Available online at www.sciencedirect.com

ScienceDirect

Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology 6 (2016) 1−6
www.ap-smart.com

Original article

Postoperative outcome is affected by an intraoperative combination of each graft tension change pattern in a double-bundle anterior cruciate ligament reconstruction

Tomomasa Nakamura [a], Hideyuki Koga [a], Masafumi Horie [a], Toshifumi Watanabe [a], Kazuyoshi Yagishita [b], Ichiro Sekiya [a], Takeshi Muneta [a,*]

[a] *Department of Orthopaedic Surgery, Medical Hospital of Tokyo Medical and Dental University, Tokyo, Japan*
[b] *Sports Medicine Clinical Center, Medical Hospital of Tokyo Medical and Dental University, Tokyo, Japan*

Received 29 June 2016; revised 11 August 2016; accepted 22 August 2016
Available online 28 September 2016

Abstract

Background: The purpose of this study is to evaluate the intraoperative tension change pattern of each anteromedial (AM) graft and posterolateral (PL) graft and to investigate the optimal femoral tunnel position in double bundle (DB) anterior cruciate ligament reconstruction (ACLR) by comparing postoperative outcomes with each combination of graft tension change pattern.
Methods: Eighty-four unilateral primary DB ACLR cases from 2006 to 2008 with a follow-up of 24 months or more were analysed. The tension change pattern of each AM and PL graft after graft fixation was recorded during DB ACLR, and divided into over-the-top (OTT; tension at $0^\circ > 120^\circ$) and reverse OTT (graft tension at $0^\circ < 120^\circ$) pattern. The combinations of these patterns were then categorized into four groups and the postoperative results were analysed. The femoral tunnel position was measured by a modified quadrant method. The relationship between the femoral tunnel position and the tension change pattern of each graft was evaluated.
Results: The cases that presented reverse tension change pattern of native anterior cruciate ligament (ACL) performed most poorly in postoperative knee laxity among the four groups. In this group, the femoral tunnel of the AM bundle was placed significantly higher in flexion.
Conclusion: This study suggests that the least effective method for knee stability recovery is for the ACL to be reconstructed with the reverse tension change to the native ACL. It is necessary to refrain from placing the femoral tunnel for the AM bundle in a high position in knee flexion in DB ACLR.

Keywords: double-bundle anterior cruciate ligament reconstruction; femoral tunnel placement; graft tension change pattern; stability recovery

Introduction

Anatomic double-bundle (DB) anterior cruciate ligament reconstruction (ACLR)[1] attracts attention from ligament surgeons because of the theoretical advantages and the superiority of stability recovery compared with those of single-bundle reconstruction.[2,3] Anatomic DB reconstruction using medial hamstring tendons reportedly reproduces the normal tension change pattern of each anteromedial (AM) bundle and posterolateral (PL) bundle.[4,5]

A relatively high rate of clinical failure of ACLRs has been also reported.[6,7] The cause of failure is multifactorial, such as the amount of preoperative knee laxity, limb malalignment, graft materials, rehabilitation protocols, etc. Additionally, it was reported that 22−80% of reconstruction failures were thought to be due to technical errors, with the most common findings being incorrect tunnel position.[8−10]

Although there is no clear consensus on the knee flexion angle and the force of initial graft tension at graft fixation

* Corresponding author. Department of Joint Surgery and Sports Medicine, Graduate School, Tokyo Medical and Dental University, 1-5-45 Yushima, Bunkyo-ku, Tokyo 113-8519, Japan.
E-mail address: muneta.orj@tmd.ac.jp (T. Muneta).

http://dx.doi.org/10.1016/j.asmart.2016.08.002
2214-6873/

during DB ACLR, it has been reported that femoral tunnel position of the AM bundle and the PL bundle affects reciprocal tension change during knee flexion and extension more significantly than the tibial tunnel position.[11,12] Previous *in vivo* and *in vitro* studies suggest that graft tension and tension change pattern are correlated with the clinical outcome.[13–15] Although there have been a number of articles about ACLR, few reports have analysed the effects of the initial tension change pattern at the graft fixation during surgery on the postoperative outcome. However, controversies still remain regarding the optimal femoral tunnel position and anatomic placement. Detailed analyses are lacking regarding the optimal femoral tunnel placement in a DB ACLR in order to achieve better recovery of knee stability.

