Clinical Results and Risk Factors for Reinjury 15 Years After Anterior Cruciate Ligament Reconstruction : A Prospective Study of Hamstring and Patellar Tendon Grafts

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Clinical Results and Risk Factors for Reinjury 15 Years After Anterior Cruciate Ligament Reconstruction

A Prospective Study of Hamstring and Patellar Tendon Grafts

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Background: There is a lack of prospective studies comparing the long-term outcome of endoscopic anterior cruciate ligament (ACL) reconstruction with either a patellar tendon or hamstring tendon autograft.

Purpose: This prospective longitudinal study compared the results of isolated endoscopic ACL reconstruction utilizing a 4-strand hamstring tendon (HT) or patellar tendon (PT) autograft over a 15-year period with respect to reinjury, clinical outcomes, and the development of osteoarthritis.

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

Methods: Ninety consecutive patients with isolated ACL rupture were reconstructed with a PT autograft, and 90 patients received an HT autograft, with an identical surgical technique. Patients were assessed at 2, 5, 7, 10, and 15 years. Assessment included the International Knee Documentation Committee (IKDC) knee ligament evaluation including radiographic evaluation, KT-1000 arthrometer testing, and Lysholm knee score.

Results: Patients who received the PT graft had significantly worse outcomes compared with those who received the HT graft at 15 years for the variables of radiologically detectable osteoarthritis (grade A: 46% in PT and 69% in HT; P = .04), motion loss (extension deficit $<3°$: 79% in PT and 94% in HT; P = .03), single-legged hop test (grade A: 65% in PT and 92% in HT; P = .001), participation in strenuous activity (very strenuous or strenuous: 62% of PT and 77% of HT; P = .04), and kneeling pain (moderate or greater pain: 42% of PT and 26% of HT; P = .04). There was no significant difference between the HT and PT groups in overall IKDC grade (grade A: 47% of PT and 57% of HT; P = .35). An ACL graft rupture occurred in 17% of the HT group and 8% of the PT group (P = .07). An ACL graft rupture was associated with nonideal tunnel position (odds ratio [OR], 5.0) and male sex (OR, 3.2). Contralateral ACL rupture occurred in significantly more PT patients (26%) than HT patients (12%) (P = .02) and was associated with age $\leq$18 years (OR, 4.1) and the PT graft (OR, 2.6).

Conclusion: Anterior cruciate ligament reconstruction using ipsilateral autograft continues to show excellent results in terms of patient satisfaction, symptoms, function, activity level, and stability. The use of HT autograft does, however, show better outcomes than the PT autograft in all of these outcome measures. Additionally, at 15 years, the HT graft–reconstructed ACLs have shown a lower rate of radiological osteoarthritis.

Keywords: ACL reconstruction; osteoarthritis; hamstring tendon; patellar tendon; reinjury; long term

Anterior cruciate ligament (ACL) rupture is an injury commonly seen in young athletes. Treatment is aimed at eliminating episodes of instability, returning patients to a preinjury level of function, minimizing further meniscal or chondral damage, and reducing the risk of developing osteoarthritis. Treatment options include nonoperative rehabilitation programs and surgical reconstruction.[8,12] In the young, active population, ACL reconstruction is indicated to achieve the stated treatment goals, and with modern techniques, endoscopic reconstruction is the standard of care.[5]

Given the high frequency of the injury, ACL reconstruction is a commonly performed procedure, but debate continues over the technical aspects, in particular, the choice

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TABLE 1
Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Endoscopic anterior cruciate ligament reconstruction with either patellar tendon or hamstring tendon autograft between January 1993 and November 1994	Any associated ligament injury requiring surgery Evidence of chondral damage or degeneration Previous meniscectomy Excision of greater than one third of 1 meniscus at time of reconstruction Abnormal radiograph result Abnormal contralateral knee joint Patients seeking compensation for their injury Patients unwilling to participate in a research program

of graft used. Grafts in common use consist mainly of autografts such as bone–patellar tendon–bone (PT) and 4-strand hamstring tendon (HT) grafts, both ipsilateral and contralateral. Allografts and synthetic grafts are also being used, but less data are available on their efficacy and durability.

This prospective study looks at the long-term results of ACL reconstruction, comparing multiple outcomes after reconstruction with ipsilateral PT and HT autografts.

MATERIALS AND METHODS

Ethical approval was obtained from an independent hospital Human Ethics Committee. This study is an ongoing prospective cohort study, with 15-year results being reported.

Patient Selection

Anterior cruciate ligament reconstruction was offered to patients who demonstrated clinical ACL instability with at least grade II Lachman and pivot-shift test results. The acute injury was managed with physical therapy to regain near full range of movement with minimal pain and swelling. After this, repeat clinical assessment was performed to confirm near or full range of movement as well as clinical instability before proceeding with surgery. Failure to achieve near full range of movement after 12 weeks was an indication to proceed with arthroscopy. At the time of surgery, it was then determined if significant meniscal injuries were present, and those requiring removal of more than one third of one meniscus were excluded from the study. There were 17 cases included in the study that had meniscal suturing. Those patients meeting all the selection criteria were then included. The process of patient selection for this study has been previously documented,[7] and the inclusion and exclusion criteria are presented in Table 1. The large number of exclusions is because of the strict criteria, which were designed to minimize the confounding variables and allow a true comparison of results between graft types.

From January 1993 to April 1994, 333 patients were prospectively examined and underwent surgical reconstruction of the ACL using a PT autograft. Of this group, 90 patients fulfilled the study inclusion criteria and were included in this study. In October 1993, the senior author (L.P.) started using the HT autograft and, after April 1994, used the HT graft exclusively. There were 39 patients who underwent surgery during the 6-month overlap period; 15 received the HT autograft, and 24 received the PT autograft. The decision of which graft to use during this period was based on the initial consultation where patients who were seen from mid-October 1993 were offered the HT autograft. From October 1993 to November 1994, 372 patients underwent ACL reconstruction using a 4-strand HT autograft. Of this group, 90 met the selection criteria and were included in this study. The patient demographics are outlined in Table 2 and have been reported in detail previously.[7,18,19]

TABLE 2
Patient Demographics at Time of Selection

	Patellar Tendon Group	Hamstring Tendon Group
Male patients, total (right knees/left knees), n	48 (29/19)	47 (22/25)
Female patients, total (right knees/left knees), n	42 (25/17)	43 (16/27)
Median age (range), y	25 (15-42)	24 (13-52)

Surgical Technique

All procedures were performed by the senior author (L.P.). The technique was standardized for all patients and has previously been described in detail.[7,18,19] In the PT group, the ipsilateral middle-third bone–patellar tendon–bone graft was used, and the tunnel diameter was 1 mm greater than the measured bone block diameter (range, 8-11 mm). In the HT group, a 4-strand gracilis and semitendinosus tendon graft was used, and the tunnel diameter equaled the measured diameter of the graft (range, 6-9 mm).

