Radiologic and Clinical Outcomes After Hamstring Anterior Cruciate Ligament Reconstruction Using an Adjustable-Loop Cortical Suspension Device With Retensioning and Knot Tying

Nam-Hong Choi, M.D., Tae-Hoon Park, M.D., Whang-Kyun Oh, M.D., and Brian N. Victoroff, M.D.

Purpose: To report magnetic resonance imaging (MRI) findings and clinical outcomes after anterior cruciate ligament reconstruction using an adjustable-loop device (ALD) with retensioning and knot tying. **Methods:** The inclusion criteria were patients who underwent hamstring anterior cruciate ligament reconstruction using an ALD with retensioning and knot tying between May and December 2015 and were followed up for a minimum of 2 years. The exclusion criteria were patients with combined ligament injury, revision surgery, or reinjury after reconstruction. After initial tightening of the adjustable loop, retensioning and knot tying were performed and the graft was fixed at the tibia. Multiplanar reformatted images of 3-T MRI scans were obtained on the immediate postoperative day and at 6 months after surgery to measure the gap between the top of the graft and the top of the femoral tunnel (i.e., tunnel-graft gap). Differences in the tunnel-graft gap between the immediate postoperative day and 6 months after surgery (i.e., gap difference) were calculated and correlated with knee stability and functional outcomes. **Results:** Thirty-six patients were enrolled in this study. The mean tunnel-graft gap was 2.1 $\pm$ 2.8 mm on the immediate postoperative day and 4.6 $\pm$ 3.5 mm at 6 months after surgery ($P <$ .001). The mean gap difference was 2.5 $\pm$ 2.0 mm. The mean KT-1000 measurement was 1.5 $\pm$ 2.2 mm, and mean Lysholm score and Tegner activity scale score were 93.6 $\pm$ 5.5 and 5.6 $\pm$ 1.5, respectively. The gap difference correlated negatively with the follow-up Lysholm score ($P =$ .004); however, knee stability and the Tegner activity scale score were not correlated. **Conclusions:** Although the ALD was secured by retensioning and knot tying, MRI showed that the graft was not fully inserted in some patients and the tunnel-graft gap increased at 6 months' follow-up. The increase in the tunnel-graft gap did not correlate with knee stability or the Tegner activity scale score but correlated negatively with the Lysholm score. **Level of Evidence:** Level IV, therapeutic case series.

See commentary on page 2634

Quadrupled hamstring tendon is a popular graft for anterior cruciate ligament (ACL) reconstruction.[1] The hamstring tendon graft can be fixed on the femoral side using several fixation devices, including cortical suspension devices, cross pins, and metal or bioabsorbable interference screws. Among the cortical suspension devices, fixed-loop devices are commonly used for femoral-side fixation of soft-tissue grafts and can be fixed easily on the lateral femoral cortex. A biomechanical study showed the superior biomechanical properties of fixed-loop devices compared with adjustable-loop devices (ALDs).[2]

However, the fixed-loop device needs a 6- to 8-mm additional drilling depth of the femoral tunnel to flip the button on the lateral femoral cortex. This additional drilling creates a gap between the top of the femoral tunnel and the hamstring graft. This gap may result in the "bungee-cord effect." Although the exact cause of tunnel widening after ACL reconstruction is unknown, tunnel widening after ACL reconstruction using

From the Department of Orthopaedic Surgery, Eulji Medical Center (N-H.C., T-H.P., W-K.O.), Seoul, Republic of Korea; and Department of Orthopaedic Surgery, Case Western Reserve University (B.N.V.), Cleveland, Ohio, U.S.A.

The authors report the following potential conflicts of interest or sources of funding: N-H.C. receives personal fees from AANA. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

Received September 4, 2018; accepted March 11, 2019.

