Surgical Technique

Revision ACL Reconstruction With a Rectangular Tunnel Technique

Konsei Shino MD, Tatsuo Mae MD, Norimasa Nakamura MD

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Abstract

Background We developed the rectangular tunnel ACL reconstruction (RT ACLR) using a 10-mm wide bone-patellar tendon-bone (BTB) graft through rectangular tunnels with a rectangular aperture to reduce tunnel size: the cross-sectional area of the tunnels of 50 mm² (5 × 10 mm) in RT ACLR is less than that of 79 mm² in a conventional 10-mm round tunnel technique presuming the technique would be more suitable in revision ACLR with previous improperly placed tunnels.

Description of Technique Two contiguous 5-mm tunnels inside the anatomic ACL femoral and tibial attachment areas along their long axes, and they are expanded with a 5 × 10-mm dilator into parallelepiped ones.

Patients and Methods We indicated and intended to perform the RT ACLR procedure in 31 patients requiring revision between 2004 and 2008. Eighteen of the 31 patients treated with the procedure were followed a minimum of 24 months (mean, 38 months; range, 24 to 73 months). We evaluated ROM, obtained IKDC scores, and determined stability with KT-1000.

Results The procedure could be applied in 30 of the 31 cases. One of the 18 reruptured the graft at 28 months.

Of the remaining 17 patients with followup of 24 months or longer, 15 had full ROM, while the remaining two lost 5° of flexion; 11 were classified as normal and six were nearly normal according to the IKDC evaluation. Stability measured with KT-1000 was 1.0 ± 1.5 mm.

Conclusion The RT ACLR technique provided acceptable results after one-stage revision ACLR.

Level of Evidence Level IV, therapeutic study. See Guidelines for Authors for a complete description of levels of evidence.

Introduction

The incidence of ACL injury is reportedly between 36.9 and 60.9 per 100,000 persons per year [17, 30]. Because of the poor healing potential of a ruptured ACL [2, 19, 23, 24, 28], ACL reconstruction (ACLR) has been one of the most common surgical procedures in orthopaedic practice [16, 27]. Because primary ACLR has been performed with restoration of stability in 75% to 97% of patients [4–8, 28, 35, 40], many patients require revision. Revision ACLR accounted for approximately 5% of the ACLRs in our practice between 2008 and 2009.

Revision ACLR is indicated for patients with instability resulting from a malpositioned graft, from improperly placed tunnels, poor graft healing/remodeling, and/or traumatic graft rupture. However, the most frequent cause for the failure may be femoral tunnel malposition [41, 42]. Revision ACLR is technically difficult. If possible, it is ideal to create new tunnels away from the previous tunnel aperture. Therefore, the smaller the aperture areas of new tunnels, the more likely one can avoid overlapping tunnels.

We developed the rectangular tunnel ACL reconstruction (RT ACLR) with a 10-mm wide bone-patellar

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K. Shino (✉)
Faculty of Comprehensive Rehabilitation, Osaka Prefecture
University/Yukioka Hospital, 3-7-30 Habikino, Habikino,
Osaka 583-8555, Japan
e-mail: k-shino@rehab.osakafu-u.ac.jp

T. Mae, N. Nakamura
Osaka University Medical School, Osaka, Japan

tendon-bone (BTB) graft to mimic the natural fiber arrangement inside the native ACL and to minimize tunnel size [36, 38, 39]. Because the cross-sectional area of the tunnels of 50 mm² (5 × 10 mm) in RT ACLR is less than that in a conventional 10-mm round tunnel technique (79 mm²), the former is advantageous to more consistently avoid overlapping tunnels and/or to more easily avoid improperly placed tunnels from the previous surgery.

Because tunnel encroachment would hypothetically be less of a problem, we presumed the RT ACLR technique could be applied as a one-stage revision procedure to those after failed primary ACLR. The purposes of our report were to (1) describe the procedure; (2) determine how frequently we could obtain properly placed tunnels; (3) determine whether function and stability were restored; and (4) describe complications.

Description of Technique

The principles were to (1) create parallel tunnels with rectangular apertures inside the anatomic attachment areas (Fig. 1) [1, 12, 14]; (2) avoid overlapping tunnels or staged operations (Fig. 2); and (3) accept the pre-existing tunnel apertures if they were in the anatomic attachment areas (Fig. 3).

