Revision Anterior Cruciate Ligament Reconstruction With Hamstring Tendon Autograft

5- to 9-Year Follow-up

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Background: The results of revision anterior cruciate ligament reconstruction are limited in the current literature, and no studies have previously documented the outcome of revision anterior cruciate ligament reconstruction using solely hamstring tendon grafts.

Hypothesis: Revision anterior cruciate ligament reconstruction with 4-strand hamstring tendon graft affords acceptable results and is comparable to reported outcomes with the bone–patellar tendon–bone graft.

Study Design: Case series; Level of evidence, 4.

Methods: Fifty-seven consecutive revision anterior cruciate ligament reconstructions with the hamstring tendon graft and interference screw fixation were assessed a mean time of 89 months (range, 60-109 months) after surgery. Assessment included the International Knee Documentation Committee knee ligament evaluation, instrumented laxity testing, and radiologic examination.

Results: Of the 50 knees reviewed, 5 (10%) had objective failure of the revision anterior cruciate ligament reconstruction. Of the 45 patients with functional grafts, knee function was normal or nearly normal in 33 patients (73%). An overall grade of normal or nearly normal was found in 56% of patients. The mean side-to-side difference on manual maximum testing was 2.5 mm (range, –1 to 4 mm). Degenerative changes on radiographs were identified in 23% of patients at the time of surgery, increasing to 56% of patients at review. The status of the articular cartilage at the time of revision surgery was the most significant contributor to successful outcome.

Conclusion: Revision anterior cruciate ligament reconstruction with hamstring tendon graft and interference screw fixation affords acceptable results at a minimum of 5 years' follow-up. Good objective results can be obtained, but subjectively, the results appear inferior to those of primary anterior cruciate ligament reconstruction in the literature, which may be related to the high incidence of articular surface damage in this patient population. We recommend that, when available, hamstring tendon autografts should be considered for revision anterior cruciate ligament reconstruction.

Keywords: anterior cruciate ligament (ACL) reconstruction; revision; hamstring tendon; outcome

Anterior cruciate ligament (ACL) is a common injury among young sporting persons. In the United States, more than 100 000 ACL reconstructions are performed each year.[33] Not only is the number of ACL reconstructions performed increasing, but so too are the expectations of the patients who return to their desired activity with greater enthusiasm. Inevitably, reinjury and failures occur, and an increasing number of patients are requiring revision ACL reconstruction. In Australia, the number of revision ACL reconstructions performed has almost doubled during the past 10 years (Figure 1).

Anterior cruciate ligament graft failure may result from a number of causes that can be broadly classified into 1 of 4 groups.[18] Technical errors, such as inadequate placement, tensioning, or fixation of the graft, are common.[7,9,19,20,22,25,26,43] Biologic failure may occur when the graft fails to incorporate because of avascularity, immunologic reaction, or

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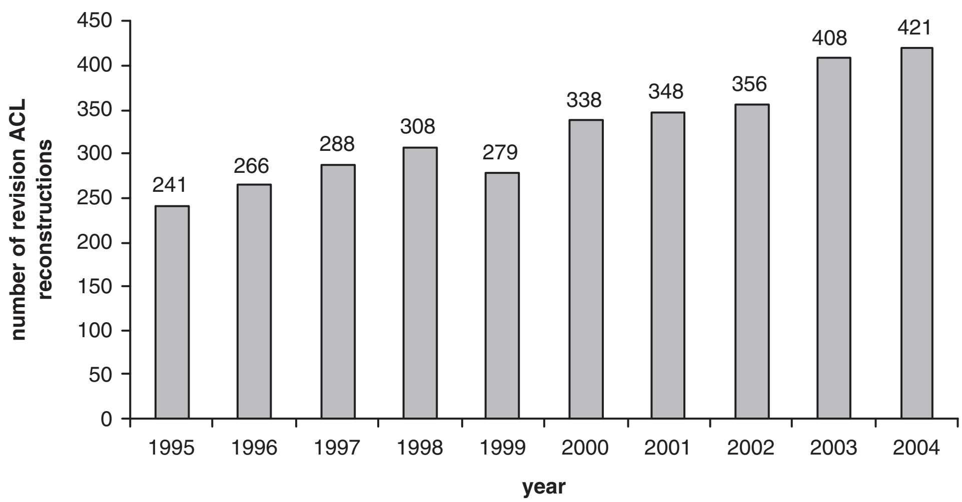

Figure 1. Number of revision ACL reconstructions performed in Australia each year. Source: Medicare Australia—Medical Benefits Schedule (MBS) Item Statistics Report. Available at: http://www.medicareaustralia.gov.au/statistics/dyn_mbs/forms/mbs_tab4.shtm. Accessed September 2005.

stress shielding.[9,18,20] Traumatic reinjury may occur early before graft incorporation or late after the patient has returned to sporting activities.[7,13,18,20,23] Lastly, failure to address associated ligament instability places the reconstructed graft under greater stress and may thereby cause graft failure.[3,22,28] In many cases, the cause of failure is multifactorial and may involve several of the above-mentioned factors.[20,22]

Current literature on the results of revision ACL reconstruction has largely focused on procedures performed with the patellar tendon graft,[§] or include subjects with a variety of graft constructs.[6,16,22,30,40,45] To date, there have been no studies specifically examining the results of revision ACL reconstruction with the hamstring tendon graft and interference screw fixation.

