No Difference in Knee Function or Prevalence of Osteoarthritis After Reconstruction of the Anterior Cruciate Ligament With 4-Strand Hamstring Autograft Versus Patellar Tendon–Bone Autograft

A Randomized Study With 10-Year Follow-up

Inger Holm,*† PT, PhD, Britt Elin Øiestad,‡ PT, May Arna Risberg,‡ PT, PhD, and Arne Kristian Aune,§ MD, PhD

From the †Division of Rehabilitation, Oslo University Hospital, Rikshospitalet, Oslo, Norway, ‡NAR, Orthopedic Center, Oslo University Hospital, Ullevaal, Oslo, Norway, and §Volvat Medical Center, Oslo, Norway

Background: The choice of different graft types and surgical techniques used when reconstructing a torn anterior cruciate ligament may influence the long-term prevalence of osteoarthritis and functional outcomes.

Hypothesis: There are no differences in the prevalence of knee osteoarthritis or knee function in patients undergoing reconstruction of a torn anterior cruciate ligament with 4-strand hamstring autograft versus patellar tendon–bone autograft.

Study Design: Randomized controlled trial; Level of evidence, 1.

Methods: Seventy-two patients with subacute or chronic rupture of the anterior cruciate ligament were randomly assigned to autograft reconstruction with 4-strand gracilis and semitendinosus tendon (HAM) (N = 37) or with patellar tendon–bone (PTB) (N = 35) from the ipsilateral side. Outcome measurements were the Cincinnati knee score, single-legged hop tests, isokinetic muscle strength tests, pain, knee joint laxity test (KT-1000 arthrometer), and a radiologic evaluation (Kellgren and Lawrence) at 10-year follow-up.

Results: At 10 years, 57 patients (79%) were eligible for evaluation—29 in the HAM group and 28 in the PTB group. No differences were found between the 2 graft groups with respect to the Cincinnati knee score, the single-legged hop tests, pain, muscle strength measurements, or knee joint laxity. Fifty-five percent and 64% of the patients had osteoarthritis corresponding to Kellgren and Lawrence grade 2 or more in the HAM and the PTB groups, respectively (P = .27). For the uninvolved knee, the corresponding numbers were 28% and 22% (P = .62).

Conclusion: At 10 years postoperatively, no statistically significant differences in clinical outcome between the 2 graft types were found. The prevalence of osteoarthritis was significantly higher in the operated leg than in the contralateral leg, but there were no significant differences between the 2 groups. The results indicate that the choice of graft type after an anterior cruciate ligament injury has minimal influence on the prevalence of osteoarthritis 10 years after surgery.

Keywords: anterior cruciate ligament (ACL) reconstruction; hamstring tendon; patellar tendon; functional tests; osteoarthritis

A number of studies have been performed comparing hamstring tendon (HAM) autograft and patellar tendon–bone (PTB) autograft.[1,5,10,17] There is, however, no distinct consensus on which graft type that gives the most optimal function in the long run, based on long-term follow-up studies.

*Address correspondence to Inger Holm, PT, PhD, Sognsvannsveien 20, 0027 Oslo, Norway (e-mail: inger.holm@rikshospitalet.no).

No potential conflict of interest declared.

The American Journal of Sports Medicine, Vol. 38, No. 3
DOI: 10.1177/0363546509350301

In 2005, Goldblatt et al[4] published a meta-analysis that compared the effectiveness of anterior cruciate ligament (ACL) reconstruction using patellar tendon versus HAM autografts. The included studies were required to provide data that assessed both subjective and objective condition of the patient and graft for a minimum of a 2-year follow-up period. The authors found that the PTB graft was more likely to result in reconstructions with normal knee joint laxity and fewer patients with significant flexion loss. In contrast, patients with HAM grafts had a reduced incidence of patellofemoral crepitance, kneeling pain, and extension loss. They concluded that rather than making a generalization about a particular graft, one should assign significance to individual outcomes based on functional expectations and desires.