The patient is positioned supine with the thigh horizontally kept using a leg holder. The anteromedial portal is used for viewing and the far anteromedial portal for instrumentation [33, 36]. For the femoral tunnel, instruments are used through the far anteromedial portal with the knee fully flexed, whereas the tibial tunnel is created through the anteromedial cortex to the anatomic intra-articular insertion. Two contiguous 5-mm tunnels along the long axis of the attachments are created and then expanded with a 5 × 10-mm dilator into a single tunnel.

With previous properly placed tunnels after BTB reconstruction, the revision can be performed as the primary RT ACLR using any type of graft: two double-looped semitendinosus tendon (SMT) grafts, quadriceps

tendon-bone (QTB), or the contralateral BTB graft (Fig. 4; Cases 11, 12). However, for those with a widened femoral tunnel after use of a SMT graft, the extra space might be filled with an interference screw of greater than 6 mm (Fig. 5; Case 16).

With improperly placed previous tunnels on the femoral side, the distance between the aperture rim of the previous tunnel and that of the new tunnel is 5 mm or greater; the new femoral tunnel is created as the primary ACLR (Fig. 6). If the distance is less than 5 mm, however, the divergent tunnel can be used either by changing the approach to inside-out through the far anteromedial portal [3, 33] or outside-in through a lateral femoral incision

Fig. 2A–B (A) A prepared bone-patellar tendon-bone (BTB) graft of 10-mm width. (B) Schema of revision rectangular tunnel ACL reconstruction (RT ACLR) with BTB graft. The bone plug is fixed to the femur with a 6-mm interference screw, whereas tibial fixation is achieved with a modified suture technique using the DSP (Double Spike Plate) and a screw. With this procedure, the new properly placed femoral tunnel can be created in most cases without overlapping tunnels despite the previous high and anterior femoral tunnel (PFT) leading to a vertical graft. In most cases, a new tibial tunnel is created with the same aperture as the previous tibial tunnel (PTT), whereas the direction is changed.

Fig. 1A–B Intra-articular tunnel apertures of the tibia (A) and the femur (B) in rectangular tunnel ACL reconstruction (RT ACLR). (A) The tibial tunnel aperture is almost filled with the tendon (black-painted area); (B) note the tendinous side of the bone plug (black-painted area) located posteriorly superiorly on the femoral tunnel aperture.

Fig. 3A–B Radiographs of a case with previous improperly placed tunnels (Case 3 in table 1). (A) Posteroanterior 45° flexion weight-bearing view; (B) lateral view. The primary surgery had been performed with a hamstring tendon graft through two high femoral tunnels (*) and a single central tibial tunnel (dotted line). Note two residual Endobuttons used for femoral fixation at the time of primary

ACL reconstruction (ACLR) (dotted arrow). A rectangular new femoral tunnel was created in a proper place, whereas the direction of the tibial tunnel was changed to obtain a new tunnel wall of fresh cancellous bone. Note the solid lines of the new tibial tunnels and fixation hardware on the femur and the tibia. The circles show the aperture locations of the new properly placed tunnels.

[2, 14, 37]. However, we recommend grafting over the top of the lateral condyle for those with severe tunnel widening around the original femoral attachment (Fig 7).

On the tibial side, a tunnel placed too anteriorly is easily revisable, whereas a tunnel placed too posteriorly is not. For the latter, the direction of the tunnel should be changed to obtain a new posterior tunnel wall of fresh cancellous bone using a divergent tunnel technique (Fig. 3). This should help the graft to heal to the tunnel wall and resist anterior tibial force. With a tunnel malpositioned by 1 cm or less posteriorly, it may be reasonable to reuse the same tunnel aperture, to avoid merging the two tunnel apertures. When the posterior malpositioning exceeds 1 cm, however, the previous tunnel may be filled with a bone graft or its substitute.

Femoral graft fixation is usually achieved with a 6-mm interference screw (Fig. 3), although additional cortical suspensory fixation may be considered if the fixation is questionable as a result of the previous tunnel.

