Available online at www.sciencedirect.com

ScienceDirect

Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology 2 (2015) 43–48
www.ap-smart.com

Review article

One-stage revision anatomic anterior cruciate ligament reconstruction with rectangular tunnel technique

Konsei Shino [a,*], Tatsuo Mae [b], Yasuhiro Take [b], Ryo Iuchi [a], Shigeto Nakagawa [a]

[a] *Center for Sports Orthopaedics, Yukioka Hospital, Kita-ku, Osaka, Japan*
[b] *Department of Orthopaedic Surgery, Osaka University Medical School, Suita, Osaka, Japan*

Received 12 September 2014; revised 16 December 2014; accepted 17 December 2014
Available online 17 February 2015

Abstract

We developed the anatomic rectangular tunnel anterior cruciate ligament reconstruction (ART ACLR) with a bone–patellar tendon–bone graft to mimic fibre arrangement inside the native ACL via tunnels with smaller apertures. With a 10-mm-wide graft, the cross-sectional area of the tunnels of 50 mm^2 in ART ACLR is less than that of 79 mm^2 in a 10-mm round tunnel one. Because tunnel encroachment would be less of a problem, the ART ACLR technique could be most frequently applied to patients after a failed primary ACLR. In this instructional lecture, the indication and technical considerations for ART ACLR as one-stage revision ACLR are described.

Keywords: anatomic rectangular tunnel technique; bone–patellar tendon–bone graft; one-stage; revision ACL reconstruction

Introduction

Revision anterior cruciate ligament reconstruction (ACLR) is technically difficult because of preexisting tunnels in the primary ACLR.[1] As the native ACL is oblong in the cross section of its midsubstance, a gold standard bone–patellar tendon–bone (BTB) graft with rectangular cross section is one of the morphologically suitable ones to mimic the native ACL for revision or primary ACLR.[2] Biomechanically, a 10-mm-wide BTB graft has sufficient maximum tensile load (1.2 × that for the normal ACL) with bone–tendon junctions and bone plugs.[3]

We developed the anatomic rectangular tunnel ACL reconstruction (ART ACLR) with a BTB graft to mimic natural fibre arrangement inside the native ACL and to minimize tunnel size.[4–6] The crescent-shaped ACL femoral attachment area is < 10 mm in width, whereas the triangular-shaped tibial attachment area is wider.[7–11] Thus, the technique makes it possible to create the tunnel aperture inside the attachment area. The tunnel aperture remaining inside the area with a thicker cortex could be assumed as more robust, and may potentially reduce the tunnel widening.[12] Biomechanically, this reconstruction technique is superior to the conventional transtibial tunnel single bundle procedure.[13]

The cross-sectional area of the tunnels of 50 mm^2 (5 mm × 10 mm) in ART ACLR is less than that in a conventional 10-mm round tunnel technique (79 mm^2), if a 10-mm-wide BTB graft is used. For revision ACLR, therefore, the ART procedure is advantageous because it leaves a larger space between the previous tunnels and the new ones. Because tunnel encroachment would hypothetically be less of a problem, the ART ACLR technique could be more frequently applied as a one-stage revision procedure to patients after a failed primary ACLR.

Surgical principles

Our principle at the time of one-stage revision ACLR is either (1) to create rectangular tunnels (parallelepiped tunnels

* Corresponding author. Center for Sports Orthopaedics, Yukioka Hospital, 2-2-3 Ukita, Kita-ku, Osaka 530-0021, Japan.
E-mail address: shinok0220@gmail.com (K. Shino).

http://dx.doi.org/10.1016/j.asmart.2014.12.003

with rectangular apertures) inside the anatomic attachment areas regardless of preexisting nonanatomic tunnels (Figs. 1 and 2) or (2) to reuse the preexisting tunnel apertures if they were in the anatomic attachment areas.