The aim of this study was to document the outcome of ACL reconstruction with a single-incision technique, quadrupled hamstring tendon graft, and interference screw fixation. We also sought to identify factors that predict successful outcome of revision ACL surgery.

METHODS

Study Group

The study group comprised 57 consecutive revision ACL reconstructions with 4-strand hamstring tendon graft in 57 patients from the Sydney metropolitan area performed by the senior author (L.A.P.) between 1996 and 1998. During the same period, 3 additional patients underwent revision ACL reconstruction with bone–patellar tendon–bone graft. The reason for the use of the patellar tendon graft in these patients was lack of hamstring tendon graft in 2 patients who had previously undergone bilateral ACL reconstruction with hamstring tendon. In another patient, significant enlargement of the femoral tunnel precluded adequate soft tissue fixation; therefore, bone–patellar tendon–bone graft was used with additional bone grafting. As the aim of this study was to assess the outcome of revision ACL reconstruction with the hamstring tendon graft, these 3 patients were not included. A single-incision technique was used by the surgeon in all revision ACL reconstructions during this period. Ethical approval for this study was granted by the University of Sydney. The diagnosis of failure of the primary ACL graft was based on clinical history and objective findings of positive pivot-shift and Lachman test results. Since 1993, all patients undergoing ACL reconstruction at our center were entered into a prospective database, which was used to select the patient population. The cause of primary ACL failure was determined at the time of revision surgery, based on clinical history and radiographic and intraoperative findings.

Surgical Technique

All surgeries were performed by the senior author, with the patient under general anesthesia and with a tourniquet. The surgical technique was similar to that used for primary ACL reconstruction, which has been previously reported in detail.[8] A single-incision endoscopic technique was used in all patients. All ligaments were reconstructed with a 4-strand hamstring tendon graft. The source of the revision ACL graft was the contralateral hamstring tendon in 26 patients and the ipsilateral hamstring tendon in 30 patients. One patient who had previously undergone 3 ACL reconstructions using her ipsilateral patellar tendon and both ipsilateral and contralateral hamstring tendons received a hamstring tendon allograft. The median graft diameter was 7.5 mm (range, 7-9 mm). Femoral drilling was performed via the anteromedial portal. Previous hardware was removed only if required to achieve good tunnel place-

§References 3, 7, 10, 14, 21, 26-28, 31, 47.

ment. Fixation was achieved with a 7 × 25-mm RCI interference screw (Smith and Nephew Acufex, Mansfield, Mass) in the femoral and tibial tunnels in all patients. After femoral fixation, firm manual traction was applied while the knee was taken through a full range of motion to pretension the graft and to ensure that full extension could be achieved without impingement. Notchplasty was performed only if required to prevent impingement of the graft. In 11 cases in which the tibial tunnel was enlarged or poor tibial bone stock was found, a supplementary tibial staple was used in a belt-buckle fashion in addition to the interference screw. As previously discussed, in 1 patient who was excluded from the study, significant femoral tunnel enlargement precluded the use of adequate fixation with the hamstring tendon graft in the femoral tunnel, and a bone–patellar tendon–bone graft was used with additional bone grafting.

Postoperative Rehabilitation

Patients were permitted to bear weight as tolerated on crutches immediately after surgery. They were given oral analgesics for pain control and daily physical therapy to reduce postoperative swelling and to allow active exercises, aiming for full extension by 14 days. No brace was used. The intensive rehabilitation program included closed chain exercises and an emphasis on proprioceptive training. Stationary cycling and swimming were commenced at 2 weeks postoperatively. At 6 weeks, patients began jogging in straight lines. From 12 weeks, general strengthening exercises were continued with agility work, and sports training activities were encouraged. Patients were advised to refrain from competitive sports involving jumping, pivoting, or sidestepping until 12 months after the revision reconstruction, if rehabilitation goals had been met.

