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Anterior Cruciate Ligament Reconstruction: The Rush Experience

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Summary: Arthroscopically assisted anterior cruciate ligament (ACL) reconstruction has been performed at Rush Medical Center since January 1986. Since then, over 3000 arthroscopically assisted ACL reconstructions have been performed at this institution by the 2 senior authors. The surgical procedure has evolved from a 2-incision technique to a single-incision technique. The graft of choice has been autogenous patellar tendon, although the use of allograft tendon for ACL reconstruction has increased in recent years. We report the results of patients who have undergone ACL reconstruction with a patellar tendon graft at Rush Medical Center from 1987 to 2000. Our results indicate that this procedure reliably improves knee stability, patient function, and yields a high patient satisfaction rate. These results are reproducible in both men and women in the general population as well as certain subgroups of patients, including patients over the age of 35, worker's compensation patients, and revision reconstructions. Primary ACL reconstructions using allograft tendon have yielded results similar to reconstructions using autograft tendon but are typically used in older patients. **Key Words:** Anterior cruciate ligament—RUSH Medical Center—Patellar tendon.

Reconstruction of the anterior cruciate ligament (ACL) is a reproducible surgical procedure with a high success rate.[1–6,12–19,22–25,27–34,36–54] Data on arthroscopically assisted anterior cruciate ligament (ACL) reconstruction using bone–patellar tendon–bone (BTB) grafts has been compiled at Rush Medical Center since July 1986. From June 1987 through September 1991, a 2-incision technique[7] was used to perform the reconstruction. In an attempt to minimize surgical morbidity, a single-incision surgical technique was adopted by the senior authors in October 1991.[26] Since 1987, the senior authors' combined experience includes over 3000 arthroscopically assisted ACL reconstructions. Several manuscripts have been written reporting the results of these patients.[8–11,20,21,35,55] The purpose of this article is to summarize the outcomes of patients who have undergone arthroscopically assisted ACL reconstructions at Rush Medical Center and to compare these results with those reported in the literature from other institutions.

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METHODS

Patients undergoing arthroscopically assisted ACL reconstruction have been identified for inclusion into the outcomes studies performed at Rush Medical Center from a computerized database that includes detailed information on all surgical patients. Although none of the studies from Rush Medical Center have been prospective, randomized, controlled trials, a consistent methodology has been used. Standardized patient-administered questionnaires are used. Physical examinations are performed independently of the treating surgeon. KT-1000 arthrometric measurements have been performed exclusively by a single trained, experienced individual. Functional testing (timed single-leg hop, single-leg hop for distance, single-leg vertical jump) has also been measured by a single office assistant. Operative reports have

exclusively been dictated by the senior surgeons to provide a consistency in surgical findings and physical examination findings under anesthesia. In all studies Tegner, Lysholm, modified Hospital for Special Surgery (HSS), and Noyes Cincinnati Knee Rating Scales were used. In the more recent allograft studies, the International Knee Documentation Committee (IKDC) rating system has also been implemented. With the evolution of outcome measures, the Knee injury and Osteoarthritis Outcome Score (KOOS) and Short Form 12 (SF-12) have also been reported. Three measures of subjective patient satisfaction have been routinely used in the investigations as well.

