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Comparison of anterior knee laxity immediately after anatomic double-bundle anterior cruciate ligament reconstruction: Manual tensioning vs tensioning boot techniques

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Purpose: Tensioning technique at graft fixation is one of key factors for successful outcomes in ACL reconstruction. The tensioning boot, which had two tensioners and was fixed to the tibia with a bandage, was developed for precise graft tensioning. The purpose was to compare the anterior knee laxity between the manual tensioning and the tensioning boot techniques immediately after ACL reconstruction under anesthesia in order to elucidate the effectiveness of using the tensioning boot.

Methods: 33 patients had anatomic double-bundle ACL reconstruction with semitendinosus tendon graft. After grafts were fixed with EndoButton-CL on lateral femoral cortex, grafts were tied to Double Spike Plate (DSP). Each graft was pre-tensioning with 20 N (totally 40 N) at 20 degree of flexion for 3 minutes using manually-held tensioner in 11 patients and using tensioner installed to tensioning boot in the remaining 22 patients before graft fixation, and were then fixed in the same manner. Tibial displacement under 67 and 89 N of tibial anterior load was measured by KT-2000 Knee Arthrometer under anesthesia before and immediately after operation.

Results: The anterior knee laxity in the operated knee was 4.5 ± 1.0 mm in the manual tensioning group and 2.9 ± 0.9 mm in the tensioning boot group at 89 N of anterior load, showing a significant difference. ($P < .0001$) The side-to-side difference in the manual tensioning group was significantly less than that in the tensioning boot group. ($P = .002$)

Conclusions: Anterior laxity of the operated knees as well as KT side-to-side difference immediately after ACL reconstruction was larger in the tensioning boot technique than the manual tensioning technique, when the graft was fixed in the same manner. Thus, the initial tension at graft fixation with the tensioning boot can be smaller than 40 N.

1. Introduction

Graft tension and tensioning technique at graft fixation in ACL reconstruction are one of key factors for successful outcomes. As the excessive initial tension can lead to abnormal tibio-femoral relationship, loss of extension, graft damage/failure and degeneration of articular cartilage by increase of tibio-femoral compressive load, excessive initial tension should be avoided, and the less stress will be imposed to the graft or its fixation sites with smaller graft tension.[1–7] Some over-tensioning to the graft at its fixation is required to control the laxity or to restore the stability after ACL

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reconstruction, while the optimal tension is still unknown.

Manual maximum tension with post screw or interference screw is preferred at graft final fixation in ACL reconstruction, as an increase in graft tension reduces anterior knee laxity.[8] However, there are following insecure factors on this technique; 1) considerable tension variation depending on the surgeons' tractive power and skill, 2) unknown initial tension because of difficulty in control of graft tension, and 3) suture loosening or break in knot tying. O'Neil et al.[9] described that even under closely controlled conditions, experienced ACL reconstruction surgeons were not able to consistently tension an ACL graft using the maximum sustained one-handed pull technique. Furthermore, graft failure rate in manual tensioning was actually 8.9% and was higher compared to 4.3% in device-assisted tensioning in systematic review.[10] Thus, the graft tension should be controlled at fixation in ACL reconstruction.

Manually-controlled tensioning technique with tensioners is commonly performed at graft fixation in ACL reconstruction because of its easiness. Some surgeon advocated to fix the graft at quantitative tension using a manual tensioner.[11,12] Yasuda et al.[11] reported that the 30-N tension applied to each graft at 10 degree of flexion was preferable in the anatomic double-bundle ACL reconstruction with hamstring tendon grafts, while initial tension was manually applied to the graft with a spring tensioner held by hand. In this manual tensioning technique, however, when the graft is manually pulled, the tension is transmitted only to the graft and the creep phenomenon occurs just in the graft. Therefore, the tension may drop after final graft fixation at the tibia, because the femur-graft-tibia complex as a whole must undergo the load relaxation again.

