Hamstring Tendon Versus Patellar Tendon Anterior Cruciate Ligament Reconstruction Using Biodegradable Interference Fit Fixation

A Prospective Matched-Group Analysis

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Background: There are still controversies about graft selection for primary anterior cruciate ligament reconstruction, especially with respect to knee stability and functional outcome.

Hypothesis: Biodegradable interference screw fixation of hamstring tendon grafts provides clinical results similar to those achieved with identical fixation of bone–patellar tendon–bone grafts.

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

Methods: In 1996 and 1997, primary isolated anterior cruciate ligament reconstruction using a bone–patellar tendon–bone autograft was performed in 72 patients. Since 1998, hamstring tendons were used as routine grafts. Matched patients with a hamstring tendon graft were selected from a database (n = 284). All patients were followed prospectively for a minimum of 2 years with KT-1000 arthrometer testing, International Knee Documentation Committee score, and Lysholm score.

Results: In the bone–patellar tendon–bone group, 9 patients were excluded because of bilateral rupture of the anterior cruciate ligament, 3 patients (4.2%) had a graft rupture, and 4 patients were lost to follow-up (follow-up rate, 92.1%), leaving 56 patients for a matched-group analysis. In the hamstring tendon database, the graft rupture rate was 5.6% (P = .698). The Lysholm score was 89.7 in the patellar tendon group and 94 in the hamstring tendon group (P = .003). The KT-1000 arthrometer side-to-side difference was 2.6 mm for the patellar tendon group and 2.1 mm for the hamstring tendon group (P = .041). There were significantly less positive pivot-shift test results in the hamstring tendon group (P = .005), and hamstring tendon patients showed lower thigh atrophy (P = .024) and patellofemoral crepitus (P = .003). Overall International Knee Documentation Committee scores were better (P = .001) in the hamstring tendon group (hamstring tendon: 34 × A, 21 × B, 0 × C, 0 × D; bone–patellar tendon–bone: 17 × A, 32 × B, 6 × C, 0 × D).

Conclusions: In this comparison of anterior cruciate ligament reconstruction with bone–patellar tendon–bone and anatomical hamstring tendon grafts, the hamstring tendon graft was superior in knee stability and function. These findings are partially contrary to previous studies and might be attributable to the use of an anatomical joint line fixation for hamstring tendon grafts. Thus, hamstring tendons are the authors' primary graft choice for anterior cruciate ligament reconstruction, even in high-level athletes.

Keywords: anterior cruciate ligament (ACL); hamstring tendons; patellar tendon; biodegradable interference screw; clinical study

Rupture of the ACL affects knee stability, resulting in giving-way symptoms in daily and sports activities,[4,17,35] increased risk of meniscal injuries,[4,34] and early degeneration of the injured knee.[21,25,41] If surgery is indicated, the use of autologous tendon grafts for the replacement of the injured ligament is recommended.[22] One of the controversial topics in ACL reconstruction is the choice of a graft and its fixation.[6,9] The midthird patellar tendon and multiple-

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No potential conflict of interest declared.

The American Journal of Sports Medicine, Vol. 33, No. 9
DOI: 10.1177/0363546504273488

stranded hamstring tendons (semitendinosus and gracilis) are the most frequently used autografts today.[6,22,36,52] The bone–patellar tendon–bone autograft is considered to be the gold standard because of the bone-to-bone healing that allows for an early and accelerated rehabilitation with documented good and excellent long-term results.[39,40,44,52] During the past few years, hamstring tendon grafts have increased in popularity as an alternative to the bone–patellar tendon–bone graft.[10] Advantages of the hamstring tendon compared with the patellar tendon are reduced donor site morbidity associated with fewer kneeling problems and muscular deficits and less anterior knee pain in the long-term follow-up.[1,10,11,48,51] In recent years, numerous clinical outcome studies comparing hamstring tendon grafts and bone–patellar tendon–bone graft ACL reconstructions have been published.[†] In a recent meta-analysis, Yunes et al[52] reported significantly poorer static knee stability after hamstring tendon ACL reconstruction compared with the patellar tendon graft. However, most of these investigations included different types of fixation for the bone–patellar tendon–bone compared to the hamstring tendon graft.[‡] Mechanical and biological improvements in hamstring tendon graft fixation have been achieved, such as the use of anatomical joint line fixation.[9,48]

Corry et al[12] used a tibial and femoral metal interference screw fixation for both types of graft. After a 2-year follow-up, they found no significant differences in knee stability, range of motion, or general symptoms.