Evaluation

Assessment was performed by either a physical therapist or a clinical researcher with extensive experience in knee assessment. Assessment consisted of the International Knee Documentation Committee (IKDC) Knee Ligament Evaluation Form (2001),[1] which incorporates multiple subjective and objective criteria. Ligament stability was measured by the Lachman[42] and pivot-shift tests.[17] The Lachman test was graded as 0 (less than 3 mm laxity), 1 (3-5 mm laxity), or 2 (>5 mm laxity), and the pivot-shift test was graded as 0 (negative), 1 (glide), 2 (clunk), or 3 (gross). Instrumented knee testing was performed using the KT-1000 arthrometer (MEDmetric Corp, San Diego, Calif) using the manual maximum test. Patients rated pain intensity when kneeling on a carpeted surface on a scale of 0 to 10. The level of sporting activity was assessed according to the IKDC levels I to IV, that is, strenuous (rugby, basketball); moderate (tennis, heavy manual labor); light (jogging); sedentary. Patients completed the Lysholm knee score[41] to further document subjective symptoms.

Radiologic examination was performed using bilateral 30° posteroanterior weightbearing, AP, lateral, and patellar skyline views. Radiographs were classified according to the IKDC guidelines as follows: A, normal; B, minimal changes and barely detectable joint space narrowing; C, moderate changes and joint space narrowing of up to 50%; and D, severe changes and more than 50% joint space narrowing. Radiographic evaluation of femoral and tibial tunnel placement was evaluated from the lateral film using the method reported by Harner et al.[24] On the tibial side, a line is drawn along the subchondral bone margin of the lateral tibial plateau and divided into 4 quadrants, and the quadrant containing the tibial tunnel is identified. On the femoral side, a line is drawn along the roof of the intercondylar notch (Blumensaat line) and divided into 4 quadrants. The quadrant containing the femoral tunnel was identified.

TABLE 1
Functional Grading of the Revision Anterior Cruciate Ligament Graft (n = 49)[a]

	n	%
Functional		
manual maximum		
<3 mm, negative pivot	24	48
Partially functional		
3- to 5-mm manual		
maximum, trace pivot	21	42
Failure		
>5 mm manual		
maximum, >trace pivot	5	10
	50	100

[a]Nine patients with contralateral anterior cruciate ligament deficiency graded according to pivot only.

Statistical Analysis

The Wilcoxon signed ranked test was used to assess change over time. Linear regression analysis was performed to assess the relative contribution of selected variables on linear outcomes. Statistical significance was set at .05. SPSS 11.0 for Windows (SPSS Science Inc, Chicago, Ill) was used for all statistical analysis.

RESULTS

Of the 57 patients in the study group, 50 (88%) were reviewed at a mean of 89 months (range, 60-109 months) after revision ACL reconstruction. Of the 7 patients lost to follow-up, 3 were known to have moved overseas or interstate but could not be contacted, and 4 could not be located. Six of these 7 patients attended a 6-month postoperative assessment, and all had grade 0 to 1 Lachman and pivot-shift test results at that time; however, full IKDC assessment was not routinely performed. One patient did not return for any postoperative assessments and was lost to follow-up.

Graft Failure and Complications

Failure of the graft was defined per the criteria applied by O'Neill[30] and is shown in Table 1.

TABLE 2
Details of 5 Patients Who Had Failure of the Revision Anterior Cruciate Ligament (ACL) Reconstruction[a]

	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
Gender	Male	Male	Female	Male	Male
Age at primary ACL injury, y	16	39	37	17	21
Family history of ACL injury	No	No	Yes	Yes	No
Mechanism of primary ACL failure	Failure, no injury	Rugby sidestep	Fall down stairs at 1 month	Hurdles, hyperextension	Soccer while intoxicated
Time to failure of primary ACL, mo	2	44	1	8	2
Mechanism of revision ACL failure	Walking backward, fall with 15-kg weight	Rugby sidestep	No injury	Tennis twist	Jump 1 m from truck
Time to failure of revision ACL, mo	96	48	6	60	18
Subsequent revision ACL reconstruction	No	Yes	No	Yes	Yes
Time from revision ACL to review, mo	108	88	79	104	91
Subjective knee function grade, A-D	D	B	C	C	C
Lysholm knee score, of 100	61	100	75	84	62
Lachman grade, 0-3	3	1	2	2	2
Pivot-shift grade, 0-3	2	0	2	2	1
KT-1000 arthrometer manual maximum, mm	10	2	NA[b]	4	5
Overall IKDC grade, A-D	D	B	C	C	C
Radiologic grade, A-D	C	B	C	A	B
Notes	High tibial osteotomy performed 9 years after revision		High tibial osteotomy performed 18 months before revision	Graft ruptured again at 60 months after surgery during tennis. Revision ACL with allograft performed, which ruptured again during soccer 19 months after surgery	

[a]IKDC, International Knee Documentation Committee.
[b]KT-1000 arthrometer testing not performed because of contralateral ACL deficiency.