RESULTS

Anterior Cruciate Ligament Autograft

Dual Incision

Results of the initial group of patients who underwent a 2-incision ACL reconstruction were first reported by Bach et al in 1994.[9] In a cohort of 62 patients evaluated at a minimum 2-year follow-up interval, 96% of patients had a Grade 0/1 Lachman (77% grade 0) and 96% had a grade 0/1 pivot shift (95% grade 0). The average postoperative KT-1000 side-to-side difference was 0.3 mm; 92% of patients had a maximum manual side-to-side difference ≤3 mm, 4% between 3 and 5 mm, and 4% ≥5 mm. Ninety percent of patients were mostly/completely satisfied with the results of their surgery, and 95% of patients would recommend the procedure to others. At a minimum 5-year follow-up interval, a larger group of these patients was subsequently published by Bach et al in 1998.[11] Compared with the initial results, the long-term results showed an overall improvement in patient function and satisfaction with 96% of patients mostly or completely satisfied. Objective measurement showed a slight increase in graft laxity as measured by KT-1000 data (average side-to-side difference 1 mm; 70% ≥3 mm, 26% 3–5 mm, 4% ≥5 mm), Lachman, and pivot shift (100% grade 0/1 [84% grade 0]) testing. However, patient activity and function either remained the same or actually improved with time, depending on the outcome measurement. For example, the 5- to 9-year follow-up Lysholm score, HSS score, Noyes activity score, and Noyes sports function score all remained within 2 points of the scores obtained at the 2- to 4-year follow up. The Tegner activity score remained unchanged at 6.3. The side-to-side deficits seen in the timed single-leg 6-m hop, the single-leg hop for distance, and the single-leg vertical jump were substantially smaller at long-term follow up when compared with the early results.

Endoscopic Technique

Despite the success of ACL reconstructions performed using a 2-incision technique, high rates of knee flexion contractures and the additional surgical morbidity of a second incision led to the development of a single-incision endoscopic technique. The single-incision technique did not require a violation of the posterior joint capsule and eliminated the distal femoral incision, elements which were felt to contribute to increased postoperative pain. The results reported by Bach et al[10] on the early outcomes of patients undergoing single-incision ACL reconstructions revealed knee stability and subjective measurements that were comparable to the early results of patients undergoing the 2-incision technique.[9] At a minimum 2-year follow up, 98% of patients had a grade 0/1 Lachman and 100% of patients had a grade 0/1 pivot shift. Postoperative arthrometric evaluation with the KT-1000 arthrometer revealed an average side-to-side difference of 1.1 mm with 83% of patients having a maximum manual side-to-side difference of ≤3 mm, 14% between 3 and 5 mm, and 3% ≥5 mm. Ninety-three percent of patients were mostly/completely satisfied with their results, and 95% would recommend the procedure to others. The incidence of knee flexion contracture (defined strictly as a prone heel height difference of >2 cm) in this initial series of patients undergoing a single-incision reconstruction was 18%. Patients who underwent a 2-incision reconstruction had a 15% reported incidence of flexion contracture in the early results[9]; however, this incidence increased to 28% when these patients were reevaluated at 5- to 9-year follow up.[11] Less thigh girth atrophy and improved function of the injured leg were noted in patients who underwent a single-incision reconstruction versus those who underwent a 2-incision reconstruction. These differences are most likely attributable to the change in the postoperative rehabilitation protocols for the patients who had a single-incision reconstruction and the decreased morbidity with the single-incision technique. Restricted range of motion and protected weight bearing with return to sporting activity at 8 months postoperatively was standard for the rehabilitation protocol for 2-incision reconstructions performed in the late 1980s to early 1990s. The rehabilitation changed substantially for those patients who underwent a single-incision reconstruction in the early to mid-1990s. Unrestricted range of motion with full weight bearing and return to sporting activities at 4 to 6 months postoperatively reflected the more aggressive physical therapy that followed the single-incision reconstructions (Table 1).

TABLE 1. *Summary of Primary Anterior Cruciate Ligament Reconstructions Performed at Rush Medical Center*