Address correspondence to Nam-Hong Choi, M.D., Department of Orthopaedic Surgery, Eulji Medical Center, 280-1, Hagye-1-dong, Nowon-gu, Seoul, 01830, Republic of Korea. E-mail: cnh2406@yahoo.com

0749-8063/181093/$36.00

https://doi.org/10.1016/j.arthro.2019.03.029

a fixed-loop device is usually attributed to the bungee-cord effect.[3] More tunnel widening with the fixed-loop device than with other devices has been commonly reported in the literature.[4-6]

Compared with the fixed-loop device, the ALD is composed of a button and an adjustable loop through which the soft-tissue graft passes. Tightening this loop attached to the button can pull the hamstring graft into the femoral tunnel completely. Although the ALD is secured by tightening the loop, several biomechanical studies showed significant loosening of the ALD compared with the fixed-loop device,[2,7] and some researchers recommended retightening of the adjustable loop.[7] Therefore, the purpose of this retrospective study was to report magnetic resonance imaging (MRI) findings and clinical outcomes after hamstring ACL reconstruction using an ALD with retensioning and knot tying. We hypothesized that retensioning and knot tying would show a fully inserted hamstring graft on MRI and the clinical outcomes would be satisfactory.

Methods

Subjects

The inclusion criteria were patients who underwent hamstring ACL reconstruction with the TightRope (Arthrex, Naples, FL) for femoral fixation and the Intrafix sheath and screw (DePuy Mitek, Raynham, MA) for tibial fixation between May and December 2015. All patients were followed up for a minimum of 2 years after surgery. The exclusion criteria were patients with combined ligament injury, revision surgery, or reinjury after reconstruction. Patients who underwent ACL reconstruction using quadriceps or patellar tendon graft, allografts were also excluded. All patients signed an informed consent form. The protocol of this retrospective study was reviewed and approved by the institutional review board.

Surgical Procedure

The semitendinosus and gracilis tendons were harvested and prepared for a quadrupled graft in the usual manner.[8] A circumferential mark was made on the graft 25 mm from its proximal end. The femoral tunnel was prepared using a modified transtibial technique. A guide pin was inserted at the center of the anatomic femoral footprint of the ACL. This guide pin was advanced out of the skin of the distal thigh, and a small skin incision was made along the guide pin for later retightening of tensioning sutures. The femoral tunnel was drilled to a depth of 25 mm. The passing and tensioning sutures were passed through the tibial and femoral tunnels using a guide pin. The adjustable-loop button was passed through the femoral tunnel and flipped on the lateral cortex of the distal femur by distal traction applied to the graft. The tensioning sutures were pulled slowly and robustly to insert the graft completely into the femoral tunnel. Arthroscopic visualization confirmed that the mark on the graft was flush with the outlet of the femoral tunnel, indicating full insertion of the graft into the femoral tunnel. With the tensioning sutures, retensioning was performed and a reverse half-hitch knot was made using an endoscopic knot pusher to prevent loosening of the adjustable loop.

After cyclic loading of the graft, the Intrafix tibial sheath and Intrafix screw were inserted within the tibial tunnel while the knee was flexed at 20°. Tolerable weight bearing using a brace was permitted as soon as possible postoperatively. Closed kinetic chain exercises were started as early as possible. Full weight bearing was permitted 6 weeks after surgery. Jogging was started after 8 weeks. Return to sports activity was allowed after 10 months.