Description of technique for a 10-mm-wide graft

The patient is placed in the supine position with the thigh horizontally kept using a leg holder. The anteromedial portal is used for an arthroscope, whereas instruments are introduced via the far anteromedial portal.[14]

For creating rectangular tunnels, two continuous 5-mm round tunnels along the long axis of the attachment area are created in the centre of the attachment area, and then dilated using the 5 mm × 10 mm dilator with a hockey stick-shaped head (Ref.: E0014050-2; Smith & Nephew Inc., Andover, MA, USA; Fig. 3).

For the femoral tunnel, the instruments are used in an inside-out manner through the far anteromedial portal with the knee flexed beyond 145°. In case the knee could not be flexed beyond 145°, this step also can be accomplished in an outside-in fashion via a small lateral thigh incision to avoid blowout of the tunnel.

The tibial tunnel is created from the anteromedial cortex to the anatomic intra-articular insertion.[5]

Technical considerations

For graft choice

With this procedure, autogenous or allogeneic tendon grafts with or without bone plugs can be used. As we are located in Japan where allogeneic tissues are not readily available, our primary graft choice for revision is a BTB graft from the contralateral knee, or the one from the ipsilateral knee if it had not been used at the time of the primary ACLR. However, the BTB graft may not be indicated for every patient. For example, some judo wrestlers would not accept the BTB graft harvest from the contralateral knee. They tend to prefer an unbalanced dominant leg to well-balanced bilateral legs because of their sport event. For these patients, the ART technique could be applied with semitendinosus tendon (SMT) or quadriceps tendon–bone (QTB) graft if the double/triple bundle procedure might be compromised because of preexisting tunnel(s).[15] On the contrary, rugby or American football players may be good candidates for use of the contralateral BTB graft, because muscle imbalance between legs could be dissolved. However, an extremely careful postoperative rehabilitation has to be taken to minimize anterior knee pain or

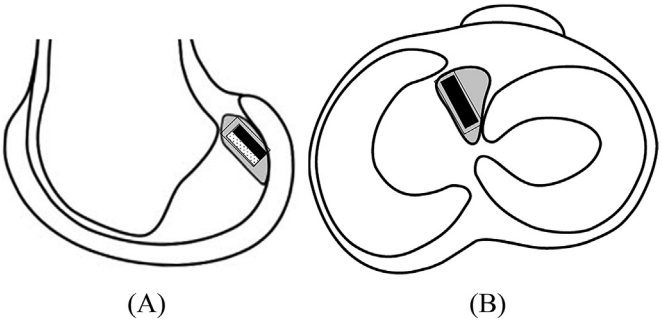

Fig. 1. Intra-articular tunnel apertures of the femoral and the tibial attachment areas for anatomical rectangular tunnel anterior cruciate ligament reconstruction (ART ACLR). (A) Note the tendinous side of the bone plug (black area) located posteriorly–superiorly in the femoral tunnel. (B) The tibial tunnel is almost filled with the tendon (black area).