Thus, we hypothesized that with anatomical biodegradable interference screw fixation of hamstring tendon grafts, similar results as those reported by Corry et al[12] could be achieved. Therefore, the purpose of the present study was to compare bone–patellar tendon–bone and 4-strand hamstring tendon autografts for arthroscopic single-incision ACL reconstruction, with biodegradable interference screw fixation for both grafts in a prospective, matched-group, clinical outcome study with a minimum follow-up of 2 years.

MATERIALS AND METHODS

Patients and Entry Criteria

Entry criteria for this investigation included an isolated ACL insufficiency. Patients with a bilateral ACL insufficiency; a former stabilization procedure of the injured knee; a lateral, posterolateral, or medial insufficiency greater than 2+; or an insufficiency of the PCL were excluded. Also, patients who required revision surgery during the follow-up period were excluded from the performed matched-group analysis.

In 1996 and 1997, all ACL reconstructions in our department were performed using an autologous midthird bone–patellar tendon–bone autograft. There were 72 patients who met the above entry criteria and who were then followed prospectively for a minimum of 2 years. Starting in 1998, the autologous quadrupled hamstring tendon was used as a routine graft. To perform a matched-group analysis, patients with a hamstring tendon graft and a minimum follow-up of 2 years were selected from a database comprising 284 prospectively documented cases. The matching procedure was blinded to the outcome. Matching parameters were (1) age (with a radius of 3 years for the ages of 15-30 years, a radius of 5 years for the ages of 30-40 years, and a radius of 8 years for patients older than 40 years), (2) gender, (3) comorbidity (meniscal tear, medial collateral ligament [MCL] injury, chondromalacia grade I and II, chondromalacia grade III and IV), and (4) chronicity (acute, <12 months; chronic, >12 months). If more than one matching partner was identified, the one with the longest follow-up was chosen.

The investigation was approved by the local university review board, and all patients gave informed consent before participation.

Surgery was performed by 1 of 2 surgeons using identical fixation techniques for both types of grafts. At the time of arthroscopy, the knee was examined, associated injuries were documented, and torn menisci were removed or repaired. The ACL reconstruction was then performed using an arthroscopic single-incision technique, with anatomical and direct fixation using biodegradable interference screws in all knees.

SURGICAL TECHNIQUE

Bone–Patellar Tendon–Bone Graft

The midthird of the ipsilateral patellar tendon was harvested with proximal (10 × 25-mm) and distal (9 × 25-mm) bone plugs using a handheld helical tube saw via a medial longitudinal parapatellar incision. After the usual diagnostic arthroscopy, including the treatment of concurrent lesions, first the femoral tunnel was created through the anteromedial arthroscopy portal. A pilot tunnel was drilled in the 10:30 position (for right knees) or in the 1:30 position (for left knees) with the knee in maximum knee flexion, followed by serial dilatation up to 9 mm using the technique described by Johnson and Dyk.[30] Positioning of the tibial tunnel followed the usual standards using a drill guide system followed by an impingement test. Cannulated drill bits were used, and serial dilatation to a tunnel diameter of 10 mm was performed. After insertion of the graft, the femoral bone plug was fixed using a biodegradable 8 × 23-mm poly-(D,L-lactide) interference screw (Zimmer Orthopedics, Freiburg, Germany). The femoral screw was countersunk a few millimeters below the surface of the femoral cortex. Tibial fixation was performed using an 8 × 23-mm biodegradable poly-(D,L-lactide) interference screw in an outside-in direction at a knee flexion angle of approximately 10° and manual pretension.

[†]References 1-3, 5, 7, 8, 12, 14-16, 18-20, 24, 26, 27, 29, 31, 33, 37, 38, 50.

[‡]References 5, 7, 8, 15, 16, 19, 20, 29, 31, 37, 45, 50.