Of the 50 knees reviewed, 5 patients (10%) had failure of the revision ACL reconstruction. Three of these 5 patients proceeded to subsequent revision ACL surgery. All failures of the revision ACL were excluded from further analysis but are shown in Table 2.

There were no cases of infection after revision ACL. Four patients had a meniscectomy subsequent to the revision ACL reconstruction performed at respective periods of 6, 12, 36, and 59 months postoperatively.

Patient Demographics

Forty-five patients with intact ACL grafts were reviewed at a mean of 90 months (range, 60-110 months) after revision ACL reconstruction. The mean age of the patients at the time of primary ACL reconstruction was 23 years (range, 14-37 years). The mean age of the patients at the time of revision ACL reconstruction was 27 years (range, 15-39 years). There were 9 female and 36 male patients. A positive family history of ACL injury was present in 16 of the 45 patients (36%). Eleven of the 45 patients (24%) had suffered a bilateral ACL injury.

Operative Details

Graft failure of the primary ACL reconstruction occurred at a mean of 36 months (range, 2-132 months). The primary ACL graft was a patellar tendon in 21 patients (47%) and a hamstring tendon in 21 patients (47%), and synthetic grafts were used in 3 patients (6%). The cause of primary ACL graft failure was noted at the time of revision surgery and is listed in Table 3. The primary ACL graft ruptured

TABLE 3
Cause of Primary Anterior Cruciate Ligament (ACL) Graft Failure

	Cause of Primary ACL Graft Failure	n	%
Traumatic reinjury	Traumatic rupture during sports after 6 months postoperatively	26	58
	Traumatic rupture during sports before 6 months postoperatively	3	7
Technical or biologic failure	Incorrect graft placement	10	22
	Failure of graft without trauma	5	11
	Fixation failure	1	2
		45	

in the midsubstance in 24 patients (53%), proximally in 8 patients (18%), distally in 4 patients (9%), was intact but lax in 1 patient (2%), and unknown in 8 patients (18%).

The source of the revision ACL graft was a contralateral hamstring tendon in 22 patients (49%) and ipsilateral hamstring tendon in 22 patients (49%). One patient (2%) who had previously undergone 3 ACL reconstructions using her ipsilateral patellar tendon and both ipsilateral and contralateral hamstring tendons received a hamstring tendon allograft. The median quadrupled hamstring tendon graft size was 7.5 mm (range, 7-9 mm). The revision ACL graft was fixed with RCI interference screws on the femoral side in all patients. Tibial fixation was achieved with RCI interference screw alone in 34 patients and with RCI interference screw with supplementary tibial staple in 11 patients. The revision ACL reconstruction was performed during the subacute stage (within 3 months) of ACL graft rupture in 25 patients (56%) and in the chronic stage (after 3 months from ACL graft rupture) in 20 patients (44%). At the time of revision surgery, radiographs were classified as normal (grade A) in 35 patients (78%), and minimal changes and barely detectable joint space narrowing (grade B) were noted in 10 patients (22%). At the time of revision ACL reconstruction, meniscectomy was required in a total of 18 patients (40%), 12 patients (27%) had undergone previous meniscectomy, and 15 patients (33%) had intact menisci. The articular surfaces were classified as normal in 21 patients (47%), and damage was graded as mild in 17 patients (38%), moderate in 5 patients (11%), and severe in 2 patients (4%). On regression analysis, articular surface damage was significantly associated with chronicity of injury ($P = .02$). The relationship between articular surface damage and the reason for primary graft failure ($P = .28$) or primary graft type ($P = .13$) was not statistically significant. The incidence of articular surface damage was 80% in patients with chronic injury, compared with 32% in those with subacute injury ($P = .01$).

Self-Reported Assessments

Self-reported assessment included the Lysholm knee score and the IKDC categories of perceived knee function, symptoms with activity, current activity level, and graft harvest site symptoms.

The mean Lysholm knee score was 85 (95% confidence interval, 81-90). International Knee Documentation Committee knee function was graded as normal or nearly normal in 33 patients (73%) and abnormal or severely abnormal in 12 patients (27%). Regression analysis revealed that poorer self-reported knee function was significantly related to articular surface damage at the time of revision surgery ($P = .05$). There was no significant relationship between knee function and instrumented laxity testing ($P = .09$), reason for primary ACL failure ($P = .56$), or meniscectomy at the time of revision reconstruction ($P = .75$) on regression analysis.

Moderate to strenuous activities could be performed without pain in 32 patients (71%), without swelling in 37 patients (82%), and without giving way in 41 patients (91%). On the IKDC knee ligament evaluation, the worst grade from each component determines the overall grade of symptoms with activity and is graphically shown in Figure 2.