The femoral tunnel was drilled before the tibial tunnel via the anteromedial arthroscopic portal, with the knee in maximal flexion, and positioned 5 mm anterior to the posterior capsular insertion. The tibial tunnel was centered on a line between the anterior tibial spine and the posterior margin of the anterior horn of the lateral meniscus, half a graft diameter lateral along that line. In all cases, the fixation consisted of a 7 × 25–mm titanium cannulated interference screw (RCI, Smith & Nephew Endoscopy, Andover, Massachusetts) for both femoral and tibial fixations.

Rehabilitation

Both groups were treated with the same rehabilitation program. Patients began weightbearing and co-contractions of the hamstrings and quadriceps immediately after surgery. No brace was used, and crutches were discarded as soon as possible. An accelerated rehabilitation program was instituted by physical therapists, focusing on achieving full extension ideally by 14 days after surgery and full flexion and extension by 6 weeks. Jogging was commenced at 6 weeks, and return to competitive sports was restricted until 6 months and only after reconfirming knee stability on clinical examination.

Assessment

All patients were assessed by an experienced, independent examiner before surgery and 6 and 12 months after surgery, then annually for 5 years, and again at 7, 10, and 15 years after surgery. The International Knee Documentation Committee (IKDC) evaluation form[2] was used, and symptoms and signs of knee function were assessed to determine the IKDC grade. From 2003 onward, the updated IKDC[3] evaluation form was used. The Lysholm knee score was obtained by a self-administered questionnaire.[10,16,29] Clinical assessment of knee stability was performed and recorded as a side-to-side difference compared with the normal contralateral knee, using the Lachman, anterior drawer, and pivot-shift tests. Instrumented laxity testing was determined using the KT-1000 arthrometer (MEDmetric Corp, San Diego, California) measuring side-to-side differences in displacement on manual maximum testing. Range of motion was determined using a goniometer. Pain from kneeling on a standard carpet surface and hamstring muscle discomfort were recorded for site and severity using a visual analog scale from 0 (no pain) to 10 (most severe pain). Single-legged hop test was also performed as a further assessment of function.

Radiographs were taken at 2, 5, 7, 10, and 15 years after surgery including weightbearing anteroposterior (AP), 30° of flexion posteroanterior (PA), lateral, and 45° Merchant views. These were assessed by an independent, experienced musculoskeletal radiologist for evidence of degenerative change in the medial, lateral, and patellofemoral compartments and classified according to the IKDC guidelines as follows: A, normal; B, minimal change and barely detectable joint space narrowing; C, moderate changes and joint space narrowing of up to 50%; and D, severe changes and more than 50% joint space narrowing. The worst grade of the 3 compartments was used to assign the overall radiographic grade.

The radiographs were also reviewed to assess tunnel position, using methods previously reported.[20] The radiographs were assessed on lateral view to determine the sagittal position of the femoral and tibial tunnels and reported as a percentage of the distance from the anterior to the center of the tunnel along the Blumensaat line for the femoral tunnel and from the anterior to the center of the tunnel along the tibial plateau for the tibial tunnel. On the 30° of flexion PA view, the coronal position of the tunnels was recorded, with the tibial tunnel position reported as a percentage from medial to lateral along the tibial plateau and the graft inclination angle recorded to assess overall coronal position of the graft. The ideal tunnel position has been defined as being a sagittal tibial tunnel 40% to 50% anterior, sagittal femoral tunnel 80% to 90% posterior, and coronal graft inclination greater than 17°.[20]

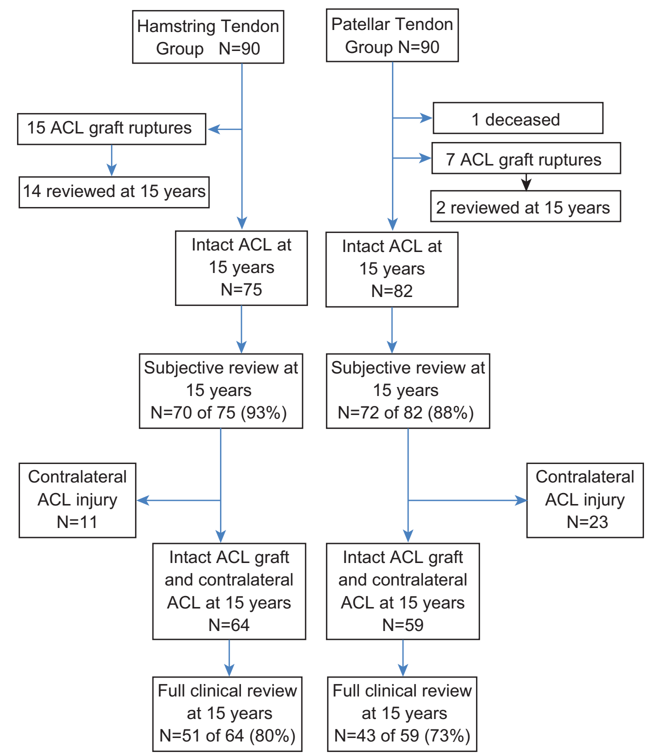

Figure 1. Participant flow chart.

Statistical Analysis

The outcomes of the continuous measurements (KT-1000 arthrometer, range of motion, Lysholm score) were compared between the 2 groups using the Mann-Whitney *U* test. Ordered categorical variables (IKDC categories) were compared with the χ^2 test. Logistic regression analysis was used to assess the relative contribution of the selected variable on the outcomes of ACL graft rupture, contralateral ACL injury, and radiographic osteoarthritis. Statistical significance was assessed at the 5% level.