Tibial fixation is achieved with a modified pullout suture technique using DSP (Double Spike Plate; Smith-Nephew Endoscopy, Andover, MA) and a screw. This technique makes it possible to fix the graft under a predetermined amount of tension [34].

The knee is immobilized in 10° flexion for 1 week with a brace for BTB grafts, whereas the immobilization is continued up to 2 weeks for SMT grafts. After that, passive and active ROM exercises are followed. Partial weight-bearing is allowed at 2 to 3 weeks followed by full weightbearing at 4 to 5 weeks. Full extension or flexion exceeding 130° is not permitted until 5 weeks. Jogging is recommended at 3 to 4 months. Return to strenuous activity is not allowed until 6 months.

Patients and Methods

From June 2004 to December 2008, we treated 31 patients with failed ACLR using the described technique. Our indications for revision ACLR were (1) subjective instability or giving way during strenuous activity or daily activities; (2) positive Lachman and pivot shift tests; and (3) more than 3 mm side-to-side difference with KT-1000 at maximum manual force. The contraindications were: (1) arthrofibrosis: ROM deficit such as an extension or flexion deficit exceeding 10°; (2) deep infection; and (3) severe osteoarthritis. In one patient with massive bone loss, we chose the graft fixation over top of the lateral femoral condyle; this

Fig. 4A–E A case with previous proper rectangular tunnels (Case 12 in Table 1). **(A)** Arthroscopic view of the previous femoral tunnel was densely filled with tendon and bone plug; **(B)** arthroscopic view of the new rectangular femoral tunnel recreated in the same place as that in the previous surgery. The bone-patellar tendon-bone (BTB) graft from the contralateral side was introduced through the same rectangular tibial tunnel after curettage, and the bone plug was fixed

to the femoral tunnel with an interference screw. **(C)** Arthroscopic view of BTB graft in situ after fixation. **(D)** Three-dimensional CT of the lateral femoral condyle at 4 weeks after the revision. Note the bone plug fixed with an interference screw (dotted arrow) inside the femoral tunnel; **(E)** three-dimensional CT of the tibial plateau. Note the bone plug located medially inside the properly placed tibial tunnel.

patient was excluded. We also excluded 12 patients who were lost to followup between 1 and 18 months. This left 18 patients' one of whom was excluded because of retear of the graft at 28 months. Thus, the remaining 17 with a mean followup of 38 months with a range from 24 to 73 months were evaluated (Table 1). There were 10 male and seven female patients with a mean age at the revision of 23 years (range, 15–34 years). The mean time from diagnosis of the failure to revision was 2.3 months. No patients were recalled specifically for this study; all data was obtained from medical records and radiographs.

Our followup routines recommended to patients are as follows: (1) a monthly examination including ROM and Lachman and pivot shift tests up to 12 months; (2) examination every 3 months after 12 months to 24 months; (3) examination and plain radiographs at 24 months; and (4) annual examinations from 24 to 60 months. At each examination we completed the IKDC evaluation form [21] and obtained laxity measurement with KT-1000 (MED-metric Corp, San Diego, CA). There were no missing data

from these examinations. Radiographs were taken at followup between 24 and 60 months in 17 patients in whom we obtained the following views: 45° posterior-anterior flexion weightbearing view, lateral view at 90°, and Merchant view.

Results

The femoral tunnel could be created in the center of the anatomic attachment area in 30 of the 31 patients using the RT ACLR technique, whereas the technique could not be applied in one (Fig. 7). The tibial tunnel was successfully created within the tibial attachment area in 29 of the 30 patients, whereas the remaining one required bone grafting to fill out the previous tunnel because of its posterior location. None of the patients underwent staged surgeries.

Of the 18 patients followed for a minimum of 24 months, none reported giving way or subjective

Fig. 5A–E A case with previous properly placed tunnels for double-bundle graft (Case 16 in Table 1). (A) Arthroscopic view of the hamstring graft resulting from stretch-out; (B) arthroscopic view of the rectangular femoral tunnel aperture created by dilation after graft removal. The bone-patellar tendon-bone (BTB) graft was introduced through the rectangular tibial tunnel created by dilating the previous two tunnels, and the bone plug was fixed to the femoral tunnel with a

7-mm interference screw. (C) Arthroscopic view of the revision BTB graft in situ. Note the interference screw used for femoral fixation (dotted arrow). (D) Three-dimensional CT at 4 weeks after the revision showing the bone plug fixed with an interference screw inside the femoral tunnel; (E) three-dimensional CT at 4 weeks showing the bone plug located medially inside the tibial tunnel.