Activity level was graded according to the IKDC questionnaire, with level I being strenuous activity, level II being moderate activity, level III being light activity, and level IV being sedentary activity. Twenty-six patients (58%) were participating in level I or II activities, and 19 patients (42%) were participating in level III or IV activities. Thirty-five of the 45 patients (78%) reported that their knee had no or mild effect on their activity level, and 10 patients (22%) reported a moderate to severe effect on their activity level.

Patients were asked to note tenderness, irritation, or numbness at the hamstring tendon harvest site and grade as A (none), B (mild), C (moderate), or D (severe). Thirty-two patients (71%) reported no symptoms arising from the hamstring tendon site, 10 patients (22%) reported mild symptoms, and 3 patients (7%) reported moderate symptoms.

Ligament Testing

Ligament laxity was assessed with the Lachman, pivot-shift, and KT-1000 arthrometer tests. Lachman testing was graded as 0 in 24 patients (53%), 1 in 20 patients (45%), and 2 in 1 patient (2%). On pivot-shift testing, 31 patients (69%) had grade 0 and 14 patients (31%) had a grade 1 test result. Instrumented testing with the KT-1000 arthrometer was performed on 34 patients. The 11 patients not assessed with the KT-1000 arthrometer had suffered a contralateral ACL injury and were therefore excluded from this analysis, which assumes a normal contralateral knee. The mean side-to-side difference on manual maximum testing was 2.5 mm (range, –1 to 4 mm). A side-to-side difference of less than 3 mm was recorded in 17 patients

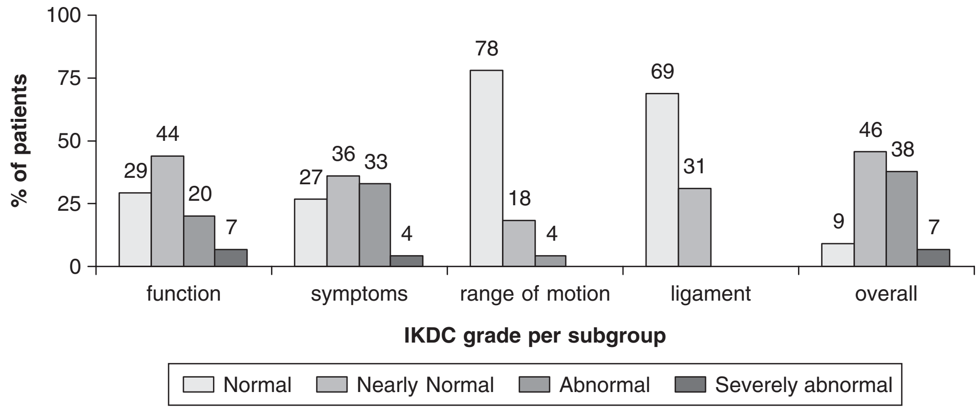

Figure 2. International Knee Documentation Committee (IKDC) grading of subgroups and overall grade.

(50%), and a side-to-side difference between 3 and 5 mm was recorded in 17 patients (50%). The worst grade from each of these tests determines the IKDC ligament grade and is shown in Figure 2.

Regression analysis was performed to assess the relative contributions of gender, cause of primary graft failure, meniscectomy, and articular surface damage noted at index surgery on the outcome of pivot-shift testing and manual maximum testing. Greater laxity on pivot-shift testing was significantly associated with poorer articular surface grades at the time of revision surgery ($P = .003$) and female gender ($P = .04$) but not reason for primary graft failure ($P = .22$) or meniscectomy ($P = .13$). Greater laxity on manual maximum testing was not significantly associated with poorer articular surface grades at the time of revision surgery ($P = .16$), female gender ($P = .85$), meniscectomy ($P = .40$), or reason for primary graft failure ($P = .60$).

Range of Movement

Extension loss of less than 3° was found in 36 patients (80%), between 3° and 5° was found in 7 patients (16%), and between 6° and 10° was found in 2 patients (4%). Flexion loss of less than 6° was found in 43 patients (96%), and flexion loss between 6° and 15° was found in 2 patients (4%). The IKDC range of motion score was normal in 35 patients (78%), nearly normal in 8 patients (18%), and abnormal in 2 patients (4%) (Figure 2).

Overall International Knee Documentation Committee Grade

The overall IKDC grade is determined from the worst score of the 4 components of knee function, symptoms with activity, range of motion, and ligament evaluation. Of the 45 patients reviewed, 25 patients (56%) had a normal or nearly normal overall IKDC grade, and 20 patients (44%) had an abnormal or severely abnormal grade (Figure 2). If the 5 patients who had a revision ACL graft failure are assumed to have an abnormal grade, the proportion of patients with a normal or nearly normal knee is 50%.