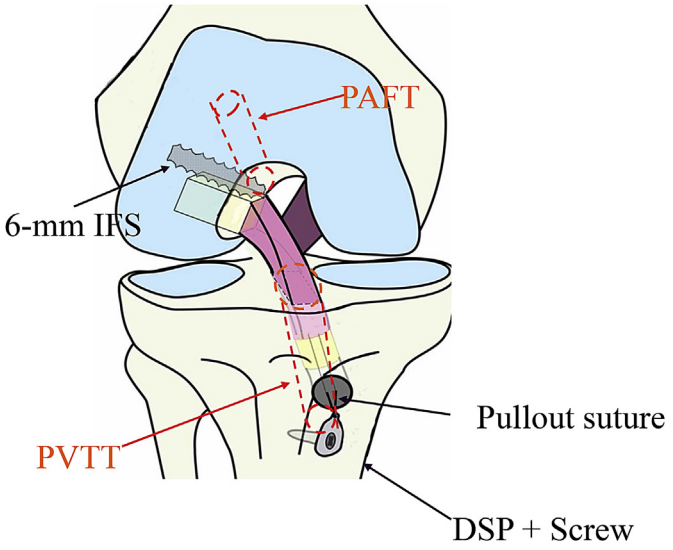

Fig. 2. Schema of revision rectangular tunnel ACL reconstruction with BTB graft. The bone plug is fixed to the femur with a 6-mm interference screw (IFS), whereas tibial fixation is achieved with a modified pullout suture technique using the DSP (Double Spike Plate) and a screw. A new anatomic femoral tunnel can be properly placed in most cases without overlapping tunnels despite the previous anterior femoral tunnel (PAFT) leading to a vertical graft. A new tibial tunnel is created to the aperture of the previous vertical tibial tunnel (PVTT) in most cases, whereas the direction of the tunnel is changed.

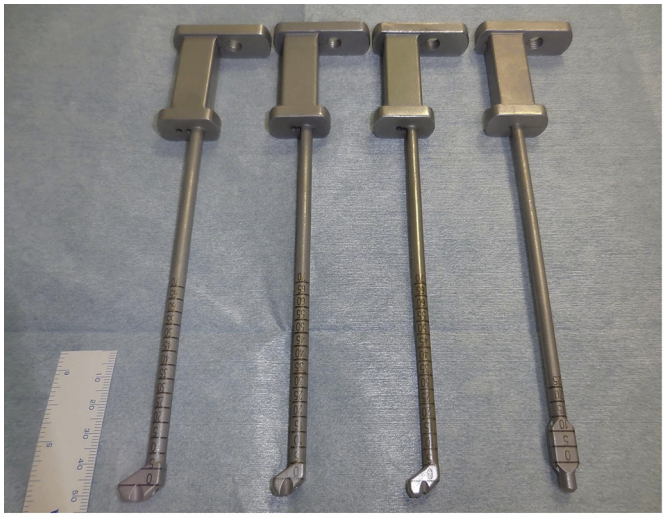

Fig. 3. Dilators of four sizes: 13 mm × 6.5 mm, 10 mm × 6.5 mm, 10 mm × 5 mm, and 8 mm × 5 mm.