In contrast to the aforementioned recommendations from the meta-analysis study, Pinczewski et al[11] decided to recommend HAM graft as the first choice to their patients. They performed a cohort study with a 10-year follow-up, in which they compared PTB and HAM autografts in 2 consecutive series of patients. They found a significantly higher incidence of radiographic osteoarthritic changes in knees reconstructed with PTB autografts compared with HAM autografts. The difference, however, was composed of patients with mild osteoarthritis (OA). In addition, kneeling pain was statistically increased in the PTB group and there was a trend toward lower overall International Knee Documentation Committee score in the PTB group compared with the HAM group.

There are no previous published randomized controlled trials evaluating the long-term effects (minimum 10-year follow-up) of graft choice on knee function and prevalence of OA. The aim of the present study was to compare the functional results and prevalence of OA 10 years after ACL surgery. Our primary hypothesis was that there was no difference in knee function and prevalence of OA in patients repaired for a torn ACL with 4-strand HAM autograft versus with PTB autograft.

MATERIALS AND METHODS

Participants

Seventy-two patients with an average age of 26 years (range, 15-50 years) who had a subacute (N = 18) or chronic (N = 54) rupture of the ACL were randomized to ACL reconstruction with HAM autograft (N = 37) or a PTB autograft (N = 35) from the ipsilateral side. Patients with subacute ruptures were those cases in which the patients selected reconstruction after the injury, while patients with chronic ruptures were those cases in which nonoperative treatment was selected by the patients after the injury, but who later underwent a reconstruction because of significant functional problems. At 10 years postoperatively, 5 patients had been excluded because of ACL injury of the contralateral knee and 10 patients were lost to follow-up (Figure 1). This left 57 patients (79%) who complied with the follow-up procedure—29 in the HAM group and 28 in the PTB group. Table 1 shows the characteristics of the patients from the 2 graft groups 10 years after primary surgical reconstruction. There were no differences between the intervention groups concerning gender, age, or activity level. The study was approved by the Norwegian Ethics Committee of Medical Research and the patients gave their written, informed consent to participate.

TABLE 1
Characteristics of the 2 Study Groups at 10-Year Follow-up

	Group		
Variable	Hamstring Tendon (N = 29), Mean (SD)	Patellar Tendon (N = 28), Mean (SD)	*P* Value
Gender (women/men)	14/15	10/18	.424
Age at operation, y	27 (9)	25 (7)	.072
Age at follow-up, y	37.9 (9.1)	33.9 (6.2)	.060
Heigth, cm	176 (8.4)	178 (7.1)	.334
Weight, kg	78.2 (13.6)	83.9 (13.5)	.122
Body mass index	25.2 (2.8)	26.5 (3.5)	.122
Time from injury to operation, mo	40.5 (41.6)	41.3 (41.0)	.244
Time from operation to follow-up, y	10.7 (0.4)	10.2 (0.4)	.001
Tegner activity level at follow-up (1-10)	4.8 (2.3)	4.3 (2.2)	.379

Surgical Procedures

All the surgical procedures were performed by the same surgeon. For the patients randomized to the group undergoing PTB reconstruction, a 10-mm graft was harvested via a longitudinal incision. A guidewire was drilled from the medial side of the tibial tubercle at a 45° angle from the medial side of the tibial shaft and advanced to the preserved ligament stump in the posterior portion of the ACL footprint with use of a drill guide (Linvatec Corp, Largo, Florida). A 9-mm cannulated drill bit was used to drill the tibial tunnel. With the knee flexed, a femoral aimer with 7-mm offset (Linvatec Corp) was introduced through the tibial tunnel and positioned at the 11- or 1-o'clock over-the-top position (right or left knee, respectively). A guidewire was drilled through the aimer and advanced 3 to 4 cm into the femur. A 9-mm cannulated drill bit was introduced over the guidewire and drilled to a depth of 25 mm. The graft was passed into the knee using the Paramax system (Linvatec Corp) and fixed with a 7-mm × 25-mm titanium femoral interference screw (Linvatec Corp). The knee was cycled under graft tensioning to allow stress relaxation of the graft. The graft was then tensioned to 20 lb and, with the knee at 0° of flexion, fixed in the tibial tunnel with a 7-mm × 25-mm tibial interference screw.