RESULTS

Follow-up

The original study group contained 180 patients, with 90 in each group. The participant flow is shown in Figure 1. Within the follow-up patients, certain results within the analysis have been removed to avoid bias. The objective components of the IKDC require comparison of the reconstructed knee with the contralateral normal knee;

TABLE 3
Details of Further Surgery to Index Knee

	Patellar Tendon Group	Hamstring Tendon Group
Nil	76	69
Meniscectomy	5	10
Revision anterior cruciate ligament reconstruction	4	8
Excision of tibial screw	2	0
Excision of tibial ganglion	0	1
Excision of patellar tendon cyst	1	0
Excision of cyclops lesion	1	2
Arthroscopy	2	0
Open reduction and internal fixation of tibial fracture	0	1

however, 34 patients sustained a contralateral ACL rupture within the follow-up period of this study. The objective results for these patients have, therefore, been removed, while the subjective results are included.

Operative Findings

The timing of surgery was the same for both groups. Reconstruction was performed less than 12 weeks after injury for 70 of 90 in the HT group and 66 of 90 in the PT group (P = .42). Patients with significant meniscal injury requiring removal of greater than one third of one meniscus were excluded; however, medial meniscal injuries were noted in 20 of 90 in the HT group and 18 of 90 in the PT group. Lateral meniscal injuries were seen in 43 of 90 in the HT group and 34 of 90 in the PT group (P = .35). The management of these meniscal injuries consisted of meniscal suturing in 10 HT and 7 PT patients and minimal resection of less than one third in 9 HT and 6 PT patients (P = .52).

Further Surgery. The details of any subsequent surgery on the index knee are listed in Table 3. This illustrates no statistically significant difference (P = .15) between the 2 groups. Ten patients from the HT group and 5 patients from the PT group required subsequent meniscectomy as a result of a subsequent trauma (P = .19).

ACL Graft Rupture. In the 15 years of follow-up from the time of surgery, there were 17% (n = 15) of patients with ruptured grafts from the HT group and 8% (n = 7) from the PT group. There is no statistically significant difference in the graft rupture rate between the groups (P = .07), and there was no difference in the timing of rupture, as shown in Figure 2.

Regression analysis was performed to assess the association between ACL graft rupture and selected variables. An ACL graft rupture was associated with sex and tunnel position. Men were more likely to rupture than women, with an odds ratio (OR) of 3.2 (95% confidence interval [CI], 1.1-9.4; P = .032). Nonideal tunnel position, as defined above, was more likely to rupture than an ideal tunnel position, with an OR of 5.0 (95% CI, 1.4-18; P = .037). An ACL graft rupture was not associated with graft type (OR, 2.1; 95% CI, 0.8-5.8; P = .146) or age less than 18 years (OR, 2.0; 95% CI, 0.6-6.3; P = .258).

Contralateral ACL Rupture. In the 15-year follow-up period of this study, a total of 34 ruptures of the contralateral ACL occurred. There was a significant difference between the 2 groups, with 12% (n = 11) of ruptures in the HT group and 26% (n = 23) of ruptures in the PT group (P = .02) (Figure 3).

Regression analysis of contralateral ACL rupture revealed 2 significant associations. Age less than 18 years had significantly higher odds of contralateral ACL injury than age greater than 18 years (OR, 4.1; 95% CI, 1.7-9.7; P = .002). The PT graft had significantly higher odds of contralateral injury than the HT graft, with an OR of 2.6 (95% CI, 1.1-5.9; P = .022). Contralateral ACL rupture was not associated with patient sex, with men having 22% compared with women having 16% (OR, 1.6; 95% CI, 0.7-3.5; P = .253).

Incidence of Further ACL Injury. The incidence of further ACL injury to either the reconstructed or contralateral knee was assessed, and there was no difference between the 2 groups, with 29% (n = 26) in the HT group and 32% (n = 30) in the PT group (P = .59) sustaining a further ACL injury (Figure 4).

Subjective Results

The subjective assessments include the IKDC knee subjective symptom evaluation, the Lysholm knee score, activity level, and kneeling pain.

IKDC Subjective Symptoms Assessment. The IKDC subjective knee evaluation form assesses pain, swelling, and giving way and gives a score out of 100, with 100 being the best possible score. There was a significant difference between the 2 groups (P = .05). The mean IKDC score for the HT group was 90 (standard deviation [SD], 11.8) compared with the PT group with a mean of 85 (SD, 17).

IKDC Functional Assessment. The IKDC functional assessment asks the patients to rate the function of their knee on a scale of 0 to 10, with 0 being the inability to perform any of their usual daily activities and 10 being normal, excellent function. At 15 years, a significant difference (P = .032) was shown between the 2 groups, again with the HT group performing better. The HT group had a mean of 9.1 (SD, 1.3) compared with the PT group with 8.5 (SD, 2.2).

Lysholm Knee Score. The Lysholm knee score[2,16] evaluates symptoms related to knee function (limp, need for support, locking, instability, pain, swelling, and impairment of stair climbing and squatting ability), with a best possible score of 100. At the 15-year evaluation, there was no significant difference between the 2 groups (P = .114), with the HT group having a mean of 93 (SD, 10) and the PT group having a mean of 89 (SD, 14). If patients with an ACL graft rupture were assumed to be in the poor category (Lysholm score <65), the total of good or excellent results was 72% (56 of 78) in the HT group and 65% (49 of 75) in the PT group (P = .343).

Activity Level. The current regular activity level was assessed by asking the patients to rate their activity level

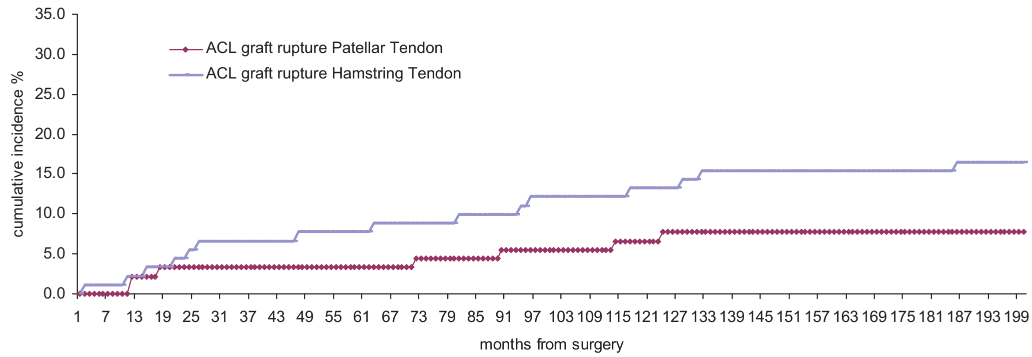

Figure 2. Incidence of graft rupture. Percentage of patients with graft rupture in the patellar tendon and hamstring tendon groups over a 15-year period.