Hamstring Tendon Graft

Graft harvest was performed through a 3-cm skin incision medial to the tibial tuberosity. The semitendinosus and gracilis tendons were delivered with a tendon hook, and accessory fibers were cut. The tendons were harvested using an open-ended tendon stripper. The 4-strand graft was prepared with the help of a suture board while the arthroscopic preparation of the knee was performed. The proximal and distal endings of the tendons were armed with 4 No. 2 polyester sutures (Ethibond; Ethicon GmbH, Norderstedt, Germany) in a whipstitch fashion. The tendons were quadrupled, and a polyester passing suture was passed through each loop. A marking suture using No. 0 absorbable suture was set 2.5 cm from the femoral end of the graft to ensure good entry of the graft in the tunnel and to prevent the graft from twisting around the screw during insertion. The tibial end of the graft was sutured in a baseball-stitch technique using No. 0 absorbable sutures. Tunnel creation was identical to the patellar tendon technique. Diameters of the tunnel were matched to the graft diameters, in increments of 1 mm. Graft fixation was achieved with an 8 × 23-mm biodegradable poly-(D,L-lactide) interference screw (Zimmer Orthopedics) at both sites. The tibial screw was advanced just a few millimeters below the joint line using a cannulated screwdriver. Because of the lower bone density of the proximal tibia compared with the distal femur, a tibial backup fixation was done in all cases. A monocortical drill hole was created 2 cm distal to the tibial tunnel exit site. One strand of each attached polyester suture was passed through the hole and then tied over the created bony bridge.[42]

Postoperative Rehabilitation

An identical 4-month rehabilitation program was employed for both groups. Patients began immediate active quadriceps isometric and passive flexion exercises. A fixed splint in full extension was worn the first week, and patients were allowed toe-touch weightbearing using crutches increased to half body weight as tolerated. After the first week, the patients wore a functional knee brace limited to 90° of flexion for a period of another 2 weeks. Six weeks after surgery, full flexion was allowed, and patients were told to gradually walk without the brace. Full weightbearing was allowed after the fourth week as tolerated. Physical therapy started the day after surgery and was performed in an outpatient rehabilitation center. Two to 3 months after surgery, patients were allowed to ride a bicycle outdoors, to jog on solid ground, and to swim. Return to cutting actions and contact sports was allowed after 6 months if there were no effusion, full range of motion, and a muscle strength of 90% compared with the contralateral side as determined in the 1-legged hop test.

Follow-up Evaluation

All patients were examined upon entry to the hospital, under anesthesia before and after surgery, at 6 weeks after surgery, and at 6, 12, and 24 months after surgery. A specially trained research nurse performed all examinations in both groups. Blinding of the groups to the examiner was not possible because of the different approaches that were used for harvesting the patellar tendon and the hamstring tendon grafts.

Patients were evaluated using the International Knee Documentation Committee (IKDC) score and the Lysholm score. For the final IKDC results, the parameters of (1) effusion, (2) passive motion deficit, and (3) ligament examination were included according to the 2000 IKDC Knee Examination Form. In addition to the IKDC form 1-legged hop test, we evaluated a 1-legged knee-bending test, the ability to duck walk, and the ability to squat.

Besides the parameters of the IKDC score, we used other subjective outcome questions. In detail, patients were asked for the quality and quantity of pain, swelling, giving way, ability to work, and their sporting activities. In addition, the subjective outcome was assessed with the questions, "How does your knee influence your activity?" and "How does your knee function?" After the evaluation of the IKDC score, we graded these parameters as A (normal), B (nearly normal), C (abnormal), and D (severely abnormal) compared with the patients' preoperative conditions or the control knees.

Laxity was measured by comparison with the healthy knee using the KT-1000 arthrometer (MEDmetric, San Diego, Calif) at maximal manual tension and a knee flexion angle of 20°.[13]

Statistical Methods

Statistical analysis was performed using parametric and nonparametric tests. The χ^2 test was used for the nominal results of the IKDC form, and the Mann-Whitney test was used for the metric results of the Lysholm score, the KT-1000 arthrometer side-to-side difference, and statistical analysis of the matching parameters. Statistical analysis was conducted with the SPSS software package, version 10.0 (SPSS, Chicago, Ill). The probability level was set at $P \leq .05$.

RESULTS

Patient Collectives and Follow-up

In the patellar tendon group, 9 of the initial 72 patients were excluded because of an ACL injury of the contralateral knee, 3 patients (4.2%) had a graft rupture due to an adequate trauma during the follow-up period (5.6% in the hamstring tendon database, $P = .698$), and 4 patients were lost to follow-up (follow-up rate of 92.1%). Thus, 56 patients with a complete 2-year follow-up were left for a matched-group analysis. In 55 cases, we found a corresponding matching partner in the hamstring tendon database according to the previously described parameters, resulting in a total of 110 patients involved in this study. The mean follow-up time was 2.7 years in the hamstring tendon group and 3.4 years in the patellar tendon group ($P = .015$).