Postoperative Evaluation

Tight contact of the button of the ALD on the lateral cortex of the distal femur was confirmed in all patients by use of immediate postoperative radiographs. Follow-up 3-T MRI scans (Magnetom Verio; Siemens Healthcare, Erlangen, Germany) on the immediate postoperative day and at 6 months after surgery were obtained in all patients to evaluate the position of the hamstring graft within the femoral tunnel. MRI on the immediate postoperative day was checked before weight bearing was initiated. By use of 3-T MRI, the 2-dimensional conventional sequences consisted of axial proton density (PD) transverse high-bandwidth, sagittal T2 turbo inversion recovery magnitude, sagittal turbo spin echo, and coronal T2 and PD sequences. In addition, a 3-dimensional PD SPACE (sampling perfection with application-optimized contrasts using different flip angle evolution) sequence (Siemens Healthcare) was acquired in the sagittal plane. Three-dimensional PD SPACE sequences were subsequently reformatted into oblique coronal images to view the entire length of the femoral tunnel by a magnetic resonance technologist using a magnetic resonance console with commercially available software (Syngo MR; Siemens Healthcare). The reformatting was performed with a 0.5-mm slice thickness. During review of the multiplanar reformatted images, a coronal image showing a 25-mm length of the femoral tunnel was chosen (Fig 1). The distance between the top of the femoral tunnel and the top of the hamstring graft (i.e., tunnel-graft gap) was measured (Fig 2). The tunnel-graft gap was easily measured because the top of the graft was cylindrical rather than conical or bullet shaped. We chose a 3-mm cutoff for the tunnel-graft gap because 3 mm of device lengthening was chosen to indicate clinical failure based on KT-1000 (MEDmetric, San Diego, CA) side-to-side difference measurements in a biomechanical study.[9] The measurements were performed on a picture archiving and

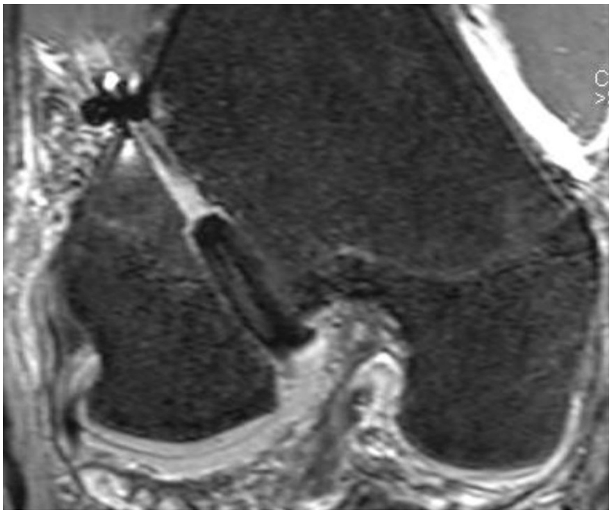

Fig 1. A 3-T magnetic resonance image of the right knee of a 17-year-old student shows that the hamstring graft was fully inserted into the femoral tunnel.

communication system (General Electric, Chicago, IL) by use of a mouse cursor with automated distance calculation.

A preoperative physical examination and clinical scoring were performed; however, they are not described. At 2 years after surgery, postoperative knee stability was evaluated using the Lachman test, pivot-shift test, and KT-1000 arthrometer. KT-1000 arthrometer testing was performed at maximal manual forces by an experienced orthopaedic technician. Functional evaluations were performed using the Lysholm score and Tegner activity scale score. Knee stability and functional scores were evaluated by an orthopaedic fellow (T-H.P.) who was not involved in the surgical procedure. Differences in the tunnel-graft gap between the images obtained on the immediate postoperative day and at 6 months after surgery (i.e., gap difference) were calculated and correlated with knee stability and functional outcomes.

Statistical Analysis

The Pearson correlation test was performed between the KT-1000 measurements, Lysholm score, and Tegner activity scale score and the gap difference. The Spearman correlation test was performed between the Lachman and pivot-shift tests and the gap difference. Analysis was performed using SPSS software (SPSS for Windows, release 12.0; IBM, Armonk, NY), and significance was assumed at $P < .05$.

Results

Thirty-six patients were enrolled in this study. The average age of the patients at the time of surgery was 31.5 years (range, 16-51 years). There were 30 male and 6 female patients. Concomitant procedures included meniscal repair in 17 patients, meniscectomy in 4, and microfracture in 1.