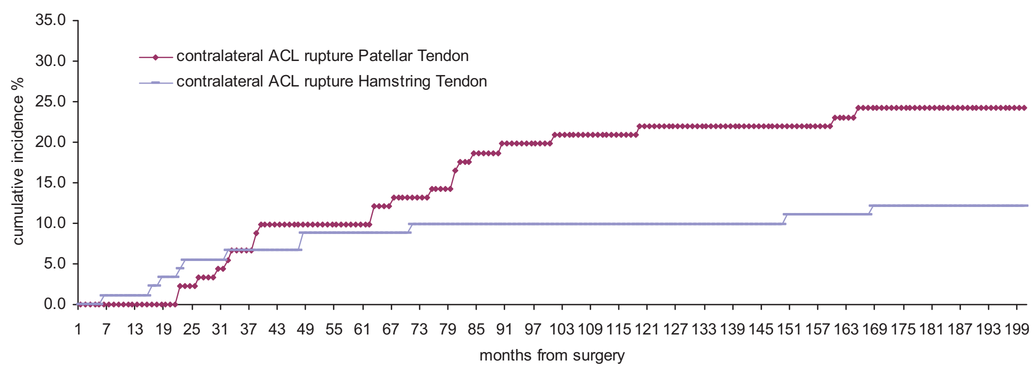

Figure 3. Incidence of contralateral anterior cruciate ligament (ACL) rupture. Percentage of patients with contralateral ACL rupture in the patellar tendon and hamstring tendon groups over a 15-year period.

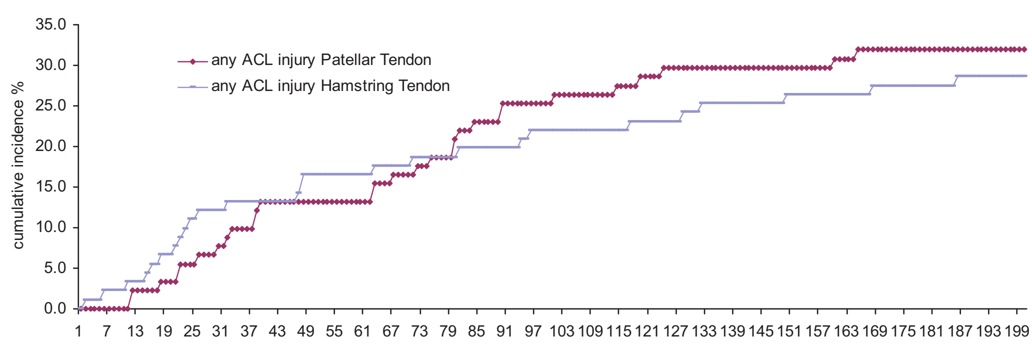

Figure 4. Incidence of any anterior cruciate ligament (ACL) rupture after surgery. Percentage of patients with either ACL graft rupture or contralateral ACL rupture in the patellar tendon and hamstring tendon groups over a 15-year period.

as being very strenuous (such as jumping and pivoting sports like basketball or soccer), strenuous (such as heavy physical work, skiing, or tennis), moderate (such as moderate physical work or running), light (such as walking and house or yard work), or unable to perform any of the above activities. The data for this are shown in Table 4. The HT group had a significantly higher level of activity, with 53% (n = 37) undertaking very strenuous activities and 24% (n = 17) undertaking strenuous activities compared with the PT group with 44% (n = 32) undertaking very strenuous activities and 18% (n = 13) undertaking strenuous activities ($P = .04$).

Kneeling Pain. Kneeling pain was reported after kneeling on carpet and graded on a visual analog scale as having no pain, minimally painful, moderately painful, extremely painful, or unable. The results are demonstrated in Figure 5 comparing no or minimal pain to moderate or greater

TABLE 4
Comparison of Activity Levels at 15 Years Between Hamstring and Patellar Tendon Groups (in Percentages)

	Patellar Tendon Group	Hamstring Tendon Group
Very strenuous	44	53
Strenuous	18	24
Moderate	24	21
Light	14	1
Unable	0	0

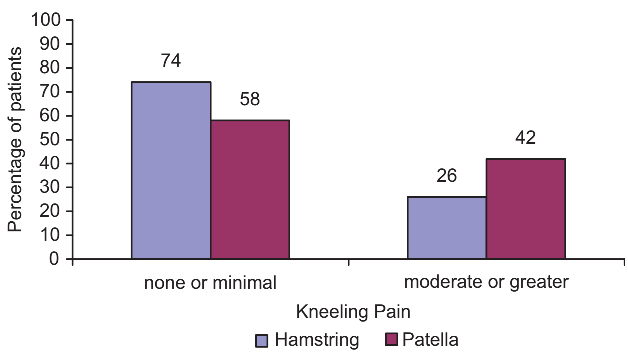

Figure 5. Kneeling pain. Percentage of patients with no or minimal pain compared with minimal or greater pain in the patellar tendon and hamstring tendon groups at 15 years' follow-up.

pain. The PT group had significantly more kneeling pain (P = .04), with 42% (n = 30) having moderate or greater pain compared with 26% (n = 18) in the HT group.

Objective Results

Objective results assessed include clinical ligament evaluation, range of movement, single-legged hop test, and the overall IKDC grade. Given that these clinical assessments require comparison with the normal contralateral knee, those patients who had sustained a contralateral ACL rupture are not included in these results. As a result, there were 51 patients tested clinically in the HT group and 43 in the PT group.