TABLE 1
Comparison of Matched Groups[a]

	Patellar Tendon Group	Hamstring Tendon Group	*P*
Age, y (range)	33.6 (18.9-52.1)	31.1 (14.8-49.6)	.090
Gender			
Male	40	40	
Female	15	15	
Chronicity[b]			
Acute	46	46	
Chronic	9	9	
Medial collateral ligament			
Grade I	28	28	
Grade II	4	4	
Meniscal lesions			
Medial	12 (3 with suture)	12 (3 with suture)	
Lateral	4	4	
Both	4	4	
Lysholm score	59.7 ± 18.5	56.9 ± 21.1	.754
IKDC score (%)[c]			.482
A	0 (0)	0 (0)	
B	1 (2)	0 (0)	
C	32 (58)	37 (67)	
D	22 (40)	18 (33)	
KT-1000 arthrometer, mm[d]	5.98	5.55	.844

[a]Because of the matching procedure, there were no significant differences in preoperative epidemiologic factors, knee stability, and knee scores between the bone–patellar tendon–bone and hamstring tendon groups.
[b]Acute, less than 1 year; chronic, more than 1 year.
[c] IKDC, International Knee Documentation Committee: A, normal; B, nearly normal; C, abnormal; D, severely abnormal.
[d]Mean value (manual maximum).

Preoperative/Intraoperative Findings and Concomitant Operations

Because of the matching procedure, there were no significant differences in the preoperative rating of the IKDC overall result (patellar tendon group: A, 0; B, 1; C, 32; D, 22; hamstring tendon group: A, 0; B, 0; C, 37; D, 18) and the Lysholm score (patellar tendon group: 59.7 ± 18.5; hamstring tendon group: 56.9 ± 21.1) (Table 1). These preoperative scoring results confirm that patients were symptomatic with restricted activity. Instrumented laxity measurement with the KT-1000 arthrometer showed no significant difference in the mean side-to-side difference between both groups (patellar tendon group: 6.0 ± 2.9 mm; hamstring tendon group: 5.6 ± 2.1 mm). The mean age was 31.1 years (range, 15-50 years) in the hamstring tendon group and 33.6 years (range, 19-52 years) in the patellar tendon group. Each group consisted of 40 male and 15 female patients. There were 46 acute and 9 chronically insufficient ACLs in both groups according to the previously described criteria. Each group showed 20 meniscus tears. There were 12 patients who had a medial and 4 who had a lateral meniscus tear in each group. Four patients in each group showed a lesion of both menisci. All lateral meniscus tears and 13 medial meniscus tears in each group underwent partial resection. Three medial meniscus tears in each group were treated with suture repair. There was no difference in the prevalence of MCL lesions. Each group had 28 patients with a grade I and 4 patients with a grade II instability of the MCL. None of the patients had an insufficiency of the PCL or the lateral collateral ligament, or underwent former stabilizing procedure of any knee.

CLINICAL 2-YEAR ASSESSMENT

Lysholm Score

Preoperative versus postoperative Lysholm scores showed a significant improvement in both groups (bone–patellar tendon–bone: $P < .0001$; hamstring tendon: $P < .0001$). The overall result of the Lysholm score 2 years after surgery showed a significantly different rating of 89.7 ± 9.2 for the patellar tendon group and 94 ± 8.9 for the hamstring tendon group ($P = .003$). Significant differences were found in terms of pain ($P < .0001$), thigh muscle strength ($P = .024$), and squatting ($P = .002$). Other parameters of the Lysholm score (swelling, instability, limping, stair climbing, support) did not differ significantly.

Subjective Evaluation

None of the questions asked showed a significant difference at final follow-up (Table 2). There was a trend toward a better subjective outcome in the hamstring tendon group (group grading for subjective evaluation: patellar tendon group: A, 35; B, 18; C, 2; D, 0; hamstring tendon group: A, 41; B, 13; C, 1; D, 0; $P = .446$).

International Knee Documentation Committee Clinical Evaluation

Significant differences with the better outcome in the hamstring tendon group were found for patellofemoral crepitus ($P = .003$), medial crepitus ($P = .042$), and knee flexion ($P = .05$) (Table 3). Effusion was rare in both groups and did not differ significantly.