The tensioning boot system was developed to monitor the tibia-based tension to the graft and could let the creep phenomenon occur on the femur-graft-tibia complex as a whole (Fig. 1).[13] This tensioning boot is fixed to the calf with a bandage and has two tensioners to be connected with grafts' end sutures, when the initial tension is applied to the grafts. Mae et al.[13] previously reported the graft fixation with a tensioning boot with repetitive manual pulls is the most secure procedure to maintain the graft tension closer to the intended initial tension in ACL reconstruction. However, there are few clinical reports to demonstrate how effectively the graft is fixed with this tensioning and fixation technique. Therefore, the purpose of this study was to compare the anterior knee laxity between the manual tensioning technique and the one using the tensioning boot system immediately after ACL reconstruction under anesthesia in order to elucidate the effectiveness of using the tensioning boot. It was hypothesized that the knee laxity after graft fixation with the tensioning boot system was smaller than that with the manual tensioning, when graft was fixed with the same initial tension.

Fig. 1. Tensioning boot with two tensioners.

2. Materials and methods

Sequential thirty-three patients with ipsilateral ACL injury underwent an anatomic double-bundle ACL reconstruction with semitendinosus tendon grafts. There were 22 males and 11 females, and their mean age was 26 years (14–49). All patients had consented to be involved in this study. Eleven patients had medial meniscal tear, while tear to lateral meniscus was found in eleven patients. In those with medial meniscal tear, 4 patients underwent meniscal repair, while 5 knees underwent partial meniscectomy and 2, rasping without repair. In the case with lateral meniscal tear, 4 underwent meniscal repair, while 7 underwent partial meniscectomy. There was neither other ligament injury nor severer articular cartilage damage than Grade II, fissuring or fibrillation less than one-half the thickness of the articular cartilage. The surgery was performed in two hospitals by two surgeons (T.M, H.N.) with more than 20-year experience of arthroscopic surgery. Then, the patients were divided into two groups according to a hospital operated on, because one hospital had a tensioning boot system and the other hospital didn't have it (Table 1). Our institutional review board for human subject approved this study protocol.

3. Operative procedure

An anatomic double-bundle ACL reconstruction with two femoral and two tibial tunnels was performed in all knees.[14] After cleaning up the ACL remnant around the femoral attachment area, each portion of the anteromedial (AM) and posterolateral (PL) bundle footprints was marked behind the resident's ridge and just anterior to posterior cartilage margin. Using an antero-lateral entry femoral aimer (Smith & Nephew Inc. Endoscopy, Andover, MA, USA), two 2.4-mm guide-pins were separately inserted from lateral femoral cortex to each portion. Then, 5.0- to 6.0-mm tunnels were created for the AM and PL grafts by over-drilling along the guide-pins. For tibia, medial intercondylar ridge, anterior ridge and anterior horn of lateral meniscus were also clearly visualized after removal of remnant. After two guide-pins were inserted from the medial tibial cortex to the center of the AM and PL bundle footprints along the medial intercondylar ridge with a drill guide system (Smith & Nephew Inc. Endoscopy, Andover, MA, USA), two 5.0- to 6.5-mm tunnels were created by over-drilling.

4. Graft preparation and fixation

More than 24 cm length of semitendinosus tendon was harvested at first before arthroscopy. Then, the semitendinosus tendon was transected in half and then folded to make two pairs of doubled

Table 1
Patients' demography.

	Manual	Tensioning boot	p-value
Gender (male: female)	8:3	14:8	.602
Age at operation	27.3	25.8	.605
Meniscal lesion (lateral: medial)	5:2	6:9	.170
Anterior knee laxity (side-to-side difference)			
67 N	3.4 ± 3.1	3.5 ± 2.5	.644
89 N	4.5 ± 3.0	4.6 ± 2.5	.590
134 N	6.3 ± 3.7	6.2 ± 3.4	.787
manual max.	9.7 ± 4.0	9.8 ± 4.1	.969

grafts. EndoButton-CL (Smith & Nephew Inc. Endoscopy, Andover, MA, USA) of appropriate length based on the femoral tunnel length was placed to the loop end of the graft, while the free end of each doubled graft was sutured with two No.3 polyester threads with the Krackow stitch. After Pre-tensioning of 10 N was performed for each graft more than 3 minutes on the table, each graft was introduced through the tibial tunnel to the femoral tunnel and was fixed on the lateral femoral cortex by flipping EndoButton. Then, the sutures from grafts were separately tied to two Double Spike Plates (DSP: Smith & Nephew Inc. Endoscopy, Andover, MA, USA)[15] at tibial side, and were connected to two tensioners in 11 patients (manual tensioning group) and to the tensioners in the tensioning boot in 22 cases (tensioning boot group) (Fig. 2). A total of 40 N of initial tension (20 N to each graft) was then applied using tensioners at 20 degree of knee flexion, and the creep of the construct was removed by repetitively pulling the graft sutures for 3 minutes at the same position. Finally, both DSPs connected to grafts were fixed on the tibia with a total of 40 N of initial tension at the same position. The operation time was 88 ± 12 minutes in the manual tensioning group and 84 ± 16 minutes in the tensioning boot group.