Clinical Ligament Evaluation. The reconstructed ACL was assessed clinically with the Lachman test and pivot-shift test and instrumented testing with the KT-1000 arthrometer.

Lachman Test. The Lachman test grades the knee as a comparison with the contralateral knee. Grade 0 is no difference, grade 1 is 1- to 5-mm laxity, grade 2 is 5- to 10-mm laxity, and grade 3 is greater than 10-mm laxity. In the HT group 78% of patients (n = 40) had grade 0 Lachman, and 22% (n = 11) had grade 1. In the PT group, 81% (n = 35) had grade 0, and 19% (n = 8) had grade 1. There were no cases in either group with grade 2 or 3 Lachman test results. These values show no difference between the 2 groups (P = .72). This has been consistent throughout this study at all intervals at 2, 5, 7, and 10 years.[7,18,19,21]

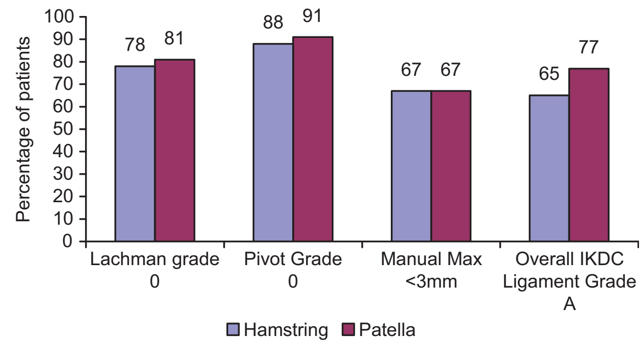

Figure 6. Clinical ligament evaluation at 15 years. Percentage of patients with grade 0 ligament evaluation in the patellar tendon and hamstring tendon groups at 15 years' follow-up. There was no significant difference between the groups on the Lachman test (P = .72), pivot-shift test (P = .70), manual maximum testing (P = .32), or overall International Knee Documentation Committee ligament grade (P = .34).

Pivot-Shift Test. The pivot-shift test was assessed as grade 0 being negative, grade 1 being a glide, grade 2 being a clunk, and grade 3 being gross. In the HT group, 88% (n = 45) had a grade 0 pivot, and 12% (n = 6) had a grade 1 pivot. In the PT group, 91% (n = 39) had a grade 0 pivot, and 9% (n = 4) had a grade 1 pivot. No patients had a grade 2 pivot, and there was no difference between the groups (P = .70).

Instrumented Testing. The KT-1000 arthrometer was used to assess the side-to-side difference on manual maximum testing. At 15 years, there was no difference between the 2 groups (P = .32), with the HT group having 66% (n = 34) with less than a 3-mm difference, 32% (n = 16) with a 3- to 5-mm difference, and 2% (n = 1) with a 6-mm difference. The PT group had 79% (n = 34) with less than a 3-mm difference, 21% (n = 9) with a 3- to 5-mm difference, and no patients with greater than a 5-mm difference.

Figure 6 summarizes the overall IKDC clinical ligament evaluation at 15 years.

Range of Movement. The range of movement has been evaluated in terms of both extension deficit and flexion deficit. Extension deficit was calculated by measuring the loss of passive extension in the involved knee, compared with the opposite knee, and grouped into 3 groups, as being less than 3°, 3° to 5°, and greater than 5°.

The HT group had 94% (n = 48) with less than 3°, 6% (n = 3) with 3° to 5°, and none with greater than 5° extension deficit. This compares with the PT group having 79% (n = 34) with less than 3°, 21% (n = 9) with 3° to 5°, and none with greater than 5° extension deficit. This shows a significantly higher rate of extension deficit in the PT group (P = .03), and the results are summarized in Figure 7.

The flexion deficit was measured in a similar manner and graded as less than or greater than 5° flexion deficit. There was no difference between the 2 groups (P = .42), with the HT group having 98% (n = 50) with less than 5° flexion deficit and 2% (n = 1) with greater than 5° flexion deficit, while the PT group had 100% (n = 43) with less than 5° flexion deficit.

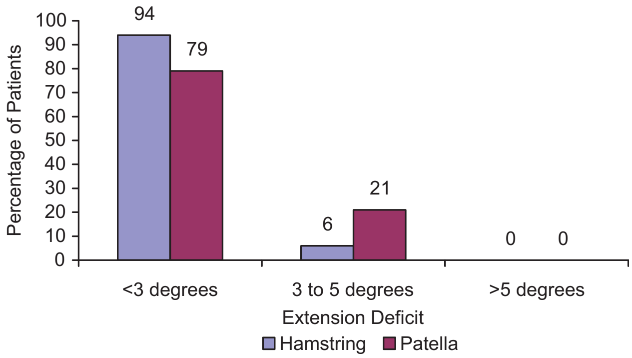

Figure 7. Extension deficit. Percentage of patients with extension deficit in the patellar tendon and hamstring tendon groups at 15 years' follow-up.

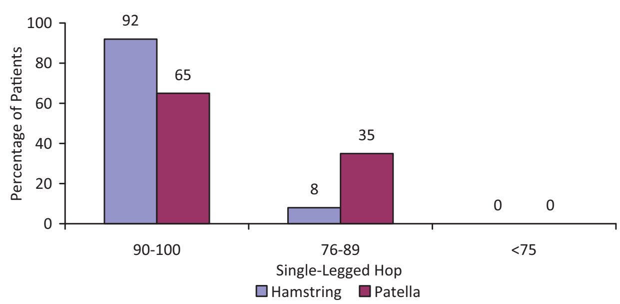

Figure 8. Single-legged hop test. Percentage of patients achieving single-legged hop test results, measured as a percentage compared with the normal contralateral limb, in the patellar tendon and hamstring tendon groups at 15 years' follow-up.

Single-Legged Hop Test. The single-legged hop test is an assessment of function that measures the distance achieved by a single-legged hop on the reconstructed leg compared with a hop on the contralateral normal leg, expressed as a percentage. A grade A hop equates to a distance 90% or greater than the contralateral limb. Grade B is 75% to 89%, and grade C is less than 75%.