Manually evaluated anterior translation of 20° to 30° (Lachman test) and 70° of flexion showed no significant difference (Table 3). Preoperative versus postoperative instrumentally measured anterior laxity with the KT-1000 arthrometer showed a significant improvement in both groups (bone–patellar tendon–bone: $P < .0001$; hamstring tendon: $P < .0001$). Postoperative anterior laxity values measured with the KT-1000 arthrometer, grouped as proposed by the IKDC (A, 0-2 mm; B, 3-5 mm; C, 6-10 mm; D, >10 mm), did not result in a significant difference, although mean KT-1000 arthrometer results showed significantly less anterior laxity in the hamstring tendon group. The mean value of anterior laxity measured with the KT-1000 arthrometer (side-to-side difference, manual maximum) was 2.6 ± 1.3 mm for the patellar tendon group

TABLE 2
Comparison of Subjective Evaluation Parameters[a]

	Patellar Tendon Group		Hamstring Tendon Group		
	n	%	n	%	P
Influence on activity level[b]					.360
A	37	67	38	69	
B	16	29	17	31	
C	2	4			
Function of the knee[c]					.348
A	27	49	32	58	
B	27	49	23	42	
C	1	2			
Pain					.135
A	42	76	49	89	
B	11	20	6	11	
C	2	4			
Swelling					.140
A	48	87	52	95	
B	7	13	2	4	
C			1	2	
Giving way					.401
A	51	93	53	96	
B	4	7	2	4	

[a]Subjective evaluation 2 years after surgery demonstrated no significant differences between bone–patellar tendon–bone and hamstring tendon groups. A, normal; B, nearly normal; C, abnormal; D, severely abnormal.
[b]Assessed by the question, "How does your knee affect your activity-level?"
[c]Assessed by the question, "How does your knee function?"

TABLE 3
Outcomes of Clinical Evaluation[a]

	Patellar Tendon Group		Hamstring Tendon Group		
	n	%	n	%	P
Manual anteroposterior translation (25° flexion)[b]					.101
A	30	55	38	98	
B	22	40	17	2	
C	3	6			
Manual anteroposterior translation (70° flexion)[b]					.099
A	38	69	47	86	
B	16	29	8	15	
C	1	2			
IKDC instrumental anteroposterior translation (KT-1000 arthrometer, 25° flexion)[b]					.101
A	30	55	38	69	
B	22	40	17	31	
C	3	5			
Pivot-shift test[c]					.005
A	32	58	47	86	
B	21	38	8	15	
C	2	4			
Medial joint opening[d]					.170
A	51	93	54	98	
B	4	7	1	2	
Group rating for ligament examination[e]					.007
A	22	40	37	67	
B	30	55	18	33	
C	3	6			
Effusion[f]					.132
A	49	89	54	98	
B	4	7	1	2	
C	2	4			
Extension[g]					.416
A	50	91	53	96	
B	4	7	2	4	
C	1	2			
Flexion[h]					.050
A	47	86	54	98	
B	7	13	1	2	
C	1	2			
Thigh atrophy[i]					.024
A	19	35	30	55	
B	21	38	21	38	
C	12	22	4	7	
D	3	6			
Crepitus anterior[e]					.003
A	25	46	39	71	
B	19	36	16	29	
C	10	18			
D	1	2			
Crepitus medialis[e]					.042
A	39	89	55	100	
B	5	9			
C	0	0			
D	1	2			
Crepitus lateralis[e]					1.000
A	54	98	54	98	
B	1	2	1	2	

[a]Clinical evaluation 2 years after surgery showed significantly less positive pivot-shift test results, better knee flexion, lower thigh atrophy, and less patellofemoral and medial crepitus in the hamstring tendon group. IKDC, International Knee Documentation Committee.
[b]A, –1 to 2 mm; B, 3 to 5 mm; C, 6 to 10 mm; D, >10 mm (side-to-side difference).
[c]A, equal; B, + (glide); C, ++ (clunk); D, +++ (gross).
[d]A, 0 to 2 mm; B, 3 to 5 mm; C, 6 to 10 mm; D, >10 mm.
[e]A, normal; B, nearly normal; C, abnormal; D, severely abnormal.
[f]A, none; B, mild; C, moderate; D, severe.
[g]Lack of extension: A, <3°; B, 3° to 5°; C, 6° to 10°; D, >10°.
[h]Lack of flexion: A, 0° to 5°; B, 6° to 15°; C, 16° to 25°; D, >25°.
[i]A, 0 cm; B, 1 cm; C, 2 cm; D, >2 cm.