Fig. 6A–C An illustrative case with previous improperly placed tunnels using a hamstring tendon graft. (A) A lateral radiograph showing an improperly placed anterior femoral and slightly posterior tibial tunnels (dotted lines); (B) arthroscopic view through the anteromedial portal of the femoral attachment area. Dotted circle shows the previous anterior femoral tunnel aperture, whereas the probe tip denotes the new properly placed tunnel aperture. Note there

is no overlapping tunnels; (C) a new bone-patellar tendon-bone (BTB) graft was introduced and fixed with an interference screw. Note more than 5-mm distance between the previous tunnel aperture (dotted circle) and the anterior border of the new tunnel. Unfortunately, this patient had undergone an accident leading to femoral bone plug slippage out of the tunnel at 3 weeks and had further surgery to refix the bone plug.

instability. One patient had a tear of the graft at 28 months. Of the remaining 17 patients, 11 were classified as normal and six were categorized as nearly normal by the IKDC evaluation form. Quantitative anterior laxity measurement

with KT-1000 showed the mean side-to-side difference at maximum manual drawer force improved to 1.0 ± 1.5 mm with a range from -1 to 4 mm. Fifteen of the 17 patients had no loss of motion or effusion, while the other two

Fig. 7A–B An illustrative case with bone absorption. **(A)** CT of the right knee before revision. Note the severe bone absorption around the anatomic femoral attachment (dotted line); **(B)** post-operative lateral radiograph showing femoral graft fixation over top of the lateral condyle.

patients had mild pain and swelling after strenuous activity and showed loss of 5° flexion (Cases 8, 17). Two had a mildly positive Lachman sign with a firm end point and pivot shift test (Cases 1, 2), whereas the remaining 15 were negative on both tests. Of the 12 patients lost to followup at 13 months ranging from 1 to 18 months, none reported subjective instability, limitation of motion, or pain on daily activities at the last examination according to the medical record (Table 2).

One patient sustained a tear of the revision graft and underwent a second revision ACLR with the ipsilateral QTB graft and was not listed in Table 1. Another 17-year-old male patient had a fall with the knee hyperflexed, resulting in femoral bone loosening from the tunnel at 3 weeks and underwent refixation of the bone plug. He resumed soccer by 8 months, was playing soccer without instability as of 13 months, and was lost to followup thereafter (not listed in the table) (Fig. 6).

Discussion

Revision ACLR is technically difficult because of pre-existing tunnels in the primary ACLR. Recent published studies suggest the femoral ACL attachment area is crescent-shaped with a maximum width of less than 1 cm [9, 22, 31]. The rectangular tunnel aperture of 5-mm width (50 mm² in cross-sectional area) in the RT ACLR as well as the two-tunnel technique is advantageous compared with a single round one of 10 mm (79 mm² in cross-sectional

area) to avoid overlapping tunnels at the time of revision ACLR [43, 45]. The femoral tunnel was created in the anatomic center of the attachment area in 97% of our series. In addition, the RT ACLR technique is useful to revise failure after double-bundle ACLR in which two tunnels were properly created along the long axis of the ACL attachment areas. A new rectangular tunnel can be easily created by dilating previous two tunnels (Fig. 5).

We acknowledge limitations of our study. First, we located only 18 of the 30 patients (60%) for followup examination at 24 months or longer. Thus, our observations may not represent those for the larger group. Second, the followup evaluation was performed retrospectively. Third, the minimum followup was relatively short. However, we found the procedure reliably restored stability without substantial loss of motion.