Functional Testing

Single-Legged Hop Test. Each patient was asked to perform a single-legged hop test for distance on the index and normal sides. Three trials for each leg were recorded and averaged. A ratio of the index to normal knee was calculated. Three patients did not complete this test because of ankle, back, or contralateral knee injury. Of the 41 patients assessed, 27 patients (63%) were able to hop greater than 90% of the contralateral side.

Kneeling Pain. Kneeling pain was assessed by having the patient kneel on a carpeted surface for approximately 1 minute and note the presence of pain. Intensity was graded from 0 to 10, with 0 being no pain and 10 being severe pain. At a mean of 89 months after surgery, 20 patients (44%) reported kneeling pain with a mean intensity of 5 (range, 1-8).

Radiologic Assessment

Radiographs were performed on 44 of the 45 patients reviewed. In 1 patient, radiographs were not performed because the review was conducted at a peripheral clinic without radiographic facilities. The results of the IKDC radiologic assessment are shown in Table 4. Twenty-three patients (52%) had a deterioration in radiologic grade at review compared with the prerevision ACL reconstruction ($P = .001$).

Regression analysis was performed to assess the relative contributions of age, cause of primary graft failure, meniscectomy, and articular surface damage noted at index surgery on the outcome of radiologic examination. Poorer radiologic grade was significantly associated with poorer articular surface grades at the time of revision surgery ($P = .004$). Meniscectomy ($P = .41$), age ($P = .66$), and reason for primary graft failure ($P = .11$) were not significantly related to outcome of radiologic examination.

From the lateral radiographs, tibial and femoral tunnel placements were assessed using the method described by Harner et al.[24] The tibial tunnel was in quadrant 2 in all patients, and the femoral tunnel was in quadrant 4 in all patients, reflecting good placement of the revision tunnels.

TABLE 4
International Knee Documentation Committee (IKDC) Radiologic Grade[a]

	Patellofemoral Compartment		Lateral Tibiofemoral Compartment		Medial Tibiofemoral Compartment		Overall Grade	
	n	%	n	%	n	%	n	%
Grade A	36	82	34	77	22	50	19	43
Grade B	8	18	8	18	15	34	17	39
Grade C			2	5	7	16	8	18
Grade D								
Total	44		44		44		44	

[a]IKDC radiologic grading: A, normal; B, minimal changes and barely detectable joint space narrowing; C, moderate changes and joint space narrowing of up to 50%; and D, severe changes and more than 50% joint space narrowing.

DISCUSSION

Although there is an abundance of literature examining the results of primary ACL reconstructions, the results of revision ACL reconstruction are relatively scarce. Most studies examining the outcome of revision ACL reconstruction have been performed on patients reconstructed with autologous, allogenic, or reharvested bone–patellar tendon–bone grafts[||] or included subjects with a variety of graft constructs.[6,22,30,40,45] The results of revision ACL reconstruction published in the current literature are difficult to interpret because of lack of standardized fixation methods, surgical techniques, graft types, and concurrent operative procedures. We present the results of revision ACL reconstruction in a series of 57 patients, all of whom underwent reconstruction with a quadrupled hamstring tendon autograft performed by a single surgeon with standardized operative technique, graft fixation methods, and postoperative rehabilitation reviewed at a minimum of 5 years' follow-up.

It has been reported that the failure rate of revision ACL reconstruction may be 2 to 3 times that of primary ACL reconstruction.[4] Objective failure was defined in this series, consistent with other authors,[14,28,30] as greater than 5 mm on manual maximum testing and greater than a grade 1 pivot-shift test result. The incidence of objective failure was 10% at the mean follow-up of 90 months, which is comparable with rates of failure after primary ACL reconstruction performed by this institution.[34,35,37,38] In previous studies, the failure rates for revision ACL reconstruction with patellar tendon allografts or autografts and shorter follow-up periods have been reported to be between 6% and 36%.[6,14,22,26,28,29,47]

It is generally accepted that the overall results of revision ACL reconstruction are inferior to those of primary ACL reconstruction.[4,21] Whereas the results of this study compare favorably with the existing literature on revision ACL reconstruction (Table 5), they are certainly inferior to previous studies of patients undergoing primary ACL reconstruction performed at this institution.[32,34,35,37,46] On overall IKDC grading, only 56% of patients received a normal or nearly normal assessment. The overall IKDC grade is determined from the worst grade of 4 components. Normal or nearly normal grading was found in 73% of patients for subjective knee function, 63% of patients for symptoms with activity, 96% of patients for range of motion, and 100% of patients for ligament evaluation. Thus, it appears that revision ACL reconstruction may be successful in objectively restoring stability to the knee, but on self-reported measures, inferior results are evident.