The HAM graft was harvested through a longitudinal incision. The tendons were looped over a 5-mm polyester tape (Endotape, Smith & Nephew Endoscopy, Andover, Massachusetts) to create a quadrupled graft, and the graft

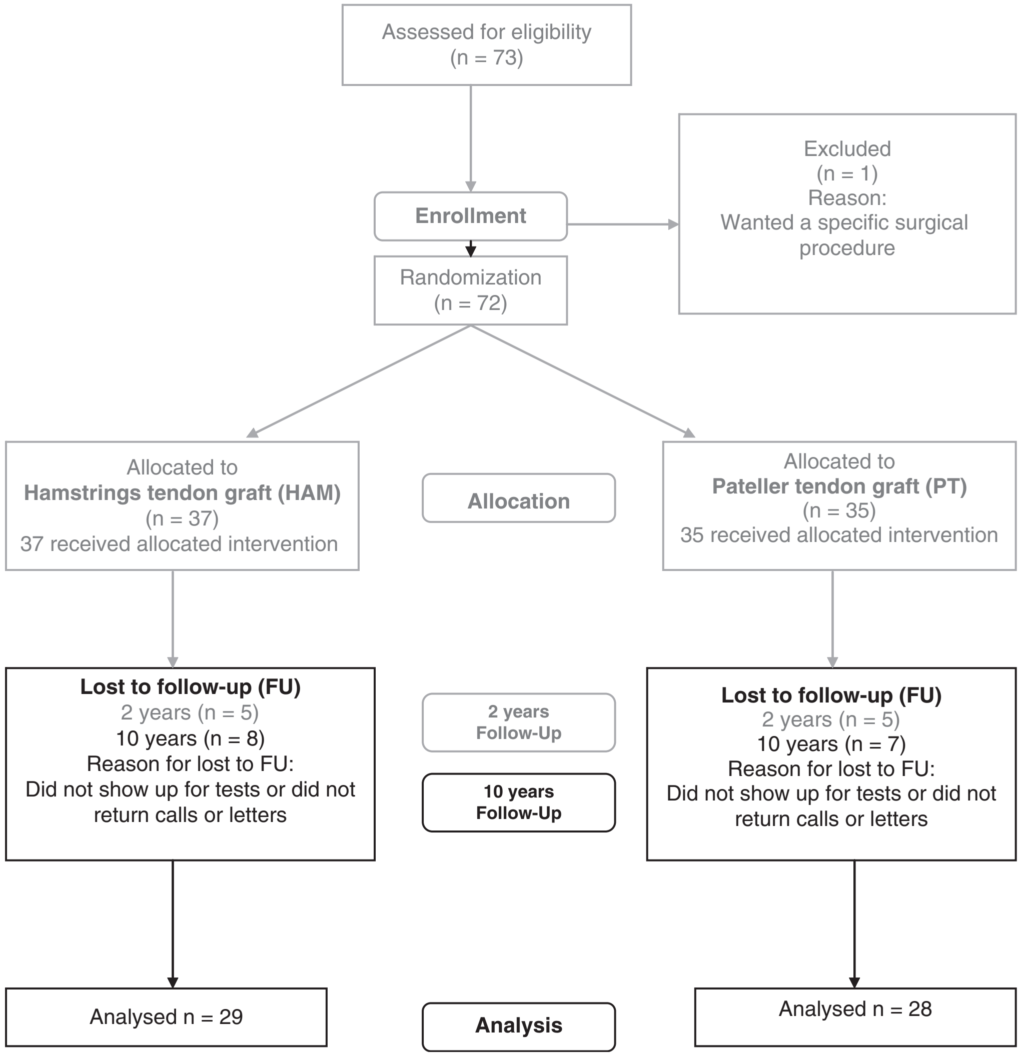

Figure 1. CONSORT diagram showing movement of patients through the study. Boxes in black indicate parts of the study presented in the present article. Boxes in gray indicate parts of the study presented in a previously published article.[1]

was sized between 7 and 9 mm. A titanium button (EndoButton, Smith & Nephew) was placed into the holder on the GRAFTMASTER (Smith & Nephew), and the Endotape was passed through its 2 central holes. The tape loop was provisionally secured by a hemostat. The span of tape was set later, once the length of the femoral tunnel was measured. The graft was pretensioned to 20 lb on the GRAFTMASTER while the remainder of the procedures were completed.