The tunnel-graft gap on the immediate postoperative day and at 6 months after surgery is described in Table 1. MRI on the immediate postoperative day showed that the graft was fully inserted into the femoral tunnel in 14 patients (38.9%). Of the patients, 27 (75%) had a tunnel-graft gap of 3 mm or less whereas 9 (25%) had a tunnel-graft gap of 4 mm or greater. The mean tunnel-graft gap was 2.1 ± 2.8 mm (range, 0-12 mm) on the immediate postoperative day. MRI at 6 months after surgery showed that the graft was fully inserted into the femoral tunnel in 4 patients (11.1%). Of the patients, 15 (41.7%) had a tunnel-graft gap of 3 mm or less whereas 21 (58.3%) had a tunnel-graft gap of 4 mm or greater. The mean tunnel-graft gap was 4.6 ± 3.5 mm (range, 0-15 mm) at 6 months after surgery and increased significantly compared with that on the immediate postoperative day ($P < .001$). The mean gap difference was 2.5 ± 2.0 mm.

The mean KT-1000 side-to-side difference measurement was 1.5 ± 2.2 mm, and the mean Lysholm score and Tegner activity scale score were 93.6 ± 5.5 and 5.6 ± 1.5, respectively. The gap difference

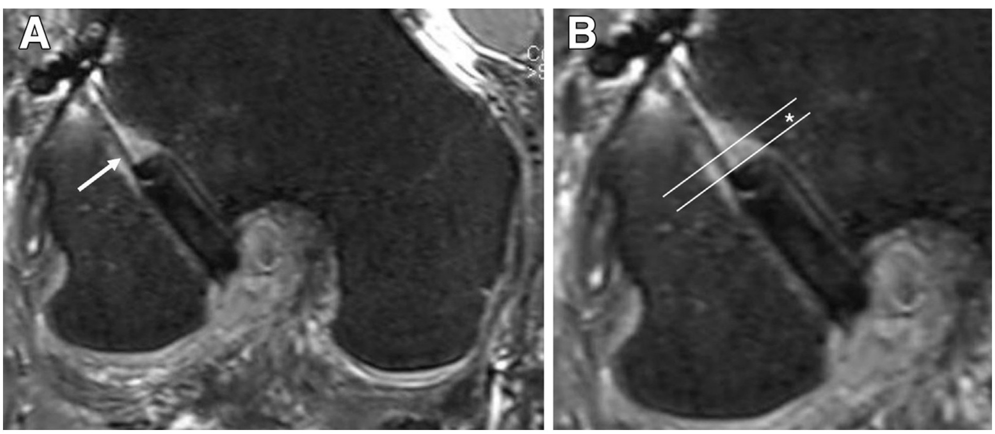

Fig 2. (A) A 3-T magnetic resonance image of the right knee of a 38-year-old man shows that the hamstring graft was not completely inserted. The arrow indicates the adjustable loop. (B) An enlarged image shows measurement of the gap (asterisk) between the top of the femoral tunnel and the graft.

Table 1. Tunnel-Graft Gap on Immediate Postoperative Day and 6 Months After Surgery

	Tunnel-Graft Gap, mm	
	Immediate Postoperative Day	6 mo After Surgery
Case No.		
1	0	9
2	0	4
3	3	4
4	1	2
5	5	9
6	12	15
7	0	2
8	0	0
9	3	6
10	5	10
11	0	3
12	0	0
13	0	3
14	0	4
15	1	4
16	0	4
17	6	9
18	7	10
19	6	6
20	1	6
21	5	5
22	0	0
23	0	0
24	1	2
25	2	2
26	1	2
27	0	2
28	2	3
29	1	2
30	7	10
31	0	4
32	0	4
33	2	5
34	3	5
35	2	8
36	1	2
Mean ± SD	2.1 ± 2.8	4.6 ± 3.5

SD, standard deviation.

correlated negatively with the follow-up Lysholm score ($r = -0.49$, $P = .004$); however, knee stability and the Tegner activity scale score were not correlated.

Discussion

The most important findings of this study were that MRI on the immediate postoperative day showed that the ALD may not pull the hamstring graft completely into the femoral tunnel. The tunnel-graft gap increased at 6 months after surgery even though retightening and knot tying were performed. The increased tunnel-graft gap did not affect knee stability or the Tegner activity scale score but affected the Lysholm score negatively.