The reason for the inferior results seen with revision ACL reconstruction compared with primary ACL reconstruction is likely to be multifactorial. Not only is revision ACL reconstruction more technically challenging for the surgeon, but also the knee has suffered yet another traumatic insult to the menisci, articular cartilage, and surrounding structures. Other authors have reported high rates of concurrent articular surface damage in revision ACL patients.[21,28-30] In this series, worse articular surface damage was associated with poorer results on pivot-shift testing (P = .003), radiologic evidence of osteoarthritis (P = .004), and subjective knee function (P = .05). Indeed, the status of the articular cartilage at the time of revision ACL reconstruction was identified as the most important contributor to successful outcome of revision ACL surgery. Given that the articular surface damage was associated with chronicity of failed primary ACL reconstruction, we recommend that failed reconstructions be revised in the subacute stage before more episodes of instability lead to further damage to the articular surfaces, and thereby poorer outcomes of revision ACL reconstruction.

The reason for failure of the primary ACL graft in this series was most commonly attributed to traumatic reinjury, but technical errors in the primary surgery such as incorrect primary graft placement were attributed as the cause of failure in 35% of patients. Other authors have reported even higher rates of technical errors accounting for failure of the primary surgery.[6,7,22,26,30,40,43] Although it is

[||]References 3, 7, 10, 14, 21, 26-28, 31, 47.

TABLE 5
Published Studies Examining Results of Revision Anterior Cruciate Ligament Reconstruction[a]

Author and Year of Publication	n	Months of Follow-up (range)	Graft Source (n)	Operative Technique (n)	Failure (%)	Pivot 0-1 (%)	Mean KT-1000 Arthrometer (mm)	KT-1000 Arthrometer <3 mm (%)	Lysholm (mean)	X-ray Normal (%)	IKDC Grade A or B (%)
Bach, 2003[3]	32	>24	PT allograft (32)	Single incision endoscopic (24) Double incision endoscopic (8)	6	89	1.9	84	75	NA	NA
O'Neill, 2004[30]	48	90 (24-156)	2-strand HT autograft (10) 4-strand HT autograft (13) PT autograft (25)	Single incision endoscopic (34) Double incision endoscopic (14)	6	NA	NA	67	NA	63	83
Kartus et al, 1998[27]	24	26 (20-33)	Reharvested PT autograft (12) Contralateral PT autograft (12)	Single incision endoscopic (23) Miniarthrotomy (1)	NA	NA	3 2	42 83	62 84	NA	25 58
Taggart et al, 2004[40]	20	12	PT autograft (8) allograft (2) HT autograft (1) LAD (8) Dacron (1)	Single incision endoscopic?	35	60	NA	40	85	NA	NA
Harilainen and Sandelin, 2001[22]	29	24	Reharvested PT autograft (14) Contralateral PT autograft (7) HT autograft (9)	Not described	7	NA	3.6	NA	84	NA	NA
Fules et al, 2003[16]	29	50 (12-97)	HT autograft (26) Quadriceps tendon (2) PT autograft (1)	Double incision endoscopic (29)	3	NA	1.7	67	87	17	76
Noyes and Barber-Westin 2001[28]	55	33 (24-74)	PT autograft (39) Reharvested PT autograft (11)	Double incision endoscopic (35) Single incision endoscopic (26)	24	78	2.2	64	NA	NA	NA
Uribe et al, 1996[43]	54	49 (25-68)	PT autograft (17) allograft (19) HT autograft (2)	Double incision endoscopic (44) Single incision endoscopic (10)	6	74	2.8	NA	83	55	NA

(continued)

TABLE 5 (continued)

Author and Year of Publication	n	Months of Follow-up (range)	Graft Source (n)	Operative Technique (n)	Failure (%)	Pivot 0-1 (%)	Mean KT-1000 Arthrometer (mm)	KT-1000 Arthrometer <3 mm (%)	Lysholm (mean)	X-ray Normal (%)	IKDC Grade A or B (%)
Johnson et al, 1996[26]	25	28 (24-36)	PT allograft (13) Achilles tendon allograft (12)	Single incision endoscopic	36	80	3.7	20	NA	NA	12
Colosimo et al, 2001[7]	15	39 (24-65)	Reharvested PT autograft (15)	Single incision endoscopic (10) Double incision endoscopic (3)		85	1.9	77	78		NA
Fox et al, 2004[14]	38	58 (24-144)	PT allograft (38)	Single incision endoscopic (24) Double incision endoscopic (8)	6	97	1.9	84	75	53	71
Carson et al, 2004[6]	43		Multiple	Multiple	9	NA	2.9	39	NA	NA	NA
Woods et al, 2001[47]	10	45 (24-63)	Reharvested PT autograft (10)	Double incision endoscopic	14	100	2.4	NA		0	63
Grossman et al, 2005[21]	29	67 (36-108)	PT allograft (22) autograft (6) Achilles tendon allograft (1)	Single incision endoscopic (26) Double incision endoscopic (3)	NA	100	2.8	NA	87	52	58
Salmon et al	50	90 (60-108)	HT autograft (48) HT allograft (1)	Single incision	10	100	2.5	50	85	44	56