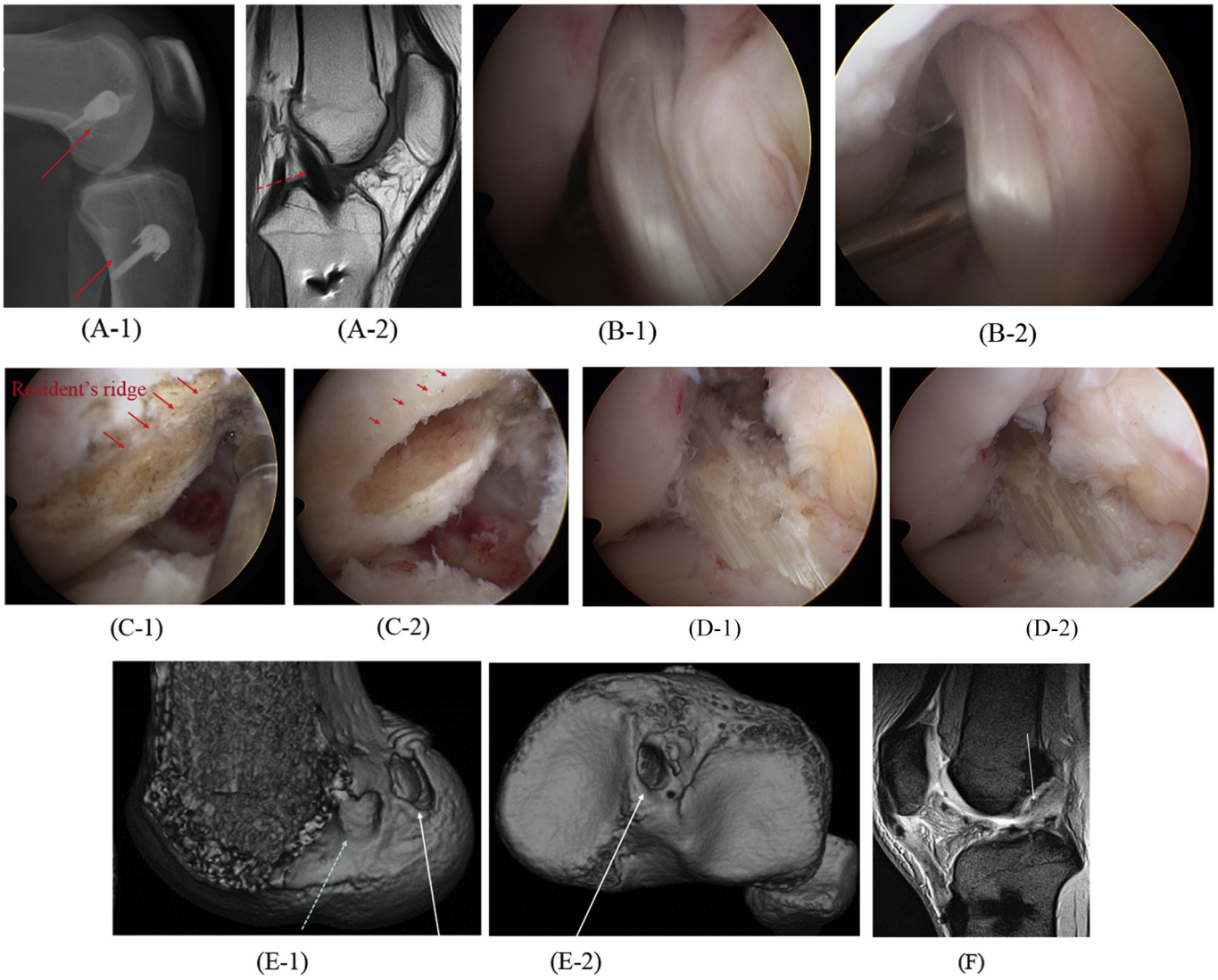

Fig. 4. (A-1) Plain lateral radiograph of Case 1. Note the big fixation hardware (unbroken arrows). (A-2) T1-weighted sagittal magnetic resonance (MR) image of Case 1 showing the vertically oriented graft (broken arrow). (B-1) Arthroscopic appearance of the graft in flexion. Note the graft-posterior cruciate ligament (PCL) impingement. (B-2) Arthroscopic appearance of the graft with abnormal looseness in extension. (C-1) Arthroscopic appearance of femoral attachment area behind the resident's ridge (unbroken arrows) via the anteromedial portal, after excising the nonfunctioning graft. (C-2) The new anatomic femoral tunnel aperture just behind the resident's ridge (unbroken arrows). (D-1) Revision anatomic ACL graft in flexion showing no graft-PCL impingement. (D-2) Revision anatomic ACL graft in extension showing no abnormal looseness in extension. (E-1) Three-dimensional (3-D) computed tomography (CT) pictures of Case 1 showing femoral and tibial tunnel apertures after revision ACLR. Note the new anatomic rectangular femoral tunnel aperture (unbroken arrow) and the primary nonanatomic one (broken arrow). (E-2) 3-D CT picture of Case 1 showing the reused tibial tunnel aperture (unbroken arrow). (F) T2-weighted sagittal MR image of Case 1 at 11 months after the revision ACLR. Note that the graft runs properly as the normal ACL (unbroken arrow).

thigh muscle weakness after harvesting BTB graft from the healthy knee.

With properly placed previous tunnels

After ART ACLR with BTB graft, the revision can be performed as the primary ART ACLR using any type of graft: two double-looped SMT grafts, QTB, or the contralateral BTB graft.

For failure cases following anatomic double bundle ACLR using soft tissue grafts including SMT, a new rectangular tunnel can be easily created by dilating previous two tunnels. For those with mildly widened femoral tunnel, the extra space may be filled with an interference screw >7 mm.