The tibial tunnel was prepared according to the method used for the patellar tendon grafts, but the size of the drill bit was selected according to the graft size. For the femoral tunnel preparation, a 5.5-mm offset femoral aimer was used. The guidewire was advanced completely through the femoral cortex and overdrilled by a 4.5-mm drill bit. A depth gauge was used to measure the length of this tunnel. A closed-end femoral socket was drilled 25 mm into the femur with an additional 10 mm for the EndoButton to clear the femoral cortex and flip. The length of the tunnel was used to set the EndoButton tape length, and the tape was tied using 2 square knots. The EndoButton with the attached graft was pulled by sutures into the joint and flipped as it passed through the femoral tunnel to fix the graft. The knee was cycled under graft tensioning to settle the EndoButton and to allow stress relaxation of the graft. The graft was tensioned with 20 lb distally and fixed with an interference screw (RCI, Smith & Nephew) in the tibial tunnel with the knee extended. Additionally, a backup fixation of the tendon ends was performed using the 2 barbed staples outside the tibial tunnel.

Rehabilitation

A cold compression device (Aircast, Inc, Summit, New Jersey) was used during the first postoperative week. The patients did not use continuous passive motion or a brace after the operation. Both graft groups went through the same rehabilitation program. Weightbearing was permitted as tolerated from day 1 postoperatively. After 2 weeks, closed kinetic chain exercises and stationary bicycling were started. After 6 weeks, agility training and light jogging were permitted. After 10 weeks, increased agility workouts, maximum strength training, and sport-specific activities were allowed. Return to full sports activities was allowed after 6 months if the criteria of full range of motion, no effusion, normal muscle strength, and knee stability were met.

Follow-up Evaluation

Follow-up evaluations were performed at 6, 12, and 24 months and 10 years after surgery and the results from the first 2 years have previously been published.[1] Except for significant hamstring muscle weakness and less donor-site pain in the patients with HAM grafts, there were no differences between the groups at the 2-year follow-up.[1]

Ten years after surgery, the patients received an invitation to participate in a further follow-up evaluation. Activity level was estimated by the Tegner activity score[19] and knee function was evaluated with the Cincinnati knee score system.[9] Knee joint laxity was recorded using a KT-1000 knee arthrometer (MEDmetric Corp, San Diego, California) at the manual maximum force.[20] The difference in displacement in millimeters between the operated and nonoperated knee was recorded. A visual analog scale (VAS) was used to evaluate pain by asking the patients how they considered their knee pain during activities or right after activities. The patients drew a line on a VAS where 0 represented no pain and 100 represented extreme pain.[12] Furthermore, a VAS was used to evaluate the patient's self-reported evaluation of knee function, a global rating of knee function as used in several other studies.[3,14] Zero represented the worst possible knee function and 100 represented the same knee function as before the knee injury.

Isokinetic muscle strength was measured with the Cybex 6000 dynamometer (Lumex Inc, Ronkonkoma, New York),[1] and the stair-hop test and 1-legged hop and triple-hop tests were used to evaluate lower limb function.[13] Each isokinetic and functional test was administered by the same physiotherapists. To evaluate the prevalence of femorotibial knee OA, weightbearing posteroanterior fixed flexion and radiographs were taken.[8] All radiographs were read by the same radiologist. Blinding was not possible because of the visible grafts in the injured knee. The radiographs were classified according to the Kellgren and Lawrence classification system,[6] defining grade 2 or more as the cutoff for knee OA. Body mass index (BMI) was calculated from weight in kilograms and height in meters with the formula kg/m^2.

Statistical Analysis

We used SPSS version 15.0 (SPSS Inc, Chicago, Illinois) for the statistical analyses. A priori statistical power analysis was performed with the Cincinnati knee score as the primary outcome variable. Sample size calculations estimated that 32 patients would be needed in each group to detect a 10-point difference in the Cincinnati knee score between the 2 groups, with a standard deviation (SD) of 12 points, an alpha level of .05, and a beta level of .10. Numbers are presented as arithmetic means and dispersion by 1 SD or frequences (categorical data). For numerical data, independent-samples t tests were used to compare the mean score between the 2 surgical procedures; for categorical data, a χ^2 test was used. The significance level was set to .05.