5. Laxity measurement

Anterior knee laxity measurement was preoperatively performed on both knees at 67 N (15lb), 89 N (20lb), 134 N (30lb) and manual maximum load with the KT-2000 Knee Arthrometer (MEDmetric, San Diego, CA) at 30°of flexion under general anesthesia. The measurement was repeated under 67 N and 89 N of anterior load on the bilateral knees at the 30°of flexion under anesthesia immediately after operation. Laxity measurement under 134 N of anterior load was not examined immediately after operation as large anterior load had possibility to decrease the graft tension. In this study, all measurements were performed by one examiner (TM).

6. Statistical analysis

Mann-Whitney's *U* test was used to detect any significant differences in the knee laxity and side-to-side difference of the measured laxity between two techniques. Pearson's chi-square test was performed for gender and meniscal lesion, while Mann-Whitney's *U* test was also used for age at operation. *P*-value of less than 0.05 was considered statistically significant. A post hoc type of power analysis with $\alpha$of 0.1 and effect size of 0.8 showed that power of this analysis was 0.804.

7. Results

There were no significant differences between two techniques in gender, age, meniscal lesion, and preoperative anterior knee laxity (Table 1). The postoperative anterior knee laxity for the operated knee was 4.5 ± 1.0 mm in the manual tensioning group and 2.9 ± 0.9 mm in the tensioning boot group at 89 N of anterior load under general anesthesia, showing a significant difference. ($p < .0001$) The side-to-side difference in the manual tensioning group was −2.7 ± 1.8 mm at 89 N of anterior load immediately after surgery and was significantly less than that in the tensioning boot group. ($p = .002$) (Table 2).

8. Discussion

Graft tensioning technique as well as graft tension at graft fixation is an important issue for successful ACL reconstruction. In the current study, less side-to-side difference and smaller operated knee laxity were smaller in the tensioning boot group at 67 N and 89 N of anterior tibial load. Thus, tensioning with the tensioning boot provided better anterior knee stability in response to the anterior tibial load than that with the manual tensioning, when grafts were fixed with the same initial tension in ACL reconstruction. This suggests that graft can be securely fixed with less initial tension in case of using the tensioning boot system.

Tensioning boot system was developed to fix grafts with intended tension in ACL reconstruction. A previous cadaveric study compared the residual graft tension after graft fixation with a manual tensioning technique in ACL reconstruction to that with tensioning boot technique, and revealed that the tensioning boot technique with repetitive pulls was the most secure procedure to maintain the graft tension closer to the intended initial tension.[13] However, this study just showed the tension 3 min after fixation and after 50 cycles of flexion-extension motion, while it is still unclear whether the graft tension can be maintained at least immediately after operation. In this clinical study, the anterior knee laxity in the tensioning boot group was significantly smaller than that in the manual tensioning group under the same initial tension immediately after operation. Thus, graft tensioning with the tensioning boot was more efficacious to reduce anterior knee laxity and could restore the normal laxity with smaller amount of the initial tension at graft fixation. Mae et al.[16] previously compared the side-to-side difference of anterior knee laxity 2 years after

Table 2
Anterior knee laxity measured with KT-2000 Knee Arthrometer.
Comparison between the manual tensioning and the tensioning boot techniques.