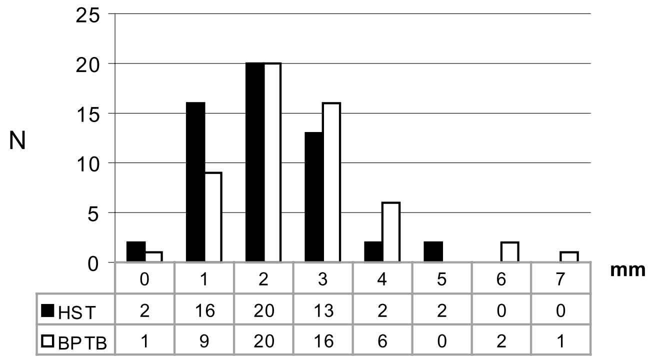

Figure 1. Comparison of anterior laxity, 2 years after surgery, measured with the KT-1000 arthrometer (side-to-side difference in millimeters, manual maximum). Mean value was 2.6 ± 1.3 mm for the bone–patellar tendon–bone (BPTB) group and 2.1 ± 1.1 mm for the hamstring tendon (HST) group (P = .041).

and 2.1 ± 1.1 mm for the hamstring tendon group (P = .041) (Figure 1). In addition, significantly less positive pivot-shift examination results were found in the hamstring tendon group. In the patellar tendon group, we found a negative pivot-shift test result in 32 cases, a glide in 21 cases, and a clunk in the pivot-shift test in 2 cases, whereas in the hamstring tendon group, we found a negative pivot-shift test result in 47 cases and a gliding positive pivot-shift test result in 8 cases (P = .005). Stability of the collateral ligaments showed no significant difference 2 years after surgery. The IKDC group result for ligament examination was significantly better in the hamstring tendon group (P = .007).

Functional Testing

Functional testing revealed significantly better results for the 1-legged hop test (P = .027) and the ability to squat (P = .002) in the hamstring tendon group (Table 4). Other functional assessment parameters such as duck walk and knee bending did not differ significantly.

International Knee Documentation Committee Overall Results

Preoperative versus postoperative IKDC scores showed a significant improvement in both groups (bone–patellar tendon–bone: P < .0001; hamstring tendon: P < .0001). Overall IKDC results were significantly better in the hamstring tendon group (P = .001) (Figure 2).

Graft rupture appeared in 4.2% of the cases in the bone–patellar tendon–bone group and in 5.6% of the hamstring tendon cases (P = .698).

TABLE 4
Outcomes of Functional Evaluation[a]

	Patellar Tendon Group		Hamstring Tendon Group		
	n	%	n	%	P
1-legged hop test					.027
A	38	69	49	89	
B	15	27	6	11	
C	2	4			
Knee bending					.067
A	46	84	52	95	
B	9	16	3	6	
Duck walk					.101
A	42	76	50	91	
B	12	22	5	9	
C	0	0			
D	1	2			
Squatting					.002
A	40	73	52	95	
B	15	27	3	6	

[a]Functional evaluation 2 years after surgery showed significantly better results for the 1-legged hop test and improved ability to squat in the hamstring tendon group. A, normal; B, nearly normal; C, abnormal; D, severely abnormal.

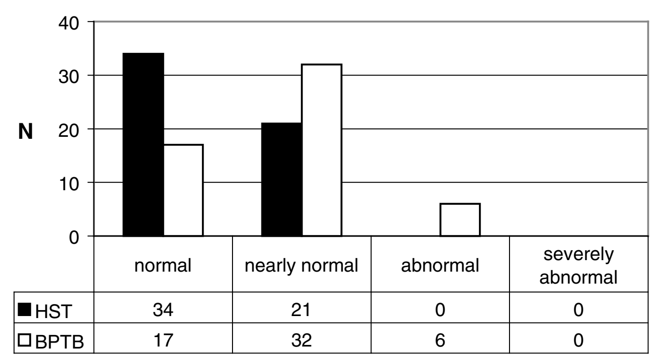

Figure 2. The International Knee Documentation Committee overall result 2 years after surgery, calculated with the group results of (1) effusion, (2) passive motion deficit, and (3) ligament examination, showed a significantly better outcome in the hamstring tendon group (P = .001). HST, hamstring tendon; BPTB, bone–patellar tendon–bone.

