patients. The principal differences between the two graft types in this study were increased pain on kneeling and increased extension deficits in patients in the bone-patellar tendon-bone group.

Because there is little overall difference between the two graft types, the operating surgeon must decide how to select the appropriate graft for an individual patient. One approach is to use the same graft type for essentially all patients. This approach has the potential advantage of increasing the expertise of the surgeon in use of the particular graft and perhaps enabling him or her to make technique modifications to extend the indications for its use.

An alternative approach is to use both graft types and have specific indications for each. Factors that might be considered include variables such as the patient's occupation, the presence of associated collateral ligament insufficiency, the presence of generalized ligamentous laxity, open growth plates, or the need for a rapid rehabilitation. Hamstring tendon grafts are preferable in the setting of open growth plates, whereas a bone-patellar tendon-bone graft may be more appropriate in a "loose" knee. The nature of the primary sport played by the patient may also be important in selecting the appropriate graft. The specific differences between the two grafts then become relevant. For instance, one might ask whether pain on kneeling would have a significant effect on the patient, whether a loss of active flexion would represent a significant deficit, or whether an extension deficit would impair performance.

As a result of the findings of this and other similar studies, the surgeon author of this paper has tried to tailor the graft type to the patient's needs. This decision has resulted in an increased preference for hamstring tendon grafts, such that they are now used in approximately two-thirds of cases, compared with one-third at the time of commencement of the study.

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