The first aim of this study was to compare the initial tension change pattern of the grafts and the femoral tunnel position. The second aim was to compare the combination of the intraoperative tension change pattern of each AM graft and PL graft, and the postoperative clinical results in DB ACLR. The first hypothesis underlying this study was that there were some anatomical rules in each AM and PL femoral tunnel position which lead to the tension change pattern of each graft. The second hypothesis was that there would be some appropriate initial tension change pattern which would give better clinical results. As a final goal, the results will suggest the anatomical concept of femoral tunnel creation for the best clinical outcome in DB ACLR.

Materials and methods

Patients

A cohort study was conducted for patients with anterior cruciate ligament (ACL) injuries who underwent DB ACLR at our institution between January 2006 and December 2008. The inclusion criteria were primary ACLR with an autologous semitendinosus tendon. The exclusion criteria included a history of injury to the ipsilateral knee and a history of ligamentous injury to the contralateral knee. During this period, 116 reconstructive surgeries were performed by a senior surgeon (T.M.) or by fellow doctors with the assistance of the senior surgeon. Out of 116, 84 patients (average age at surgery ± standard deviation: 24.6 ± 9.7 years) with follow-up for at least 24 months after surgery were included in this study. This study was approved by the Ethical Committee of Tokyo Medical and Dental University, and all the patients provided informed written consent.

Operative procedures of a DB ACLR

The anatomic ACLR advocated by Yasuda et al[1] was performed with a transtibial approach using a four-strand semitendinosus tendon. The anatomic bony landmarks of ACL tibial attachment were touched and felt with the tip of the tibial drill guide. Two tibial guide wires were inserted from the AM surface of the tibia at the tibia tubercle level with anatomic landmarks of the anterior wall of the anterior intercondylar notch, medial intercondylar tubercle, ruptured ACL remnant, and posterior cruciate ligament. These guide wires were placed in the remnant tissue with an angle of 65° for the AM bundle and 45° for the PL bundle from the joint line in the frontal view.[16] The femoral drill hole procedure was performed in a figure-four position with arthroscopic observation from the AM portal. The centre of the femoral drill hole for the AM bundle and the PL bundle was aimed at 1:30 and 3:30, respectively, on the intercondylar clock of the left knee in the deeper area of the resident's ridge in knee flexion position.[17] Graft fixation was performed in the same manner as before,[16] except for the initial tension and fixation angle. First, the PL graft was fixed to an anchor staple at 20° of knee flexion. Applied tension to the PL graft was adjusted to be equal per cross sectional area on a basis of 30 N per 6 mm in diameter. Then, the initial tension of the AM graft was determined by probing in order to equalize to the PL graft at 20° of knee flexion. The AM graft was fixed to the anchor staple by a pull-out method. Before passing grafts to the tunnels, two grafts were tensioned by 10 N for more than 20 minutes on the GraftMaster (Smith & Nephew Inc., Andover, MA, USA).

Tension change pattern recording

The tension change pattern was recorded after the AM graft and PL graft were finally fixed. The surgeon felt the graft tension carefully with a standard probe during passive knee motion from full extension to 120° flexion. If the graft tension increased during knee extension with the tension in near full extension greater than that at 120° flexion, it was recorded as an "over-the-top (OTT) pattern". When it was the opposite, with the tension in near full extension less than that at 120° flexion, it was a "reverse OTT pattern". Based on the combination of the tension change pattern of the AM graft and the PL graft, each patient was categorized into four groups (Table 1). All measurements were performed by the same surgeon, and performed three times to minimize the intrarater variability. Accuracy of the manual tension measurements was validated by comparing with the Stress Equalization (SE) Graft Tensioning System (Linvatec, Largo, FL, USA) as a gold standard.[18–21] The grafts were provisionally fixed to the SE Graft Tensioning System (Linvatec) with sutures at the tibial site after the grafts had been passed through tunnels and fixed at the femoral side with the EndoButton CL-BTB (Smith & Nephew Endoscopy; Smith & Nephew Inc.). The SE Graft