	Bach[9]	Bach[10]	Bach[11]	Bach[8]
Study type	Retrospective	Retrospective	Retrospective	Retrospective
No. of patients	62/75 (80%)	103/128 (80%)	97/147 (66%)	59/89 (66%)
Gender	44 M/18 F	65 M/38 F	72 M/25 F	21 M/38 F
Average age (yrs)	27 at injury	25 at injury	26 at surgery	41 at surgery
Range	16–45	10.4–52.7	12–53	18–61
Average follow up (months)	37	36	79	51
Range	27–51	24–55	66–112	26–170
Surgical technique	2-incision	1-incision	2-incision	2- and 1- incision
Postoperative Lachman (%)				
Grade 0/1	96	98	98	94
Grade 0	77	74	60	65
Postoperative Pivot (%)				
Grade 0/1	96	100	100	99
Grade 0	95	91	84	90
Postoperative KT-1000 (%)				
3 mm	92	83	70	95
3–5	4	14	26	5
≥5	4	3	4	0
Postoperative prone heel height difference (average)		1.4 cm	1.8 cm	0.3 cm
1 cm (%)	77	61	53	91
≤2 cm (%)	97	82	73	
Postoperative range of motion (degrees)	0–138	1 hyperextension—137	0–137	0–140
Lysholm	88	89	87	82
Hospital for Special Surgery score	88	90	97	
Noyes activity rating score	86	88	87	
Noyes activities of daily living	49	37	36	
Noyes sports function score	90	90	89	71
Noyes problems with sport score		85	85	
Tegner score				
Preinjury	7.6	7.3	7.1	
Preoperative	2.1	3.5	3.5	
Final follow up	6.3	6.5	6.3	6
	1 cm	1 cm	1 cm	
Postoperative thigh girth atrophy (average)	63% ≤1 cm	74% ≤1 cm	73% ≤1 cm	
Range	0–4 cm	0–4 cm	0–5 cm	
Timed single-leg 6-m hop	10% deficit	4% deficit	2% deficit	1% increase
Single-leg hop for distance	12% deficit	5% deficit	1% deficit	2% deficit
Single-leg vertical jump	13% deficit	6% deficit	1% deficit	7% deficit
Patient satisfaction				
Mostly/completely satisfied	90%	93%	96%	94%
Would recommend	95%	95%	94%	
Would have surgery again				96%

Anterior Cruciate Ligament

General Considerations

Subgroups of patients have been independently studied at Rush Medical Center. A comparison of men and women undergoing ACL reconstruction at Rush showed no overall difference between genders with respect to objective measurements, patient satisfaction, and patient outcome.[20] A significant difference was noted on the average postoperative KT-1000 maximum manual side-to- side difference measurements (0.76 mm for men vs 1.73 mm for women); however, no significant differences were found between genders when the arthrometric measurements were grouped into those patients with ≤3 mm of side-to-side difference (84% of men vs 79% of women), between 3 and 5 mm (12% of men vs 17% of women), and >5 mm of side-to-side difference (4% of men vs 3% of women). Ninety-four percent of men and 95% of women were mostly or completely satisfied with their results, and 96% of men and 89% of women would have the procedure done again. Barrett et al[12] prospectively analyzed the results of 37 women undergoing ACL reconstruction and reported findings that are comparable to women who had reconstructions performed at Rush.

Age Considerations

Outcomes of patients at Rush over the age of 35 were reported by Novak et al.[35] In a group of 18 patients evaluated at a minimum 2-year follow up, patients had

obtained excellent results that were similar to younger patients undergoing ACL reconstruction. Postoperatively, 94% of patients had a grade 0/1 Lachman (83% grade 0) and 94% had a grade 0 pivot shift. Ninety-four percent of patients were completely satisfied with the results of surgery, and 100% of the patients would recommend the surgery to others. Heier[28] reported the results of 45 patients undergoing ACL reconstruction with an average age of 44.6 years. Lysholm knee rating scores and patient satisfaction were similar to the results obtained at Rush. Objective and physical examination data, specifically KT-1000 arthrometric measurements, Lachman, and pivot shift testing, were better in the Rush population. It should be noted, however, that Heier's study group had more patients (45 vs 18) with a larger percentage of patient follow up (85% vs 62%). The rehabilitation protocols also differed between the study groups.