[a]IKDC, International Knee Documentation Committee; PT, patellar tendon; NA, data not available; HT, hamstring tendon; LAD, ligament augmentation device.

of little comfort to the patient, it is frequently less technically challenging to revise these reconstructions than those with correct tunnel placement of the primary graft in which hardware removal and achieving adequate fixation in a previously used tunnel is required. However, in this series, all revision tunnels were located in the posterior quadrant of the Blumensaat line on the femoral side and the second anterior quadrant on the tibial side, reflecting good tunnel placement of the revision ACL graft. We were unable to identify any significant relationship between the cause of the primary ACL graft failure and outcomes of subjective knee function, laxity testing, or radiographic evidence of osteoarthritis.

The debate regarding the most suitable graft source for primary ACL reconstruction remains contentious, but the bone–patellar tendon–bone and the quadrupled hamstring tendon autografts have both been shown to have acceptable results.[8,11,12,34,35] Despite the increasing popularity of the quadrupled hamstring tendon graft for primary ACL reconstructions, the patellar tendon graft is more commonly used for revision ACL reconstruction[22] and is frequently recommended as the preferable graft source for revision ACL reconstruction.[3,20,23,26,36,44] We have shown that comparable outcomes are achieved with the use of hamstring tendon autografts in revision ACL reconstruction.

It is our experience that the hamstring tendon graft can be successfully used for revision ACL reconstruction. However, success is largely determined by the status of the primary tunnels and availability of a previously unharvested hamstring tendon graft. The status of the primary tunnels can be classified into 1 of 3 categories. First, grossly incorrect placement of the primary tunnels creates perhaps the easiest technical challenge for the surgeon, as frequently new tunnels can be created in an anatomical position without the need for removal of primary hardware or the use of previously created tunnels. In the second scenario, the primary tunnels are correctly placed. Depending on the type of primary graft fixation, this technique may necessitate the removal of existing hardware. Once the existing hardware is removed, the tunnels are reamed to fresh cancellous bone, ensuring any sclerotic margins are removed. The third scenario creates perhaps the most technically difficult challenge. If the primary tunnels are only slightly malpositioned, creation of an anatomical tunnel can be difficult. Previous hardware should be removed only if absolutely necessary, and in some cases, the primary and revision tunnels may coalesce creating a grossly enlarged tunnel that may require bone grafting. It is the senior author's experience that the first 2 scenarios can be managed successfully with the use of a hamstring tendon graft but that the third scenario may require the use of a patellar tendon graft, with larger than normal bone blocks, tailored to the defect. A 2-stage procedure, with bone graft to the tunnels and later graft implantation, rarely is required.

Fules et al[16] performed the only other study in the literature examining the results of revision ACL surgery performed with predominantly hamstring tendon grafts. They examined 29 patients at a mean of 50 months after revision ACL surgery, 26 of whom received a hamstring tendon autograft via a double-incision technique fixed with a polyester fixation device. They reported a low failure rate (3%), a mean Lysholm knee score of 87, and overall IKDC grade of normal or nearly normal in 76% of patients. When compared with the patellar tendon graft in primary ACL reconstruction, the hamstring tendon graft has been shown to be associated with lower graft morbidity, better cosmesis, easier rehabilitation,[2,5,11,12,15,34,39] and lower rates of osteoarthritis over the long term.[35] These factors, when combined with the comparable success rates of this study, lead us to recommend the use of the quadrupled hamstring tendon graft from either the ipsilateral (if available) or contralateral knee as a viable graft construct for revision ACL reconstruction.

Radiographic evidence of osteoarthritis was evident in 56% of the study group at review, most commonly affecting the medial tibiofemoral compartment. Compared with the prerevision examination, 52% of patients demonstrated deterioration in radiologic grade. Other authors have reported degenerative changes on radiographs after revision ACL reconstruction of between 36% to 83%.[10,14,16,21,30] Given the multiple traumas associated with multiply injured ACL knees, these findings are predictable.

CONCLUSION

Revision ACL reconstruction with hamstring tendon graft and interference screw fixation affords acceptable results at a minimum of 5 years' follow-up. When compared with the existing literature on primary ACL reconstruction, the overall results may be inferior, but objective failure rates are comparable. The most significant predictor of poorer outcomes for revision ACL reconstruction was the presence of articular surface damage at the time of revision surgery, which worsened with chronicity of the primary ACL graft failure. Therefore, we suggest that failed primary ACL grafts should be revised in the subacute setting before additional episodes of instability further damage the articular surfaces. We recommend that, when available, hamstring tendon autografts should be considered for revision ACL reconstruction.

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