RESULTS

Participant Characteristics

During the 10-year study period, 15 patients (8 in the HAM and 7 in the PTB group) were lost to follow-up. At 10 years postoperatively, 6 patients (3 patients in each group) had gone through an ACL revision because of traumatic graft failure. Seven patients (4 in the HAM group and 3 in the PTB group) had torn their contralateral ACL. Twenty-eight patients (12 in the HAM group and 16 in the PTB group) had gone through a meniscal resection or repair during the total study period.

There was an increase in BMI for both groups: the HAM group increased from 23.8 to 25.1 (not significant); the corresponding numbers for the PTB group were 23.1 and 26.3 (P = .01).

Functional Outcome

Forty-six percent of the patients in the HAM group and 54% in the PTB group had returned to their preinjury sports, including pivoting activities. They were participating at the preinjury level for a mean duration of 4.7 years and 5.4 years (P = .750), respectively. At 10 years postoperatively, the activity level, assessed by the Tegner questionnaire, was 4.8 (±2.3) for the HAM group and 4.3 (±2.2) for the PTB group (P = .379).

No differences were found between the 2 graft groups with respect to the Cincinnati knee score, KT-1000 arthrometer, muscle strength measurements, or any of the functional knee tests (Table 2). Both groups reported minimal pain both at rest and with activity (Table 3). At 2 years, kneeling pain was 19 (±26) in the HAM group and 36 (±34) in the PTB group, indicating a significant difference between the 2 groups ($P < .05$).[1] After 10 years, the kneeling pain was 29 (±37) and 39 (±37) (P = .342) for the HAM and PTB groups, respectively (Table 3), indicating that kneeling pain was still a moderate problem for patients in both groups.

Osteoarthritis

The distribution of radiologic OA for the 2 groups graded according to the Kellgren and Lawrence classification is shown in Figure 2. No significant differences between the

TABLE 2
Functional Tests for the 2 Study Groups at 10-Year Follow-up[a]

Variable	Group: Hamstring Tendon (N = 29), Mean (± SD)	Group: Patellar Tendon (N = 28), Mean (± SD)	Mean Difference	95% CI	*P* Value
Cincinnati knee score (0-100)	87.8 (± 12.3)	84 (± 14.5)	3.8	−3.4, 10.9	.295
Lysholm score (0-100)	86.1 (± 15.1)	84.2 (± 15.4)	1.9	−6.1, 10	.636
Subjective function (visual analog scale, 0-10)	7.7 (± 3)	7.6 (± 2.7)	0.1	−1.4, 1.7	.856
KT-1000 arthrometer (manual max, mm; difference uninvolved/involved side)	2.0 (± 3.5)	3.0 (± 3.2)	−1.0	−2.8, 0.8	.727
Hamstring strength 60 deg/s (involved side in % of uninvolved side)	98 (± 28.5)	92 (± 12)	5.9	−5.7, 17.7	.314
Hamstring strength 240 deg/s (involved side in % of uninvolved side)	92.6 (± 25.7)	95.1 (± 12.6)	−2.5	−13.2, 8.3	.645
Quadriceps strength 60 deg/s (involved side in % of uninvolved side)	100.1 (± 30.2)	89.6 (± 10.3)	10.5	−1.5, 22.6	.086
Quadriceps strength 240 deg/s (involved side in % of uninvolved side)	96 (± 10.5)	96.1 (± 9.2)	0.2	−5.4, 5.1	.949
Triple-jump test (involved side in % of uninvolved side)	100.2 (± 7.9)	100.7 (± 17.2)	−0.5	−7.9, 6.8	.880
Stair-hop test (involved side in % of uninvolved side)	100.8 (± 10.2)	105.9 (± 28.9)	−5.1	−17.3, 7.0	.401

[a]Presented as mean (± standard deviation [SD]), mean difference, and 95% confidence interval of the difference (95% CI).