However, for those with severely widened tunnels after repeated ACLRs, grafting via over the top of the lateral femoral condyle as well as bone graft behind the revision graft in the tibial tunnel may be considered, as shown in Case 3.

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 $\geq$ 5 mm, and the new femoral tunnel is created as the primary ACLR leaving the primary tunnel. If the distance is < 5 mm, however, the primary tunnel may be filled with a titanium interference screw of an appropriate size.

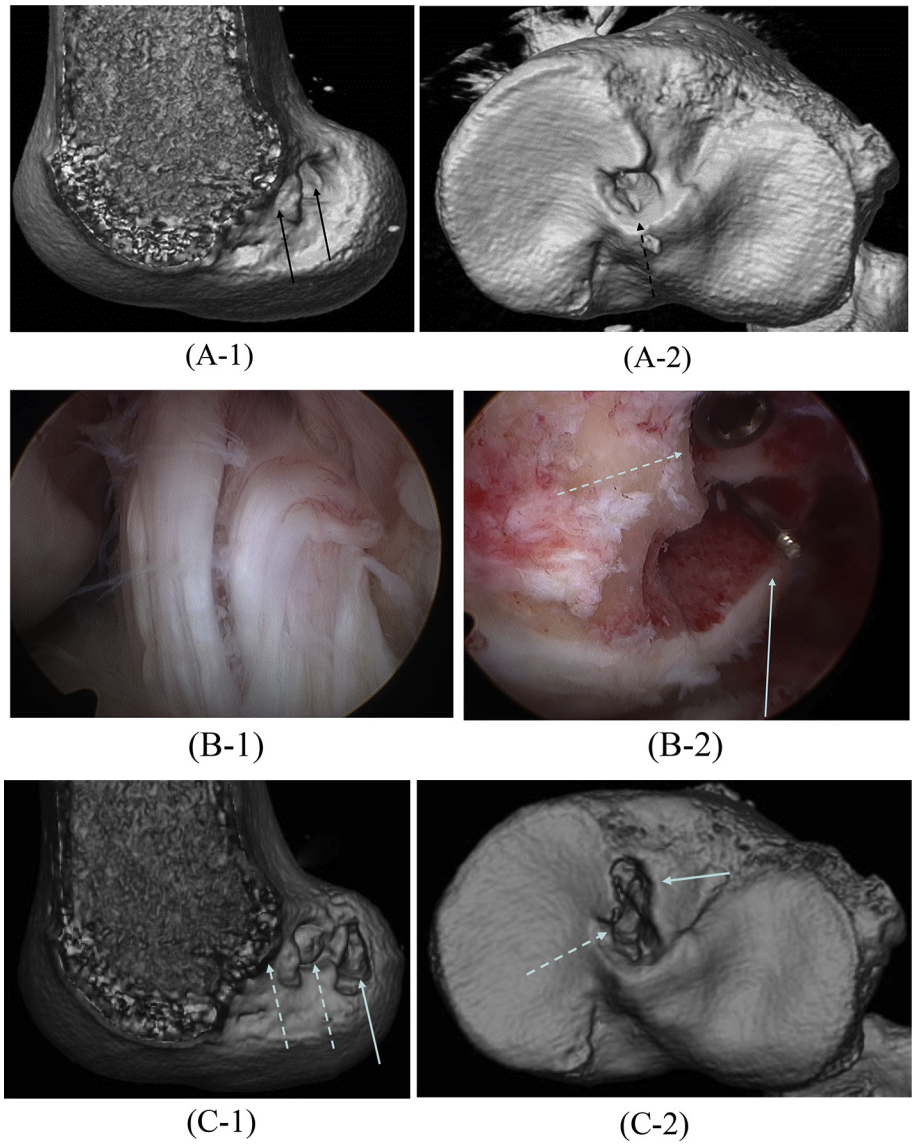

Fig. 5. (A-1) Three-dimensional (3-D) computed tomography (CT) picture of Case 2 showing improper femoral tunnels (unbroken arrows). (A-2) 3-D CT picture of Case 2 showing too far posterior tibial tunnel aperture (broken arrow). (B-1) Arthroscopic appearance of the primary nonanatomic ACL graft of Case 2. Note its vertical and loose appearance. (B-2) Arthroscopic appearance of the new femoral tunnel in the anatomic attachment area (unbroken arrow), and the primary nonanatomic tunnel aperture (broken arrow) filled with an interference screw. (C-1) 3-D CT picture of Case 2 showing femoral tunnel aperture after the revision ACLR. Note the new anatomic rectangular femoral tunnel aperture (unbroken arrow) and the primary nonanatomic ones (broken arrows). (C-2) 3-D CT picture of Case 2 showing tibial tunnel aperture after the revision ACLR. Note the new tibial tunnel aperture (unbroken arrow) and the primary posterior one (broken arrow).

On the tibial side, a tunnel placed too anteriorly is easily revisable by creating a new tunnel behind the previous one. With the tunnel placed properly in the attachment or malpositioned by $\leq$ 1 cm posteriorly, a divergent tunnel technique should be applied to obtain a new tunnel wall of fresh cancellous bone. When the tunnel is posteriorly malpositioned by $>$ 1 cm, however, the previous tunnel should be filled with a bone graft or its substitute.

For graft fixation

Femoral fixation is achieved with a 6-mm interference screw in most cases (Fig. 2). However, cortical suspensory fixation may be considered with a small lateral incision added if the fixation is not satisfactory or applicable owing to the previous tunnel, thin tunnel wall, or bone atrophy. Tibial fixation is achieved with a modified pullout suture technique using DSP (Double Spike Plate; Smith-Nephew Endoscopy, Andover, MA, USA) and a screw. This technique makes it possible to fix the graft under a predetermined amount of tension.[16] We prefer to apply the initial tension of 10–20 N to the graft after a meticulous *in situ* pretensioning with a tensioning boot.

Postoperative rehabilitation

The knee is immobilized at 10° flexion for 1 week with a brace, followed by passive and active range of motion (ROM)