The Injured Worker

Wexler et al[55] reported the results of ACL reconstruction at Rush Medical Center in worker's compensation patients. Surprisingly, subjective and objective data were not found to be significantly different in this cohort of patients than data collected on nonworker's compensation patients. Twenty-two patients were included in the study and were evaluated at an average of 55 months after the reconstruction (minimum 24-month follow up). At final follow up, 100% of patients had a grade 0/1 Lachman (68% grade 0) and 100% had a grade 0/1 pivot shift (96% grade 0). KT-1000 arthrometric measurements revealed an average maximum manual side-to-side difference of 1.9 mm, with 68% of patients having <3 mm difference and 32% having between 3 and 5 mm difference. Ninety-one percent of patients were mostly or completely satisfied, and 95% of patients would undergo the procedure again. All patients returned to work. The average return to work time was 17 weeks. Eighty-six percent of patients returned to the same job activity, 5% returned to a higher level of job activity, and 9% returned to a lower level of job activity. Noyes compared worker's compensation patients and nonworker's compensation patients who underwent ACL reconstruction.[36] Patients were matched for age, chronicity of injury, number of previous knee surgeries, and months of follow up. Although no difference in function, objective, or subjective parameters were found, the worker's compensation group had a significantly higher number of missed work days before and after surgery. Barrett reported the results of 24 patients with a work-related ACL rupture who underwent reconstruction.[13] Compared with nonworker's compensation patients, Barrett showed similar objective

TABLE 2. *Summary of Anterior Cruciate Ligament Reconstruction in Worker's Compensation Patients*

	Wexler[55]	Noyes[36]	Barrett[13]
Study type	Retrospective	Prospective	Prospective
No. of patients	22/22 (100%)	19/20 (95%)	24
Gender	17 M/5 F	16 M/3 F	22 M/2 F
Average age (yrs)	33 at injury	29 at surgery	30.8
Range	23–51	20–39	19–45
Average follow up (months)	55	27	34.5
Range	24–98	22–41	24–77
Surgical technique	2- and 1-incision	2- and 1-incision	2- and 1-incision
Postoperative Lachman (%)			
Grade 0/1	100		
Grade 0	68		
Postoperative pivot (%)			
Grade 0/1	100		
Grade 0	96	100	
Postoperative KT-1000 (%)	1.9 mm		1.54 mm
3 mm	68	87	88
3–5 mm	32	13	12
$\geq$5 mm	0	0	0
Lysholm	82		79
Tegner			
Preinjury	7.1		4.8
Preoperative	3.9		—
Final follow up	5.9		3.1
Patient satisfaction			
Mostly/completely satisfied	91		
Would have surgery again	95		

TABLE 3. *Summary of Primary Allograft Anterior Cruciate Ligament Reconstructions*

	Bach[8]	Roberts[48]	Indelicato[29]	Harner[27]	Noyes[37]
Study type	Retrospective	Retrospective	Prospective	Retrospective	Prospective
No. of patients	59/89 (66%)	36/44 (82%)	41/73 (56%)	64	28
Gender	21 M/38 F	22 M/14 F	29 M/12 F	51 M/13 F	
Average age (yrs)	41 at surgery	23 at surgery	27	24 at surgery	23 at surgery
Range	18–61	16–39	17–40		14–41
Average follow up (months)	51	24 min	27	45	84
Range	26–170		24–40	30–75	60–108
Surgical technique	2- and 1-incision	Screw/washer with suture posts both	Miniarthrostomy; pressfit femur/int. screw tibia	2-incision	1-incision
Postoperative Lachman (%)					
Grade 0/1	94	53	93		
Grade 0	65	17	61		
Postoperative pivot (%)					
Grade 0/1	99	72	98	89	
Grade 0	90	31	78		
Postoperative KT-1000 (%)	0.7 mm	6.9 mm		1.8 mm	0.7 mm
3 mm	95	16		80% 5 mm	82
3–5	5				14
≥5	0	84(≥4 mm)			4
Postoperative thigh girth atrophy		22% 1 cm			
Average		61% 2 cm			
Range					
Lysholm	82	81	91		
International Knee Documentation Committee overall	Mean 78			45% nl/nnl	
Tegner score	6				
Preinjury					
Preoperative					
Final follow up					
Single-leg hop for distance	2% deficit			8% deficit	
Patient satisfaction					
Mostly/completely	94%				
Would recommend					
Would have surgery again	96%			88%	

nl = normal; nml = nearly normal; int = interference.