A number of reports describe revision ACLR through a single round tunnel using various kinds of graft including autogenous hamstring, BTB, QTB, or allograft (Table 3). In these studies, 2.1% to 8.2% of the patients showed side-to-side differences in KT measurement greater than 5 mm, whereas none of the patients in our series had values greater than 5 mm or a 2+ pivot shift [44]. Comparing IKDC scores of their studies with those of ours, their results showed 56% to 93% of patients were in the A or B category, whereas 100% of our patients were classified into these categories. Loss of ROM exceeding 5° was reported in 2% to 4% of the patients in several studies [25, 29, 32], whereas no patient lost ROM exceeding 5° in the current study. One possible explanation for this difference could be

Table 1. List of patients with a followup of 24 months or longer

Patient number	Age at revision (years)	Followup (years)	Time from first ACL reconstruction to revision (years)	Diagnosis of graft failure to revision (months)	Cause for revision	Preoperative KT (mm)	Grafts for revision	Meniscal injury at revision	Previous grafts	Previous tunnel aperture position	
										At the tibia	At the femur
1	22	6.1	2.4	1.2	New trauma	10	BTB	LM	SMT	Anatomic × 2	Anatomic × 2*
2	16	5.8	1.8	0.5	New trauma	4	BTB	None	SMT	Anatomic × 2	Anatomic × 2*
3	34 ¹	5.7	5.9	4.0	New trauma	4	BTB	None	SMT	Anatomic × 1	High × 2
4	21	2.1	2.1	1.7	Technical failure	6	BTB	LM	SMT	Posterior × 1	High, anterior × 1
5	21	2	2	1.4	Technical failure	16	BTB	MM	SMT	Posterior × 1	High, anterior × 1
6	17	2	1.7	2.9	New trauma	5	BTB	None	SMT	Anatomic × 2	Anatomic × 2*
7	20	2	0.4	3.3	New trauma	10	SMT	LM	BTB	Anatomic × 1	Anatomic × 1
8	32	3.3	3.8	1.5	New trauma	12	BTB	LM	SMT	Anatomic × 2	Anatomic × 2*
9	34	3	8	2.1	Technical failure	5	QTB	None	BTB	Posterior × 1	High, anterior × 1
10	15	2	1	3.5	New trauma	7	BTB	None	SMT	Anatomic × 3	Anatomic × 2*
11	22	2	2.3	2.3	New trauma	9	BTB (contralateral)	LM	BTB	Anatomic × 1	Anatomic × 1
12	19 ²	2.2	8.3	1.9	New trauma	5	BTB (contralateral)	None	BTB	Anatomic × 1	Anatomic × 1
13	20	5.3	2	4.7	New trauma	12	BTB	None	SMT	Anatomic × 2	Anatomic × 2*
14	19	3.5	1.1	1.5	New trauma	7	BTB	MM	SMT	Anatomic × 3	Anatomic × 2*
15	28	2	11.5	1.8	New trauma	4	BTB	MM + LM	SMT	Anatomic × 1	High × 2
16	28 ³	5	3.5	2.0	New trauma	5	BTB	MM	SMT	Anatomic × 2	Anatomic × 2*
17	18	5.5	2.3	2.5	New trauma	4	BTB	None	SMT	Anatomic × 2	Anatomic × 2
Mean ± SD	22.7 ± 6.2	3.5 ± 1.7	3.5 ± 3.1	2.3 ± 1.1	NA	7.4 ± 3.6	NA	NA	NA	NA	NA

¹Fig. 3; ²Fig. 4; ³Fig. 5; * anterior widening of femoral tunnel aperture; BTB = bone-patellar tendon-bone autograft; QTB = quadriceps tendon-bone autograft; SMT = two double-looped semitendinosus tendon autograft; KT = side-to-side difference at manual maximum force with KT-1000 arthrometer; NA = not applicable; MM = medial meniscus; LM = lateral meniscus; contralateral = contralateral leg.

Table 2. Results of the patients with a followup of 24 months or longer

Patient number	Loss of ROM	KT (mm) at followup	IKDC		Complaints
			Subjective assessment	Sports activity level	
1	None	4	Normal	2	None
2	None	3	Nearly normal	2	None
3	None	1	Normal	3	None
4	None	1	Nearly normal	1	None
5	None	2	Normal	3	None
6	None	1	Normal	1	None
7	None	1	Normal	4	None
8	5° flexion	0	Nearly normal	1	Mild pain, swelling after strenuous activity
9	None	1	Normal	4	None
10	None	2	Nearly normal	4	None
11	None	1	Normal	4	None
12	None	−1	Normal	1	None
13	None	2	Normal	3	None
14	None	−1	Normal	4	None
15	None	−1	Nearly normal	3	None
16	None	2	Normal	1	None
17	5° flexion	−1	Nearly normal	3	Mild pain, swelling after strenuous activity
Mean ± SD	NA	1.0 ± 1.5	NA	NA	NA

KT = side-to-side difference at manual maximum force with KT-1000 arthrometer; IKDC = International Knee Documentation Committee score; NA = not applicable.