The most important advantage of the ALD compared with the fixed-loop device is that the adjustable loop can pull the graft completely to the top of the femoral tunnel. However, the hamstring grafts were inserted completely in only 14 patients (38.9%) on the immediate postoperative day. The exact reason the hamstring graft was not inserted completely into the femoral tunnel in 22 patients on the immediate postoperative day is unknown. Possible explanations are as follows: First, the hamstring graft may not be fully inserted by tightening the adjustable loop even though the marking line is flush with the aperture of the femoral tunnel. The marking line may be blurred during the proximal pulling, distal pulling, and proximal re-pulling of the graft. Friction within the femoral tunnel may prevent complete insertion of the hamstring graft. To confirm whether a hamstring graft is fully inserted into the femoral tunnel after tightening the adjustable loop, MRI needs to be checked to measure the tunnel-graft gap before pretensioning and fixation of the graft on the tibial side, but this is impossible in clinical practice. Second, a fully inserted graft after tightening of the adjustable loop may be retracted distally by loosening of the tightened loop. After fixation of the hamstring graft on the femoral side, cyclic loading of the graft using flexion and extension 15 to 20 times is commonly performed for pretensioning of the graft. This pretensioning procedure could potentially loosen the tightened adjustable loop. In addition, pulling the graft distally for fixation on the tibial side could loosen the tightened adjustable loop. These possibilities may be explained by the biomechanical studies. The ALD showed greater displacement under the preloading condition and the most displacement during the first cycle.[2,7] Therefore, Petre et al.[7] suggested retightening the adjustable loop after initial cycling of the knee and fixing the graft.

The exact reason the tunnel-graft gap at 6 months after surgery increased significantly compared with that on the immediate postoperative day is unknown. Possible explanations are as follows: First, loss of tension applied to the graft by both femoral and tibial fixation could be a reason. The tension that was applied to the graft on the immediate postoperative day would be reduced during the period of graft healing within the femoral tunnel. This decreased tension of the graft would increase the tunnel-graft gap. Second, the tightened adjustable loop may loosen during the postoperative period. Accelerated rehabilitation is commonly used as a postoperative protocol after ACL reconstruction. Immediate weight bearing and early flexion exercises may loosen the tightened adjustable loop. Barrow et al.[9] suggested that the more important clinical concern regarding the mechanical properties of the ALD may be the volume of cycles rather than the intensity of load experienced postoperatively. Third, longitudinal tunnel widening would create the appearance that the tunnel-graft gap increased although the same length of graft as on the immediate postoperative day was inserted within the femoral tunnel. However, a 25-mm length of the femoral tunnel without any longitudinal tunnel widening was confirmed on a reformatted image in all patients at 6 months after surgery.

To prevent loosening of the adjustable loop in this study, retensioning and knot tying were performed before pretensioning and graft fixation at the tibia, because pretensioning and graft fixation at the tibia may loosen the tightened adjustable loop. Retensioning and knot tying may be performed after tibial fixation of the graft to secure the adjustable loop again. The optimal sequence for retensioning and knot tying when securing the ALD is not yet determined.

In this study, follow-up MRI showed that the tunnel-graft gap increased. An increased tunnel-graft gap, by itself, may not mean loosening of the adjustable loop. However, an increased tunnel-graft gap may be meaningful clinically because it negatively affected the Lysholm score. Moreover, the increased tunnel-graft gap may increase the distance between the fixation device and hamstring graft, resulting in the bungee-cord effect as the main cause of postoperative tunnel widening. However, a recent study reported that no significant differences in postoperative femoral and tibial tunnel widening were found between the ALDs and fixed-loop devices.[2] In addition, several articles have reported satisfactory knee stability after ACL reconstruction using the ALD.[10-13]

Limitations

There were several limitations in this study. First, we enrolled a relatively small number of patients in this study. Second, the follow-up MRI scans were not checked immediately after pulling the adjustable loop, before preconditioning and pulling the graft for fixation on the tibial side. Therefore, whether the graft was inserted completely by initial pulling of the adjustable loop was not evaluated. Third, retensioning and knot tying were performed before pretensioning and graft fixation at the tibia in this study. The preconditioning and pulling of the graft on the tibial side would potentially affect the tunnel-graft gap. These procedures will be necessary after pretensioning and graft fixation at the tibia in future studies. Fourth, comparison between a group with retightening and knot tying and a group without retightening and knot tying was not performed in this study. Finally, the gap difference was not correlated with postoperative widening.