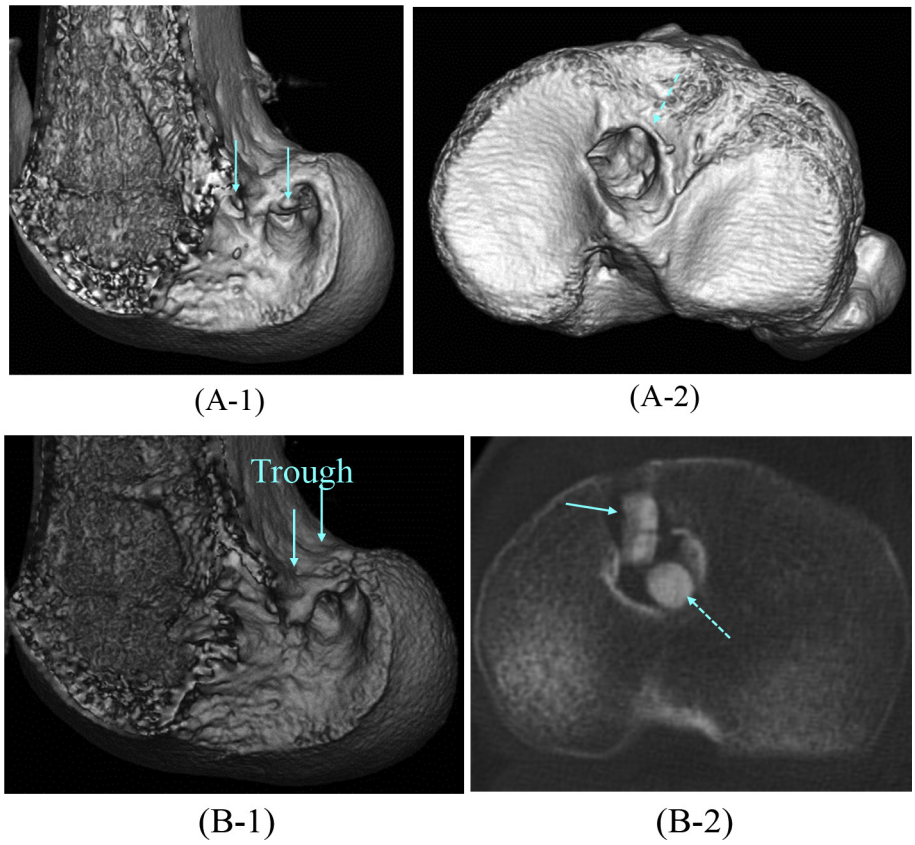

Fig. 6. (A-1) Three-dimensional (3-D) computed tomography (CT) picture of Case 3 showing femoral tunnel apertures (unbroken arrows). (A-2) 3-D CT picture of Case 3 showing a single widened tibial tunnel (broken arrow) after the third ACLR. (B-1) 3-D CT picture of Case 3 after the fourth ACLR showing through over the top of the lateral femoral condyle (unbroken arrows). (B-2) CT axial view of the tibial tunnel after the fourth ACLR. Note the bone plug of the quadriceps tendon–bone graft (unbroken arrow) and the cylindrical bone graft behind the bone plug (broken arrow).

exercises. Partial weight bearing is allowed at 2–3 weeks followed by full weight bearing at 4–5 weeks. Full extension or flexion exceeding 130° is not permitted until 5 weeks. Jogging is recommended at 3–4 months. Return to strenuous activity is allowed from 6 months to 9 months.

Illustrative cases

Case 1

Case 1 is a 19-year-old female basketball player who had undergone a single-bundle ACLR with hamstring tendon graft via high/improper femoral tunnels and a central/proper tibial tunnel (Fig. 4). This patient was suffering from persistent instability in her right knee. She underwent a revision ART ACLR, in which ipsilateral BTB graft was used, and stability was restored.

Case 2

A 23-year-old female judo wrestler had previously undergone a double-bundle ACLR with a hamstring tendon graft via improper femoral and tibial tunnels created by transtibial tunnel technique (Fig. 5). However, she suffered from persistent instability in her right knee. She underwent a revision ART ACLR using the BTB graft, after which knee stability was restored; she returned to judo at 8 months postoperatively.

Case 3

A 22-year-old male collegiate soccer football player who had undergone his third ACLR (performed by another surgeon) was suffering from persistent instability in his right knee. In this case, severely widened tunnels in the anatomical attachment areas after repeated ACLRs were noted (Fig. 6). The third revision ACLR using the ipsilateral QTB graft was performed via over the top of the lateral femoral condyle. This person is now in rehabilitation with stability restored in his knee.

Summary of clinical results

The ART ACLR technique made it possible to create a femoral tunnel in the anatomic attachment area in 30 of the 31 patients who had undergone revision procedures in the author's own practice between 2004 and 2008. The remaining patient, who had severe tunnel widening, had undergone the grafting process via over the top of the lateral condyle. The tibial tunnel was successfully created without tunnel overlapping 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 directly followed for a minimum of 24 months, none reported giving way, subjective instability, or loss of motion, whereas one had retorn the graft at 28 months. Quantitative anterior laxity measurement with KT-1000 showed that the mean side-to-side difference at maximum manual force improved from 6.8 ± 3.2 mm to 1.1 ± 1.4 mm, with a range of -1−4 mm. One had sustained a tear of the revision graft and underwent a second revision ACLR with the QTB graft via the same tunnels.[17]

Conclusion

The revision anatomic rectangular tunnel ACLR is one of the useful options to manage unstable knees after a failed ACL reconstruction.

Acknowledgments

K.S. has received funding from Smith & Nephew Inc.