Table 3. Published results of revision ACL reconstruction

References	Graft (%)				ROM		KT			Failure (%)	IKDC A-B (%)	RTP (%)
	Hamstring	BTB	QTB	Allograft	Extension loss > 5°	Flexion loss > 5°	Mean (mm)	> 5 mm (%)	2+ pivot shift (%)			
Diamantopoulos et al. [11]	42.1	38.3	19.6	0	—	—	0.9	6.6	10.3	—	57.9	—
Ferretti et al. [12]	100	0	0	0	0%	—	2.5	7.1	7.1	10	92.9	—
Salmon et al. [32]	100	0	0	0	4%	4%	2.5	8.2	6.1	10	56	70
Weiler et al. [44]	100	0	0	0	—	—	2.2	2.1	4.2	6	91.7	—
Noyes and Barber-Westin [26]	0	100	0	0	3.6%	0%	2.2	22	22	24	—	58
Garofalo et al. [16]	0	0	100	0	0%	—	3.1	3	0	—	93	93
Noyes and Barber-Westin [25]	0	0	100	0	—	—	2	19	19	19	81	71.4
O'Neill [29]	44	52	0	0	2%	—	—	6	—	6	84	75
Denti et al. [10]	61.7	38.3	0	0	—	—	—	10	—	—	83.3	78
Battaglia and Miller [6]	15.9	47.6	4.8	31.7	—	—	3.9	21	—	25	71	59
Ahn et al. [1]	37	36	0	26.8	—	—	1.5	3.6	0	—	73.2	—
Grossman et al. [18]	0	20.7	0	79	—	—	2.8	3.4	0	—	79.3	80
Thomas et al. [41]	69.4	30.6	0	0	—	—	1.4	5	2	—	—	—
Fox et al. [14]	0	0	0	100	—	—	1.9	6	3	6	93	—
Shino et al. (current study)	6	88	6	0	0%	0%	1.1	0	0	5.8	100	70.6

KT = side-to-side difference at manual maximum force with KT-1000 arthrometer; IKDC = International Knee Documentation Committee score; RTP = return to play sports.

attributed to femoral tunnel location or distance in its aperture between the primary ACLR and the revision. The ACL femoral attachment area is located in the superior-posterior margin of the lateral wall of the notch and less than 10 mm in width, as shown in recently published studies [9, 13, 15, 20, 22, 31, 39]. We have been consistently locating femoral tunnel aperture inside the attachment area [39] (Figs. 4, 5). Furthermore, a femoral tunnel with 5-mm wide rectangular aperture in RT ACLR might have made it possible not only to avoid overlapping tunnels, but to leave more space between the previous improperly placed tunnels and the new tunnels (Fig. 6).

With this procedure, grafts with or without bone plugs may be used. In some countries (including Japan) allograft tissue is not available owing to cultural philosophy. Thus, our principle graft choice for revision has been the BTB graft from the contralateral knee after the primary ACLR with the ipsilateral BTB graft or from the ipsilateral BTB graft if it had not been used for the primary ACLR. However, the BTB graft may not be appropriate for every patient. For example, some judo wrestlers would not accept graft harvest from the contralateral knee. They prefer an unbalanced dominant leg to well-balanced bilateral legs because of their sport. For these patients, the RT technique could be used with SMT if the double- or triple-bundle procedure could not be applied because of pre-existing tunnel(s). In contrast, rugby or American football players may be willing to have a BTB graft harvest from the contralateral limb.

One of our patients had a fall with the knee hyperflexed, resulting in femoral bone plug slippage out of the tunnel in the early postoperative period. Because the bone quality is attenuated and the previous tunnel is close to the new one in many revision cases, additional cortical fixation may be considered in addition to the interference screw fixation.

The rectangular tunnel technique restores function and stability in the short-term in most patients.

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