TABLE 3
Pain Scores for the 2 Study Groups at 10-years Follow-up[a]

Variable	Group: Hamstring Tendon (N = 29), Mean (± SD)	Group: Patellar Tendon (N = 28), Mean (± SD)	Mean Difference	95% CI	*P* Value
Pain at rest[b]	8 (± 17)	7 (± 15)	1	−7, 10	.737
Pain in activity[b]	17 (± 22)	16 (± 17)	2	−10, 11	.889
Kneeling pain[b]	29 (± 37)	39 (± 37)	−9	−29, 10	.342

[a]Presented as mean (± standard deviation [SD]), mean difference, and 95% confidence interval of the difference (95% CI).
[b]Visual analog scale: 0, no pain; 100, worst pain.

2 groups were found. Fifty-five percent and 64% of the patients had OA grade 2 or more in the HAM and the PTB groups, respectively (*P* = .27). For the uninvolved knee, the corresponding numbers were 28% and 22% (*P* = .62). No patients in either group showed severe OA (grade 4) either in the operated or in the contralateral leg (Table 4).

DISCUSSION

The aim of the present study was to compare the long-term results (10-year follow-up) with HAM or PTB autografts in a randomized study using independent observers. No significant differences between the 2 graft types were found for knee function or for prevalence of knee OA. Overall, both groups showed successful results; the Cincinnati knee score was on average 87.8 in the HAM group and 84.0 in the PTB group, and both pain during activity and kneeling pain were below 10 on a VAS from 0 (no pain)

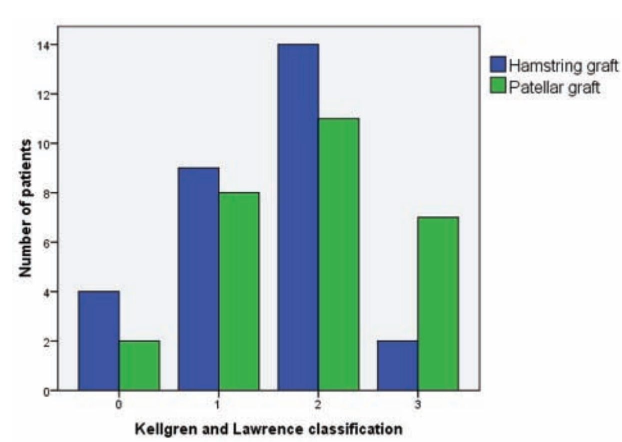

Figure 2. Kellgren and Lawrence classification.

TABLE 4
Distribution of Osteoarthritis According to the Kellgren and Lawrence Classification for Involved and Uninvolved Leg Given as a Percentage

	Hamstrings Tendon Group (N = 29)		Patellar Tendon Group (N = 28)	
Kellgren and Lawrence Classification	Involved	Uninvolved	Involved	Uninvolved
Grade 0	13.8	55.2	7.1	57.1
Grade 1	31.0	17.2	28.6	21.4
Grade 2	48.3	27.6	39.3	17.9
Grade 3	6.9	-	25.0	3.6
Grade 4	-	-	-	-

to 100 (worst pain). There was, however, a high prevalence of OA in both groups.

The prevalence of mild or moderate OA was 55% and 64% for the HAM and the PTB groups, respectively. Kessler et al[7] found a prevalence of OA of 45% 11 years postoperatively in a group of patients reconstructed with a PTB graft, a considerably lower prevalence than the PTB group in the present study. The explanation for this difference may be multifactorial, but one main reason might be that the Kessler study was retrospective, and they excluded all patients with meniscal and/or cartilaginous lesions and BMI >30 before performing the 11-year follow-up. In a prospective study with 10-year follow-up, Pinczewski et al[11] found a significantly higher incidence of osteoarthritic changes in the PTB group compared with the HAM group. The present study showed the same tendency, indicating a somewhat higher, but not significant, prevalence of OA in the PTB group. The differences in level of significance between the 2 studies may be attributable both to different study designs (prospective follow-up vs randomized study) and different OA classification systems (International Knee Documentation Committee vs Kellgren and Lawrence).