	Manual	Tensioning boot	p-value
Anterior knee laxity operated knees			
67 N	2.8 ± 0.8	1.8 ± 0.7	.001
89 N	4.5 ± 1.0	2.9 ± 0.9	<.0001
contra-lateral knees			
67 N	5.5 ± 1.8	6.5 ± 1.7	.123
89 N	7.2 ± 2.2	8.1 ± 2.0	.143
Side-to-side difference			
67 N	−2.7 ± 2.1	−4.7 ± 1.6	.007
89 N	−2.7 ± 1.8	−5.2 ± 2.0	.002

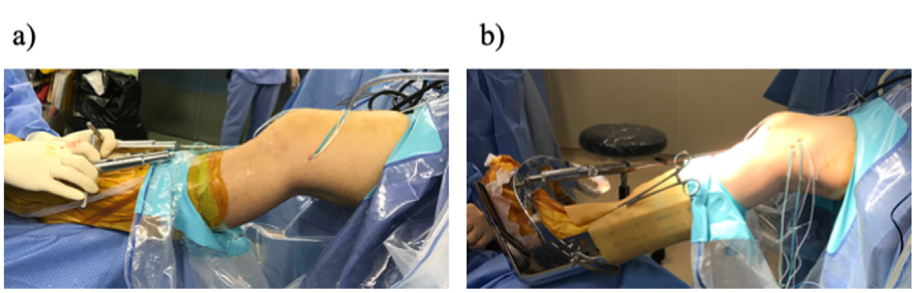

Fig. 2. Tensioning techniques. a) manual tensioning. b) tensioning with the tensioning boot.

isometric Rosenberg bi-socket ACL reconstructions with hamstring tendon graft among three different initial tensions of 60, 80 and 100 N, and described that the variation associated with the grafts tensioned to 100 N was the largest among three groups, while there were no significant differences among three groups. Thus, as the smaller initial tension is desirable, the tensioning boot is useful to reduce the initial tension at graft fixation.

In the manual tensioning technique, when the graft is manually pulled with tensioners, the graft tension and the tensioner's tension will be balanced with each other. However, after graft fixation, part of graft force is transferred to axial compressive and posterior tibial force, and shifts the tibia proximally and posteriorly, leading to reduction of the residual force. On the other hand, in the tensioning boot technique, when the graft is pulled under monitor by the tensioners installed in the tensioning boot, the tibia moves proximal and posterior during graft tensioning, and then is stabilized. And the graft tension will not change after the graft fixation. Therefore, 40 N of initial tension is adequate to fix graft with the manual tensioning technique, as the mean side-to-side difference was −2.7 mm of moderate over-constraint immediately after surgery.

Markolf et al.[17] measured the tension of the normal ACL on cadaveric knees and reported that the ACL tension was nearly 0 N at 20 degree of flexion. Mae et al.[18] previously reported minimally-required initial tension at graft fixation in anatomic double-bundle reconstruction was totally 20 N at 20 degree of knee flexion and the side-to-side difference in anterior laxity under 89 N of anterior load was −3.7 mm immediately after ACL reconstruction with the tensioning boot technique under general anesthesia. In this study, the side-to-side difference was −5.2 mm at the same manner in the tensioning boot technique, and smaller than that in the previous report. There is little consensus for appropriate over-tension, however, around -3.0 mm of side-to-side difference would be desired as the stress-relaxation must be occurred after graft fixation in knee structure as well as graft. Thus, 40 N of initial tension must be excessive in case of graft fixation with the tensioning boot system in the anatomic double-bundle ACL reconstruction. This suggests that care must be taken not to give excessive initial tension to the graft or not to make the knee too much over-constrained in the tensioning boot technique.

There are some limitations in this study. First, graft was fixed with only one tension (total 40 N). As Mae et al. described 20 N of initial tension was enough to achieve knee stability in anatomic double-bundle ACL reconstruction, less tension must be compared. However, there were possibility to make a loose knee when the less tension was applied for grafts with the manual tensioning. Second, 67 N and 89 N of anterior tibial load might be too small to evaluate the knee laxity, while we were afraid that larger anterior load might bring damage to the construct. However, applying 89 N of anterior load may be large enough to show pathological laxity of the ligament without muscular defense under anesthesia in the operating room, as Daniel et al.[19] mentioned.

9. Conclusion

Anterior laxity of the operated knees as well as KT side-to-side difference immediately after ACL reconstruction was larger in the tensioning boot technique than the manual tensioning technique, when the graft was fixed in the same manner. Thus, the initial tension at graft fixation with the tensioning boot can be smaller than 40 N. The tensioning boot is one of essential items at graft fixation to reduce the initial tension.

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Declaration of competing interest

All authors have no conflicts of interest.

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