Conclusions

Although the ALD was secured by retensioning and knot tying, MRI showed that the ACL graft was not fully inserted in some patients and the tunnel-graft gap increased at 6 months' follow-up. The increase in the tunnel-graft gap did not correlate with knee stability or the Tegner activity scale score but correlated negatively with the Lysholm score.

References

1. Chechik O, Amar E, Khashan M, Lador R, Eyal G, Gold A. An international survey on anterior cruciate ligament reconstruction practices. *Int Orthop* 2013;37:201-206.
2. Eguchi A, Ochi M, Adachi N, Deie M, Nakamae A, Usman MA. Mechanical properties of suspensory fixation devices for anterior cruciate ligament reconstruction: Comparison of the fixed-length loop device versus the adjustable-length loop device. *Knee* 2014;21:743-748.
3. Höher J, Möller HD, Fu FH. Bone tunnel enlargement after anterior cruciate ligament reconstruction: Fact or fiction. *Knee Surg Sports Traumatol Arthrosc* 1998;6:231-240.
4. Baumfeld JA, Diduch DR, Rubino LJ, et al. Tunnel widening following anterior cruciate ligament reconstruction using hamstring autograft: A comparison between double cross-pin and suspensory graft fixation. *Knee Surg Sports Traumatol Arthrosc* 2008;16:1108-1113.
5. JU Buelow, Siebold R, Ellermann A. A prospective evaluation of tunnel enlargement in anterior cruciate ligament reconstruction with hamstrings: Extracortical versus anatomical fixation. *Knee Surg Sports Traumatol Arthrosc* 2002;10:80-85.
6. Fauno P, Kaalund S. Tunnel widening after hamstring anterior cruciate ligament reconstruction is influenced by the type of graft fixation used: A prospective randomized study. *Arthroscopy* 2005;21:1337-1341.
7. Petre BM, Smith SD, Jansson KS, et al. Femoral cortical suspension devices for soft tissue anterior cruciate ligament reconstruction: A comparative biomechanical study. *Am J Sports Med* 2013;41:416-422.
8. Choi NH, Son KM, Yoo SY, Victoroff BN. Femoral tunnel widening after hamstring anterior cruciate ligament reconstruction with bioabsorbable transfix. *Am J Sports Med* 2012;40:383-387.
9. Barrow AE, Pilia M, Guda T, Kadrmas WR, Burns TC. Femoral suspension devices for anterior cruciate ligament reconstruction: Do adjustable loops lengthen? *Am J Sports Med* 2014;42:343-349.
10. Boyle MJ, Vovos TJ, Walker CG, Stabile KJ, Roth JM, Garrett WE Jr. Does adjustable-loop femoral cortical suspension loosen after anterior cruciate ligament reconstruction? A retrospective comparative study. *Knee* 2015;22:304-308.
11. Choi NH, Yang BS, Victoroff BN. Clinical and radiological outcomes after hamstring anterior cruciate ligament reconstructions: Comparison between fixed-loop and adjustable-loop cortical suspension devices. *Am J Sports Med* 2017;45:826-831.
12. Wise BT, Patel NN, Wier G, Labib SA. Outcomes of ACL reconstruction with fixed versus variable loop button fixation. *Orthopedics* 2017;40:e275-e280.
13. Zehir S, Zehir R. Suspensory fixation versus novel transverse crosspin for femoral fixation in anterior cruciate ligament reconstruction. *Arch Orthop Trauma Surg* 2014;134:1579-1585.