DISCUSSION

The purpose of this study was to compare bone–patellar tendon–bone and 4-strand hamstring tendon autografts for arthroscopic ACL reconstruction with the same type of anatomical and direct biodegradable interference screw fixation for both grafts. To our knowledge, this is the first report of a clinical comparison of bone–patellar tendon–bone and 4-strand hamstring tendon grafts in ACL reconstruction that has demonstrated superior results in terms of function as well as knee stability for the hamstring tendon group.

Other authors have compared these grafts in clinical outcome studies but have used different fixation devices for the hamstring tendons and the patellar tendon grafts.[§]

[§]References 5, 7, 8, 15, 16, 19, 20, 29, 31, 45, 50.

TABLE 5
Literature Review of Recent Prospective Studies Comparing Bone–Patellar Tendon–Bone and Hamstring Tendon Grafts for ACL Reconstruction[a]

	BPTB			HST						
Study	Technique	n	FU	Technique	n	FU	Type of Study	Stability	Function	IKDC Overall
Aune et al[5]	Interference screws	35	29/83%	4-strand (STG) femoral: EndoButton; tibial: interference screw	37	32/86%	Prospective randomized 2-year FU	Equal KT-1000 arthrometer results	HST: less kneeling pain, isokinetic flexion weakness; equal Cincinnati functional scores	Not evaluated
Beard et al[7]	Interference screws	60 (HST + BPTB)	22 (HST + BPTB = 45/75%)	4-strand (STG) interference screws	60 (HST + BPTB)	23 (HST + BPTB = 45/75%)	Prospective randomized 1-year FU	Equal KT-1000 arthrometer results	Equal IKDC and Lysholm scores; equal muscle strength	BPTB: A, 0; B, 10; C, 7; D, 5; HST: A, 2; B, 10; C, 6; D, 5 ($P > .05$)
Beynnon et al[8]	Interference screws	28	22/79%	2-strand (STG) complete extracortical (staples)	28	22/79%	Prospective randomized 3-year FU	KT-1000 arthrometer results: BPTB, 1.1 mm; HST, 4.4 mm ($P = .004$); BPTB: less positive pivot-shift results	Equal in satisfaction, activity, and knee function	BPTB: A, 13; B, 5; C, 4; D, 0; HST: A, 10; B, 9; C, 3; D, 0 ($P > .05$)
Corry et al[12]	Interference screws	90	82/91%	4-strand (STG) interference screws	90	85/94%	Prospective 2-year FU	Equal KT-1000 arthrometer results	Equal range of motion and general symptoms; HST: less kneeling pain	BPTB: A, 37; B, 29; C, 7; D, 4; HST: A, 31; B, 41; C, 4; D, 1 ($P > .05$)
Ejerhed et al[14]	Interference screws	34	33/97%	3- or 4-strand (ST) interference screws	37	36/97%	Prospective randomized 2-year FU	Equal KT-1000 arthrometer results; equal IKDC scores	Equal Lysholm scores; equal hop test results; HST: better knee walking	BPTB: A or B, 17; C or D, 15; HST: A or B, 20; C or D, 14 ($P > .05$)
Eriksson et al[15]	Interference screws	50	42/84%	4-strand (ST) femoral: EndoButton; tibial: washer	57	47/82%	Prospective half-year FU	Equal Stryker laxity test results; equal IKDC scores	Equal Tegner and Lysholm scores; equal visual analog scale, satisfaction, and function; BPTB: decreased extension; HST: better 1-legged hop test result	Not evaluated
Feller and Webster[19]	Femoral: EndoButton; tibial: interference screw	31	31/100%	4-strand (STG) femoral: EndoButton; tibial: Acufex	34	26/76%	Prospective randomized 3-year FU	KT-1000 arthrometer results: BPTB, 0.5 mm; HST, 1.1 mm ($P < .05$)	Equal Cincinnati and IKDC scores; BPTB: more kneeling pain and extension deficits	BPTB: A, 37%; B, 56%; C, 7%; D, 0%; HST: A, 33%; B, 38%; C, 24%; D, 5% ($P > .05$)

[a]BPTB, bone–patellar tendon–bone autograft; HST, hamstring tendon autograft; FU, follow-up; IKDC, International Knee Documentation Committee; STG, semitendinosus/gracilis; ST, semitendinosus.