In spite of the relatively high prevalence of OA shown in the present study, the patients in both groups reported nearly no pain during activity (Table 3). These findings indicate that structural findings on radiographs do not automatically amount to pain or functional abilities. The same phenomenon was found by Pinczewski et al,[11] and they concluded that the subjective results in both groups suggest that the arthritis detected on radiographs is largely subclinical 10 years after surgery.

There was a decline in performance both for muscle strength and all the single-legged hop tests for both groups, a decline we consider normal because all the participants had become 10 years older since inclusion. Between 25 and 40 years of age, most people usually end their athletic career of performing high-level sports and reduce their activities to a recreational level because of factors other than impaired knee function. In both groups, the Tegner activity level was between 4 and 5, indicating that they were still active on a recreational level.

Previous published results from the present study showed that kneeling pain was significantly less common in the HAM group compared with the PTB group 2 years postoperatively: the scores for the HAM and PT groups were 18.9 (±26.2) and 35.5 (±33.6), respectively.[1] The corresponding values at 10-year follow-up were 29 (±37) for the HAM group and 39 (±37) for the PTB group (Table 3), indicating that the kneeling pain was still a moderate problem for patients in both groups. These results are in contrast to other long-term follow-up studies, which found a higher incidence of kneeling pain in the PTB group at both 7 and 10 years postoperatively.[11,15] In a review, Spindler et al[18] concluded that increased kneeling pain in the PTB group was seen consistently in the 9 studies evaluated. The same findings were verified in a later review.[4]

In an editorial published in 2008, Eriksson[2] discussed if using a HAM graft may impair the muscular function of the knee and thereby reduce its protection of the ACL. He suggested that, because the quadriceps muscle is an ACL antagonist, the patellar tendon should be used instead. He concluded that we evidently do not yet know the answer to the question of how safe it is to use the hamstring tendons and that more research is needed. However, the present study indicates that there is no reason to believe that a HAM graft will impair knee muscle function to a significantly higher degree than a PTB graft. After 10 years, both the hamstring and quadriceps muscle strength was regained compared with the contralateral side (Table 2).

Some limitations of the present study need to be addressed. A challenge when performing long-term follow-up studies is the number of patients lost to follow-up or dropouts. According to the power calculations performed when planning the study, 32 patients were needed in each group. In the original plan, the present study was meant to have a follow-up time of 2 years and the power calculations were based on the Cincinnati knee score as the primary outcome measurement. Ten years after surgery, the main focus was on prevalence of OA and clinical outcomes and we do not know if we had sufficient statistical power to detect a significant difference in OA between the 2 groups. The insignificant difference in prevalence of OA between the groups is, however, in correspondence with the results from the functional tests used in the study; at 10 years, no significant differences at all were shown. Another limitation might be the reliability of the classification of the radiographs, which may be the subject of individual interpretations.

Two different femoral fixation methods were used for the 2 grafts. Therefore, this study compared not only the use of 2 different grafts, but also 2 different techniques of fixation.[1] However, the failure load and stiffness for the 2 fixation devices have been shown to be comparable,[16] and should therefore not represent a threat to the credibility of the study.

CONCLUSION

At 10 years postoperatively, no statistically significant differences in clinical outcome between the 2 graft types were found. The prevalence of OA was significantly higher in the operated leg than in the contralateral leg, but there were no significant differences between the 2 groups. The results indicate that the choice of graft type after an ACL injury has minimal influence on the prevalence of OA 10 years after surgery.