References

1. Bach Jr BR. Revision anterior cruciate ligament surgery. *Arthroscopy*. 2003;19:14−29.
2. Siebold R, Schumacher P, Fernandez F, et al. Flat midsubstance of the anterior cruciate ligament with tibial "C"-shaped insertion site. *Knee Surg Sports Traumatol Arthosc*. 2014. http://dx.doi.org/10.1007/s00167-014-3058-6.
3. Noyes FR, Butler DL, Grood ES, Zernicke RF, Hefzy MS. Biomechanical analysis of human ligament grafts used in knee-ligament repairs and reconstructions. *J Bone Joint Surg*. 1984;66-A:344−352.
4. Shino K, Nakata K, Nakamura N, Toritsuka Y, Nakagawa S, Horibe S. Anatomically-oriented ACL Reconstruction with a bone−patellar tendon graft via rectangular socket/tunnels: a snug-fit and impingement-free grafting technique. *Arthroscopy*. 2005;21:1402.e1−1402.e5.
5. Shino K, Nakata K, Horibe S, et al. Rectangular tunnel double-bundle anterior cruciate ligament reconstruction with bone−patellar tendon−bone graft to mimic natural fiber arrangement. *Arthroscopy*. 2008;24:1178−1183.
6. Shino K, Suzuki T, Iwahashi T, et al. The resident's ridge as an arthroscopic landmark for anatomical femoral tunnel drilling in ACL reconstruction. *Knee Surg Sports TraumatolArthosc*. 2010;18:1164−1168.
7. Colombet P, Robinson J, Christel P, et al. Morphology of anterior cruciate ligament attachments for anatomic reconstruction: a cadaveric dissection and radiographic study. *Arthroscopy*. 2006;22:984−992.
8. Feretti M, Ekdahl M, Shen W, Fu FH. Osseous landmarks of the femoral attachment of the anterior cruciate ligament: an anatomic study. *Arthroscopy*. 2007;23:1218−1225.
9. Friedrich NF, O'Brien WR. Functional anatomy of the cruciate ligaments. In: Jakob RP, Staeubli H-U, eds. *The Knee and the Cruciate Ligaments*. Berlin: Springer-Verlag; 1992:78−91.
10. Iwahashi T, Shino K, Nakata K, et al. Direct ACL insertion to the femur assessed by histology and three-dimensional volume-rendered computed tomography. *Arthroscopy*. 2010;26:S13−S20.
11. Purnell ML, Larson AI, Clancy WG. Anterior cruciate ligament insertions on the tibia and femur and their relationships to critical bony landmarks using high-resolution volume-rendering computed tomography. *Am J Sports Med*. 2008;36:2083−2090.
12. Hutchinson MR, Ash SA. Resident's ridge: assessing the cortical thickness of the lateral wall and roof of the intercondylar notch. *Arthroscopy*. 2003;19:931−935.
13. Suzuki T, Shino K, Otsubo H, et al. Biomechanical comparison between the rectangular-tunnel and the round-tunnel anterior cruciate ligament reconstruction procedures with a bone patellar tendon bone graft. *Arthroscopy*. 2014;30:1294−1302.
14. Shino K, Horibe S, Hamada M, et al. Allograft anterior cruciate ligament reconstruction. *Tech Knee Surg*. 2002;1:78−85.
15. Shino K, Nakata K, Nakamura N, et al. Anatomic ACL reconstruction using two double-looped hamstring tendon grafts via twin femoral and triple tibial tunnels. *Oper Tech Orthop*. 2005;15:130−134.
16. Shino K, Mae T, Maeda A, Miyama T, Shinjo H, Kawakami H. Graft fixation with pre-determined tension using a new device, the double spike plate. *Arthroscopy*. 2002;18:908−911.
17. Shino K, Mae T, Nakamura N. Revision ACL reconstruction with rectangular tunnel technique. *Clin Orthop Relat Res*. 2012;470:843−852.