At the 15-year follow-up, there were 48 patients tested for a single-legged hop in the HT group and 43 in the PT group. There was a significant difference between the 2 groups (P = .001). In the HT group, 92% (n = 44) achieved grade A, and 8% (n = 4) achieved grade B. In the PT group, 65% (n = 28) achieved grade A, and 35% (n = 15) achieved grade B, as shown in Figure 8.

These findings show a decline in hop performance in the PT group over the 10- to 15-year period. In all previous assessments, there had been no difference between the groups, and since the 10-year follow-up, there has been no change in the performance of the HT group but a decline in the PT group from 87% to 65% of patients achieving grade A. This change is demonstrated in Figure 9.

Overall IKDC. The overall IKDC gives a grade after assessing the 4 subgroups, including function, symptoms, range of movement, and laxity. The results give a grade of A, B, C, or D for each of the subgroups, and the worst rating is used to determine the overall IKDC grade. This is a very conservative measurement, as only a completely normal knee achieves grade A. Figure 10 demonstrates the percentage in each group and shows no significant difference between the HT and PT groups (P = .35). In the HT group, there were 57% (n = 29) with grade A, 41% (n = 21) with grade B, 2% (n = 1) with grade C, and 0% with grade D. In the PT group, there were 47% (n = 20) with grade A, 54% (n = 23) with grade B, and 0% with grade C or D.

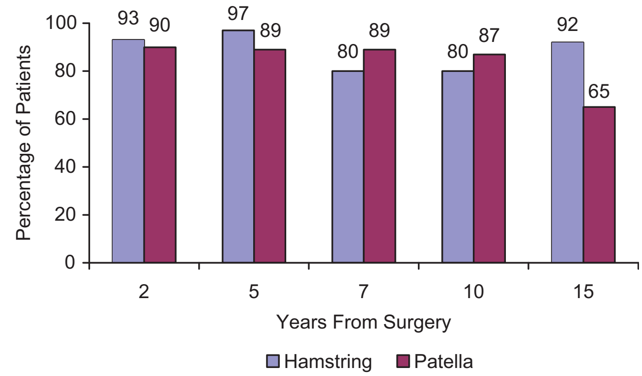

Figure 9. Single-legged hop test over time. Percentage of patients achieving greater than 90% on the single-legged hop test compared with the normal contralateral limb, comparing results at 2, 5, 7, 10, and 15 years from surgery.

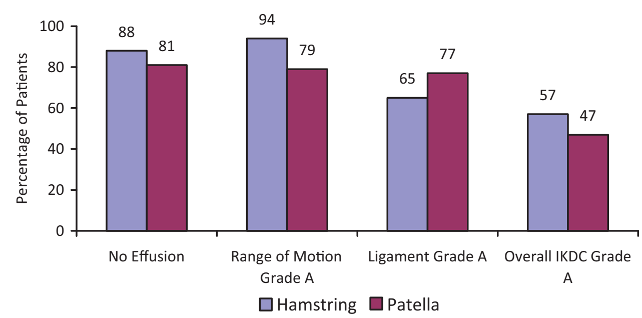

Figure 10. Overall International Knee Documentation Committee (IKDC) grade. Percentage of patients in each overall IKDC grade in the patellar tendon and hamstring tendon groups at 15 years' follow-up. There was a significant difference between groups for range of motion (P = .03). There was no significant difference between groups for knee effusion (P = .27), ligament grade (P = .34), or overall IKDC (P = .35).

If patients with an ACL graft rupture were assumed to have an abnormal overall IKDC evaluation, then the proportion of patients with normal or nearly normal overall IKDC ligament evaluation at 15 years was 89% (59 of 65) in the PT group and 79% (59 of 75) in the HT group (P = .144).

Radiographic Results

At 15 years, a total of 109 patients with an intact ACL graft had radiographs taken for review. This included 51 in the

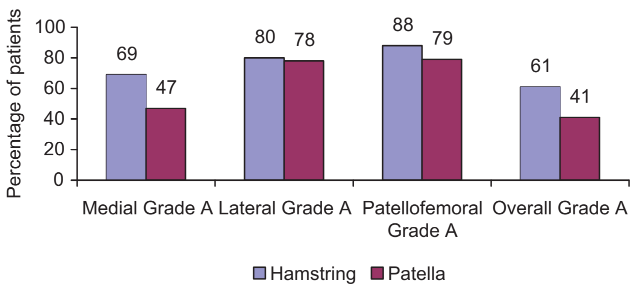

Figure 11. Fifteen-year radiological grade A. Percentage of patients with grade A radiographs in medial, lateral, and patellofemoral compartments and overall. The hamstring tendon group had a significantly higher percentage of patients with a normal medial compartment ($P = .04$) and overall compartment grade ($P = .04$) than the patellar tendon group. There was no significant difference between the groups for lateral ($P = .92$) and patellofemoral compartments ($P = .36$).

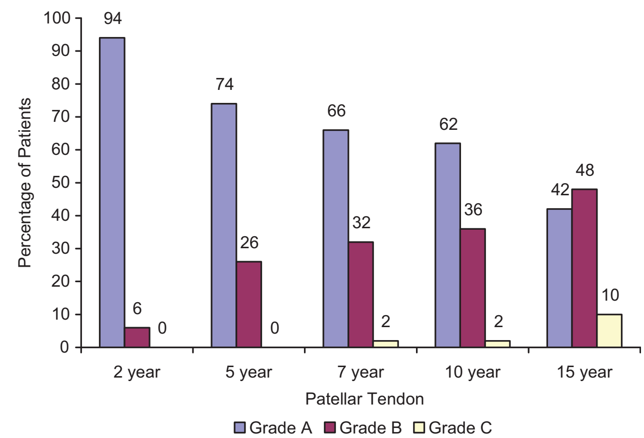

Figure 12. Patellar tendon radiographic grade over time. Percentage of patients from the patellar tendon group with radiographic grades A, B, or C over time.