REFERENCES

1. Aune AK, Holm I, Risberg M, Jensen HK, Steen H. Four-strand hamstring tendon autograft compared with patellar tendon-bone autograft for anterior cruciate ligament reconstruction: a randomized study with two-year follow-up. *Am J Sports Med*. 2001;29:722-728.
2. Eriksson E. Does harvesting the hamstrings for ACL reconstruction impair the muscular function of the knee joint? *Knee Surg Sports Traumatol Arthrosc*. 2008;16(1):2-14.
3. Flandry F, Hunt JP, Terry GC, Hughston JC. Analysis of subjective knee complaints using visual analog scales. *Am J Sports Med*. 1991;19:112-118.
4. Goldblatt JP, Fitzsimmons SE, Balk E, Richmond JC. Reconstruction of the anterior cruciate ligament: meta-analysis of patellar tendon versus hamstring tendon autograft. *Arthroscopy*. 2005;21:791-803.
5. Jansson KA, Linko E, Sandelin J, Harilainen A. A prospective randomized study of patellar versus hamstring tendon autografts for anterior cruciate ligament reconstruction. *Am J Sports Med*. 2003;31:12-18.
6. Kellgren JH, Lawrence JS. Radiological assessment of osteoarthrosis. *Ann Rheum Dis*. 1957;16:494-502.
7. Kessler MA, Behrend H, Henz S, Stutz G, Rukavina A, Kuster MS. Function, osteoarthritis and activity after ACL-rupture: 11 years follow-up results of conservative versus reconstructive treatment. *Knee Surg Sports Traumatol Arthrosc*. 2008;16:442-448.
8. Kothari M, Guermazi A, von Ingersleben G, et al. Fixed-flexion radiography of the knee provides reproducible joint space width measurements in osteoarthritis. *Eur Radiol*. 2004;14:1568-1573.
9. Noyes FR, McGinniss GH, Mooar LA. Functional disability in the anterior cruciate insufficient knee syndrome: review of knee rating systems and projected risk factors in determining treatment. *Sports Med*. 1984;1:278-302.
10. Pinczewski LA, Deehan DJ, Salmon LJ, Russell VJ, Clingeleffer A. A five-year comparison of patellar tendon versus four-strand hamstring tendon autograft for arthroscopic reconstruction of the anterior cruciate ligament. *Am J Sports Med*. 2002;30:523-536.
11. Pinczewski LA, Lyman J, Salmon LJ, Russell VJ, Roe J, Linklater J. A 10-year comparison of anterior cruciate ligament reconstructions with hamstring tendon and patellar tendon autograft: a controlled, prospective trial. *Am J Sports Med*. 2007;35:564-574.
12. Price DD, McGrath PA, Rafii A, Buckingham B. The validation of visual analogue scales as ratio scale measures for chronic and experimental pain. *Pain* 1983;17:45-56.
13. Risberg MA, Ekeland A. Assessment of functional tests after anterior cruciate ligament surgery. *J Orthop Sports Phys Ther*. 1994;19:212-217.
14. Risberg MA, Holm I, Steen H, Beynnon BD. Sensitivity to changes over time for the IKDC form, the Lysholm score, and the Cincinnati knee score: a prospective study of 120 ACL reconstructed patients with a 2-year follow-up. *Knee Surg Sports Traumatol Arthrosc*. 1999;7:152-159.
15. Roe J, Pinczewski LA, Russell VJ, Salmon LJ, Kawamata T, Chew M. A 7-year follow-up of patellar tendon and hamstring tendon grafts for arthroscopic anterior cruciate ligament reconstruction: differences and similarities. *Am J Sports Med*. 2005;33:1337-1345.
16. Rowden NJ, Sher D, Rogers GJ, Schindhelm K. Anterior cruciate ligament graft fixation: initial comparison of patellar tendon and semitendinosus autografts in young fresh cadavers. *Am J Sports Med*. 1997;25:472-478.
17. Shaieb MD, Kan DM, Chang SK, Marumoto JM, Richardson AB. A prospective randomized comparison of patellar tendon versus semitendinosus and gracilis tendon autografts for anterior cruciate ligament reconstruction. *Am J Sports Med*. 2002;30:214-220.
18. Spindler KP, Kuhn JE, Freedman KB, Matthews CE, Dittus RS, Harrell FE Jr. Anterior cruciate ligament reconstruction autograft choice: bone-tendon-bone versus hamstring: does it really matter? A systematic review. *Am J Sports Med*. 2004;32:1986-1995.
19. Tegner Y, Lysholm J. Rating systems in the evaluation of knee ligament injuries. *Clin Orthop Relat Res*. 1985;198:43-49.
20. Wroble RR, Van Ginkel LA, Grood ES, Noyes FR, Shaffer BL. Repeatability of the KT-1000 arthrometer in a normal population. *Am J Sports Med*. 1990;18:396-399.