data but significantly worse subjective data in the worker's compensation group. Similar objective data and Lysholm knee rating scores were obtained in the worker's compensation cohort when compared with the Rush worker's compensation cohort. However, the Tegner activity scale scores were substantially different. Barrett reported a preinjury Tegner score of 4.8 and a final follow-up score of 3.1. The Rush cohort had a preinjury Tegner score of 7.1 and a final follow-up score of 5.9 (Table 2).

Primary Reconstruction With Patellar Tendon Allograft

The Rush experience with patellar tendon allograft for primary ACL reconstructions was recently reported.[8] At final follow up, 94% of patients had a grade 0/1 Lachman (65% grade 0) and 99% had a grade 0/1 pivot shift (90% grade 0). The average maximum manual side-to-side difference as measured by KT-1000 was 0.7 mm. Ninety-five percent of patients had ≤3 mm side-to-side difference, and 5% had between 3 and 5 mm side-to-side difference. The overall failure rate (as defined as a pivot shift of any grade or a maximum manual side-to-side difference of ≥5 mm by KT-1000 arthrometric testing) was 10%. Ninety-four percent of patients were mostly or completely satisfied with the surgery, and 96% of patients would undergo the surgical procedure again. The decreased morbidity and surgical time with an allograft reconstruction makes the use of an allograft tendon an attractive alternative to autograft patellar tendon. A significantly increased trend in use of allograft tissues has occurred. Since 2000, 36% of primary ACL reconstructions performed by one of the senior authors (BRB) have used allograft tissue. This is reflective of several factors. Allograft reconstruction is discussed with patients over 40 years of age and in those patients of petite stature in whom autograft tissue (patellar tendon or hamstring) may be of suboptimal width or length or may jeopardize the integrity of the extensor mechanism (in the case of patellar tendon autograft). Early degenerative joint dis-

TABLE 3. *Continued*

Stringham[52]	Shelton[51]	Kleipool[33]	Peterson[46]	Chang[16]
Retrospective	Prospective	Prospective	Prospective	Retrospective
31/47 (66%)	30	36	30/48 (63%)	46/52 (88%)
16 M/15 F	18 M/12 F	17 M/19 F	19 M/11 F	41 M/5F
26	27	28	28 at surgery	33.1
17–37	15–55	14–43	14–53	16–52
34	24	46	60	33
		30–64		24–56
2- and 1-incision some w/screw/ washer post	1-incision	1-incision	1-incision	2-incision IT band tenodesis
	93	86	90	100
	73	58	80	68
	100	92	97	100
	80	78	83	95
				1.2 mm
70	73	75	73	82
22	23	19	27	9
7	4	6	0	9
	0.6 cm	0.22 cm		0.3 cm
	(-1–3)	(-3–2)		(-2.5–3)
		94	90	93.8
		85% nl/nnl		
		8		
		3		
		5		
				100%
				97%

ease, patellofemoral symptoms, and the desire for simultaneous bilateral reconstructions are additional considerations for the use of allograft tissue. Concerns of disease transmission and inferior graft stability have precluded many surgeons from using allografts for ACL reconstructions. The allograft tendon study performed at Rush used only fresh-frozen, nonirradiated patellar tendon allografts obtained from a single tissue bank (Allosource Tissue Bank, Denver, CO). When compared with the previous studies from Rush using BTB autograft for primary reconstructions, the patients selected for allograft ACL reconstruction had similar subjective and objective measurement outcomes. When the Rush results are compared with prior studies in the literature using allograft tendon for ACL reconstruction,[16,26,29,33,37,46,48,51,52] similar results were obtained with respect to Lachman and pivot shift testing. However, objective arthrometric measurements with KT-1000 testing revealed a substantially greater percentage of patients with ≤3 mm side-to-side difference in the Rush cohort (Table 3).