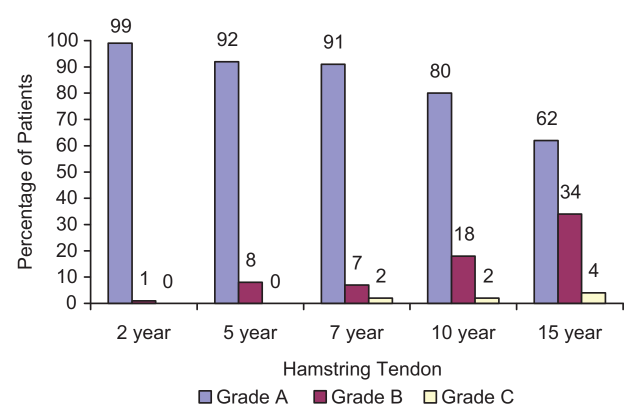

Figure 13. Hamstring tendon radiographic grade over time. Percentage of patients from the hamstring tendon group with radiographic grades A, B, or C over time.

HT group and 58 in the PT group. These radiographs were reviewed by an independent radiologist to assess for radiological signs of osteoarthritis. In addition, tunnel position was assessed using radiographs from all periods of follow-up, selecting the radiographs with the clearest view of the tunnels to measure the tunnel position as previously described.

Radiographic Osteoarthritis. The medial, lateral, and patellofemoral compartments were graded as A to D according to the IKDC grading system, and the worst grade was used to give the overall radiological grade. The predominant changes were in the medial compartment, with the HT group having significantly less radiological arthritic change ($P = .04$). The HT group radiographs showed grade A in 69% (n = 35), grade B in 29% (n = 15), grade C in 2% (n = 1), and grade D in 0% compared with the PT group with grade A in 46% (n = 27), grade B in 45% (n = 26), grade C in 9% (n = 5), and grade D in 0%.

There was no significant difference in the lateral and patellofemoral compartments, with the lateral compartment having 80% (n = 41) grade A in the HT group and 78% (n = 45) in the PT group ($P = .92$). The patellofemoral compartment had 88% (n = 45) grade A in the HT group and 79% (n = 46) in the PT group ($P = .36$).

The overall radiographic grades for the HT group were grade A in 61% (n = 31), grade B in 35% (n = 18), grade C in 4% (n = 2), and grade D in 0%. The PT group results were grade A in 41% (n = 24), grade B in 48% (n = 28), grade C in 10% (n = 6), and grade D in 0%. This showed a significantly higher rate of osteoarthritic change in the PT group when comparing grade A changes with grade B or higher ($P = .04$) (Figure 11).

Regression analysis was performed to assess for risk factors for osteoarthritic radiological change. The PT graft was found to pose a significantly higher risk than the HT graft, with an OR of 2.8 (95% CI, 1.2-6.2; $P = .01$). Other factors assessed did not show any causative relationship, including tunnel position ($P = .22$), graft inclination ($P = .42$), and further surgery ($P = .73$).

The progression of osteoarthritic change over time was reviewed, and these changes are demonstrated in Figures 12 and 13. This demonstrates a gradual progression over time, with the PT group being more rapid than the HT group.

Tunnel Position. Tunnel position was measured and classified overall as ideal or nonideal, using a technique previously described.[20] There were 174 of 180 radiographs reviewed for tunnel position measurement, with 89 from the HT group and 85 from the PT group. The mean values for tunnel placement are shown in Table 5.

The ideal sagittal femoral placement has been described as greater than 80% posterior along the Blumensaat line. In the HT group, 85% (n = 76) were ideally placed, and in the PT group, 67% (n = 57) were ideally placed ($P = .004$).

Ideal graft inclination angle has been described as greater than 17° from the vertical. Graft inclination of greater than 17° was found in 69% (n = 60) of the HT group and 78% (n = 65) of the PT group ($P = .114$).

TABLE 5
Comparison of Tunnel Placement Parameters Between Hamstring and Patellar Tendon Groups

	Hamstring Tendon	Patellar Tendon	*P* Value (Mann-Whitney *U* Test)
No. of patients	89	85	
Mean (standard deviation) tunnel placement, %			
Posterior femoral	84 (5)	82 (5)	.032
Anterior tibial	49 (4)	44 (5)	.003
Graft inclination	19 (4)	21 (5)	.076

Ideal sagittal tibial tunnel placement has been described as 40% to 50% anterior along the tibial plateau line. In the HT group, 60.7% (n = 54) were ideally placed. In the PT group, 71.8% (n = 61) were ideally placed. There was no significant difference in ideally placed sagittal tibial tunnel position (P = .083).

Overall, ideal position requires all 3 measurements to be ideal. In the HT group, 37.1% (n = 33) had an overall ideal tunnel position. In the PT group, 38.8% (n = 33) had an overall ideal tunnel position. There was no difference in the number of ideal tunnel positions between the 2 groups (P = .468).

DISCUSSION

This 15-year study provides the results of HT and PT grafts in ACL reconstruction and provides the longest prospective follow-up data currently available on endoscopic reconstructive surgery. Both techniques have shown excellent results in terms of knee symptoms and function as well as a low rate of osteoarthritis. There is, however, a high reinjury rate for both groups in terms of graft rupture and contralateral ACL rupture.

In this study, given that the procedure and fixation techniques were the same (other than graft choice), any differences in outcome should be attributed to the choice of graft. Earlier follow-up in this study showed no difference,[7,18] as have other similar studies in the short term to midterm.[9,11,13,22,26,28] It has now been shown that the HT graft is significantly better than the PT graft over the long term with respect to subjective assessments, activity level, fixed flexion deformity, and radiological osteoarthritis.

It appears that from 10 to 15 years of follow-up, there is a decline in several parameters in the PT group, which accounts for the emerging differences between the groups. At 10 years, there was no significant difference in extension deficit between the groups (P = .35), but at 15 years, significantly more of the PT group had an extension deficit compared with the HT group (P = .03). A similar decline in performance of the single-legged hop test was seen in the PT group between 10 and 15 years (Figure 9). The reason for these late-onset deficits is unclear but may be related to the onset of osteoarthritis.

The PT group showed a higher rate of radiological osteoarthritic change compared with the HT group. It is noted in Figures 12 and 13 that the degree of osteoarthritic change in the PT group at 10 years is similar to the HT group at 15 years' follow-up. There is a gradual progression of radiological degenerative change, which is more accelerated in the PT group than the HT group.