Most of these investigations showed better static stability when a patellar tendon graft was used. This finding might be attributable to the fact that extracortical fixation, often used with hamstring tendon grafts, might result in inferior mechanical and biological boundary conditions.[9,48] Beynnon et al[8] used extracortical staple fixation for a 2-strand semitendinosus-gracilis tendon graft and interference screw fixation for the patellar tendon graft and reported a mean side-to-side difference of 1.1 mm in the patellar tendon group and 4.4 mm in the hamstring tendon group (Table 5). Aune et al[5] used tibial and femoral interference screw fixation for the patellar tendon and tibial interference screw, combined with an EndoButton for the femoral fixation of 4-strand hamstring tendon grafts in a clinical study with 72 patients and a follow-up rate of 84.7% (Table 5). The results of that study were mainly equal for both grafts. At 2 years, they found no significant differences in the Cincinnati functional score or in the instrumentally measured laxity. The subjective grading and the single-legged hop test results were better in the hamstring tendon group after 6 and 12 months, but they did not differ after 24 months. They found better isokinetic knee extension strength in the hamstring tendon group after 6 months but no difference after 12 and 24 months. Anterior knee pain was not significantly different between the groups, but kneeling pain was significantly less common in the hamstring tendon group after 24 months.

Other authors have used identical fixation devices for hamstring tendon and patellar tendon grafts (Table 5). Equal clinical results for stability combined with fewer patellofemoral problems in the hamstring tendon groups were often reported in these series. Beard et al[7] showed no significant differences concerning IKDC and Lysholm scores and KT-1000 arthrometer measurement using a fixation technique with titanium interference screws for both grafts in a 1-year follow-up study of 45 patients. Ejerhed et al[14] found no significant difference in the Lysholm, Tegner, and IKDC scores and significantly better ability in knee walking in the hamstring tendon group 2 years after surgery using titanium interference screws for both grafts. Corry et al[12] demonstrated no differences concerning stability, range of motion, and general symptoms 1 and 2 years after surgery, but they found less thigh atrophy in the hamstring tendon group after 1 year. This difference disappeared 2 years after surgery, but hamstring tendon patients showed significantly better ability in knee walking after 2 years.

The results of our patient series were at least partially contrary to those reported in previous studies. We found significantly better stability in the hamstring tendon group 2 years after surgery. This finding was demonstrated by significantly less positive pivot-shift test results and in the approximately 20% lower instrumentally measured side-to-side difference of the hamstring tendon group. However, this finding might be attributable to the fact that a rigid joint line fixation was used on both sides, thus optimizing mechanical and biological boundary conditions, combined with tibial hybrid fixation preventing tibial graft slippage. Anatomical aperture fixation of hamstring tendon grafts as used in the present study reduces graft tunnel motion and provides a short graft length between the fixation devices, resulting in less viscoelastic and viscoplastic deformation.[28,32,43,46,49] As shown in histological studies by Weiler et al,[46] this method allows the graft to recreate an insertion anatomy directly at the joint line similar to the native ACL.[46,47,49]

The better outcome in terms of function in the hamstring tendon group mainly resulted from the significantly better results for the 1-legged hop test and for squatting, which might be related to better quadriceps strength. Clinical tests directly depend on a good condition of the extensor apparatus of the knee, as flexion, anterior crepitus, and thigh atrophy showed a significantly better result in the hamstring tendon group. This finding is in line with previous reports (Table 5). However, we did not measure the donor site morbidity as recommended by the new IKDC form, but it has been well documented in previous studies that harvesting of the midthird patellar tendon can lead to significantly more anterior knee pain, kneeling pain, loss of thigh strength, and a higher complication rate concerning postoperative loss of motion compared to harvesting the hamstring tendons.[1,10,11,23,48,51]

Because the hamstring tendon cases were done sequentially after the patellar tendon cases, there might have been immeasurable improvements in the surgeons' technique over the years. This factor might have been a possible contributor to the reported improvement in the results from the patellar tendon to the hamstring tendon group. However, this factor could principally be interpreted vice versa because we performed patellar tendon ACL reconstructions for several years and changed to hamstring tendon grafts in 1997. Thus, the included hamstring tendon cases also included our hamstring tendon graft learning curve. Therefore, there are 2 contrary arguments that may be viewed as a positive and a negative effect for the better clinical outcome of the hamstring tendon group.

There was a statistically significant difference in the study groups concerning the mean follow-up time, 2.7 years in the hamstring tendon group and 3.4 years in the patellar tendon group, which means that there was a time difference of 8 months. This difference is, in our opinion, a minor issue without clinical relevance regarding the comparability of the study groups.

Nevertheless, the results of this study affirmed that the hamstring tendons are our primary autograft choice for ACL reconstruction, even in high-level athletes.

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