Revision Reconstruction With Patellar Tendon Allograft

Fox et al[21] reported the Rush results of patients undergoing a revision ACL reconstruction with nonirradiated patellar tendon allograft. Objective and subjective criteria revealed less favorable outcomes in patients undergoing revision ACL reconstruction when compared with patients undergoing primary ACL reconstructions. Postoperatively, 87% had a grade 0/1 Lachman (56% grade 0) and 87% had a grade 0/1 pivot shift (71% grade 0). The average postoperative KT-1000 maximum manual side-to-side difference was 1.6 mm, with 84% of patients having ≤3 mm side-to-side difference, 6% having between 3 and 5 mm difference, and 10% having >5 mm side-to-side difference. One patient required another revision surgery. Eighty-seven percent of patients were mostly/completely satisfied with the results of surgery. The results from this study were similar with respect to physical examination findings to other reports of revision ACL reconstructions in the literature.[31,38,40,41,53] Arthrometric data showed improved stability in the Rush cohort

TABLE 4. *Revision Anterior Cruciate Ligament Outcomes*

	Fox [21]	Johnson[31]	Noyes[39†]	Noyes[39§]	Noyes[38]	Uribe[53]	Noyes[40]
Study type	Retrospective	Retrospective	Prospective	Prospective	Prospective	Retrospective	Prospective
Number of patients	32/38 (84%)	25/50 (50%)	20/24 (83%)	66/76 (87%)	48/50 (96%)	54/64 (84%)	54/56 (98%)
Gender	14 m/18 f	22 m/3 f	16 m/4 f	43 m/23 f	31 m/17 f	43 m/11 f	36 m/19 f
Average age (yrs)	28 at revision	25 at revision	27 at revision	25 at revision	27 at revision	Median 26	27 at revision
Range	16–57	16–44	14–48	13–45	14–48	16–43	14–48
Average follow up (months)	58	28	27	42	34	30	33
Range	25–145	24–36	24–43	23–78	24–74	20–79	24–74
Surgical technique	1-incision	1-incision	1-incision	1-incision	1-incision	2- and 1-incision	2- and 1-incision; post on tibia
Postoperative Lachman (%)							
Grade 0/1	56						
Grade 0	87					61	
Postoperative pivot (%)							
Grade 0/1	87	80	95	89	84	98	78
Grade 0	71					74	
Postoperative KT-1000 (%)	1.9 mm	3.7 mm	1.9 mm	3.4 mm	1.2 mm	2.8 mm	2.2 mm
≤3 mm	84	20	67	53	67		64
3–5	9	44	17	30	18		15
≥5	6	36	17	17	14		21
Lysholm	75					83.2	
International Knee Documentation Committee overall	Mean 71	12% nl/nnl					
Tegner score							
Preinjury	8.4					7.3	
Preoperative	5					2.8	
Final follow up	6.3					5.5	
Patient satisfaction							
Mostly/completely satisfied	87%						
Would recommend	76%						
Would have surgery again	76%						

*Autograft.

†Allograft.

nl = normal; nml = nearly normal.

compared with other published data on revision ACL reconstructions (Table 4).

SUMMARY

The Rush experience of ACL reconstructions using patellar tendon autografts and allografts has demonstrated that these procedures produce a reliable and reproducible outcome with predictable results and a high level of patient satisfaction and function with short- to medium-range follow up. The results obtained at Rush Medical Center compare favorably to the current literature regarding ACL reconstruction using bone–patellar tendon–bone grafts. Long-term results (>10 years) are necessary to see if the excellent results obtained in the 2- to 4-year and 5- to 9-year follow-up periods persist with time.

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