Numerous studies have assessed osteoarthritic change after ACL reconstruction. Holm et al[11] compared HT and PT grafts in ACL reconstruction and found no difference in the rate of arthritis at 10 years but an increased rate compared with the contralateral knee. Liden et al[14] found similar results at 7 years, with increased risk if an associated meniscal injury was present. Shelbourne and Gray[24] presented data with a mean of 14 years' follow-up that found a reduced range of movement compounded the other risk factors for osteoarthritis, such as meniscal and articular cartilage injury. This association between extension deficit and osteoarthritis may well explain some of the findings in this study, but it is not possible to account for all the other variables and differences in the studies to extrapolate the results of one study to another. Oeistad et al[17] performed a systematic review and found variable rates of osteoarthritis after ACL reconstruction and that there was no universal method of radiological classification, making it difficult to draw conclusions, other than that combined injuries had a higher rate of osteoarthritic change than isolated ACL injury. Louboutin et al[15] reviewed the risk factors for developing osteoarthritis 20 years after injury and again reported a higher rate of osteoarthritic change if meniscal injury was present. The same study also compared reconstructed knees to knees with cruciate ruptures managed nonoperatively and found the reconstructed knees to have a significantly lower rate of arthritis. Our study has used selection criteria that exclude cases with articular cartilage or significant meniscal injury, and therefore, differences in the rate of osteoarthritis because of these variables have been removed, leaving the graft choice as the major variable.

The vast literature on ACL reconstruction and osteoarthritis has not drawn any conclusions relating graft choice to the rate or degree of arthritis. The data in this study would suggest that given time and longer term follow-up, these differences are becoming evident. Why the PT graft is associated with a higher incidence of osteoarthritis than the HT graft is another area for further investigation. Joint kinematics studies comparing ACL reconstruction with the HT and PT grafts have shown that altered tibial rotation during walking is associated with the PT graft, which may account for the increased rate of osteoarthritis.[30]

By 15 years after surgery, 29% of the HT group and 32% of the PT group had either an ACL graft rupture or contralateral ACL injury. The high rate of reinjury in either knee has been documented and investigated in other studies.[4,6,23,25,27,31] The incidence of ACL graft and contralateral ACL injury appears highest in the first 3 years after reconstruction (Figures 1-3). While the overall incidence of injury to either knee seems alarmingly high, over a 15-year review period, this equates to an average 2% per annum rate of further ACL injury.

This study has identified risk factors for graft rupture as being nonideal tunnel position and male sex, risks for contralateral injury being age less than 18 years, and PT graft compared with HT graft. Nonideal tunnel position has been identified as a risk factor for graft rupture.[20] The high rate of reinjury in either knee has been documented and investigated in other studies.[4,6,17,23,25,27,31] It has been suggested that inappropriate ACL graft position is the most common cause of ACL graft failure.[1] In this study, the procedures were all performed in 1993 to 1994. At that time, the techniques for ACL reconstruction were still in the developmental stage, and the ideal tunnel position and its anatomic landmarks were still unknown. This is reflected in the finding in this study that only 37% of the HT group and 39% of the PT group had ideal tunnel placement on radiological assessment. Over time, the ideal tunnel position and the importance of achieving it have been identified and reported.[20] As tunnel position improves with better understanding, it may be expected that graft rupture rates will decrease.

We found male sex was associated with ACL graft rupture. In contrast, Shelbourne et al[25] recently reported a higher rate of ACL graft rupture in women. The higher rate of ACL graft rupture in men over women may be related to activity levels. At 2 years after surgery, a higher proportion of men than women had returned to level 1 or 2 activities (87% of men vs 71% of women; $P = .01$). A similar sex difference was seen preoperatively, with 79% of women compared with 93% of men reporting participating in level 1 activities before their knee injury. A study by Salmon et al[23] identified a return to high-level sports as being the primary risk factor for reinjury in either knee but no difference between graft choice or sex. If men return to higher risk sports in larger proportions, it would be expected that a higher rate of graft injury would be seen.

There was a trend toward a higher incidence of ACL graft rupture in the HT group (17%) compared with the PT group (8%), which did not reach statistical significance ($P = .07$). However, regression analysis revealed that ACL graft rupture was not associated with graft type but rather tunnel position. Indeed, there were subtle differences between groups with respect to the placement of the tibial tunnel. The HT graft tunnels were more posterior along the tibial plateau in the sagittal plane than the PT grafts ($P = .003$). It has been shown previously that posterior placement of the tibial tunnel is associated with a higher incidence of ACL graft rupture,[20] and this may explain the discrepancy between the groups. In addition, there was a higher rate of return to level 1 and 2 sports in the HT group, which may also account for the trend of graft rupture.

The reason for the increased rate of contralateral injury in the PT group is undetermined in this study but can be speculated that because of the lower functional scores achieved in the reconstructed knee, there is more reliance placed on the contralateral knee. In addition, because of the poorer performance of the reconstructed knee, there may be overall poorer conditioning, making the contralateral knee more susceptible to injury.

Criticisms of this study are that the patients were not randomized and that there was a bias present because of the change in the treatment regimen. The PT group was taken as a consecutive group of patients after significant experience had been gained in the surgical technique. The HT group, however, were consecutive patients using a new graft technique with no prior experience for the surgical team and a novel fixation technique for this graft type. This leads to a bias toward the PT group. It has been noted that since the completion of the recruitment and procedural phases of this study, the techniques of fixation have been improved, which should lead to better outcomes for patients with HT grafts than those recorded in this cohort. Other areas of bias have been minimized in that all other technical aspects were standardized by having the same surgeon, same tunnel placement, same fixation, and same rehabilitation program as well as strict selection criteria removing other variables that may confound the results.

CONCLUSION

Long-term follow-up of ACL injury has shown a high reinjury rate of approximately 30% when considering graft rupture and contralateral injury. Nonideal tunnel position and male sex, but not graft type, are associated with an increased rate of graft rupture, and age less than 18 years and PT autograft are associated with contralateral ACL injury.

Anterior cruciate ligament reconstruction using an ipsilateral autograft continues to show excellent results in terms of patient satisfaction, symptoms, function, activity level, and stability. The use of HT autografts does, however, show better outcomes than PT autografts in all of these outcome measures. Additionally, at 15 years, the HT graft–reconstructed ACLs have shown a lower rate of radiological osteoarthritis. The results seen in this study have led to our recommendation to use HT autografts for ACL reconstruction.

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