Table 1
Patients' grouping.[a]

	Group 1	Group 2	Group 3	Group 4
AM tension change	OTT	OTT	ROTT	ROTT
PL tension change	OTT	ROTT	OTT	ROTT
No. of patients	29	14	19	22

AM = anteromedial; OTT = over-the-top; PL = posterolateral; ROTT = reverse over-the-top.

[a] All patients were categorized into four groups according to the combination of AM and PL graft tension change patterns.

Tensioning System (Linvatec) is a device that can help with quantifying and applying consistent amounts of tension to each graft, with an accuracy of 0.83 ± 0.03 N (mean ± standard deviation) according to the manufacturer's guidelines. In this system, once the tension is set in the tensioning device, the excursion of the spring is locked. The advantage of this system is that the grafts are held securely in the tensioning system, allowing the graft to be cycled in line with the tunnel to remove the creep out of the construct. Analysis of the validity yielded an intraclass correlation coefficient of 0.619 for the AM graft and 0.827 for the PL graft.

Postoperative management

Weight bearing was started the day after surgery using two crutches. Full weight-bearing walk was encouraged with two crutches as long as the joint inflammation did not get worse. Knee range-of-motion exercise was started 3 days postoperatively. Adequate quadricep muscle contraction and more than 90° flexion were expected at 1 week postoperatively. Full recovery of knee motion was expected at 3 months postoperatively. Knee muscle exercise was encouraged at around 6 weeks after surgery in the closed kinetic manner. Running exercise was started by jogging at 3 months postoperatively based on the knee muscle strength recovery and single leg squatting performance, followed by step-by-step progression. Athletic exercises related to the previous sports or desired sports activities were initiated with detailed instructions in each case. Full athletic activities were allowed at 6 months after surgery when specified athletic training had been accomplished with full recovery of knee and body strength.

Postoperative outcome analyses

The results at the final evaluation were evaluated based on the differences between the operated and uninjured limbs. Anterior laxity measurements by KT-1000 arthrometer (MEDmetric, San Diego, CA, USA), rotational instability evaluated by a pivot shift test, pre- and postoperative Tegner score, total score of the Lysholm knee scale (total Lysholm score), and maximum knee extension strength measurements by a Cybex machine (Lumex, Ronkonkoma, NY, USA) at 60°/s (knee extension strength) were statistically evaluated among the four groups. The age at surgery, gender, preoperative periods, rate of meniscus injuries, and the preoperative KT measurements under anaesthesia were also analysed. The meniscus injury was counted even when it was incomplete or healed under arthroscopic examination.

Femoral tunnel position analysis

A modified quadrant method[22] was used to calculate the femoral tunnel position with two-view radiographs at 3 months postoperative in all cases. The tunnel widening at this period would be negligible. Eleven cases where the femoral tunnel could not be clearly identified in postoperative radiographs were excluded for analysis. The height and depth of each femoral tunnel in flexed knee position were calculated.

Statistical analyses

Analysis of variance was used to statistically analyse the differences among the four groups in regards to age at surgery, body mass index, preoperative periods, KT measurements, Lysholm score, Tegner score, rotational instability evaluated by the pivot shift test, graft diameter, and knee extension strength. The femoral tunnel position was also statistically analysed in depth and height with analysis of variance. The Tukey test was used as a *post hoc* test. Chi-square test was used to evaluate gender differences and frequency of meniscus injuries. The significance was determined at $p < 0.05$. The statistical analyses were performed using SPSS (version 20; SPSS Inc., Chicago, IL, USA).

Results

Relationships between graft tension change pattern and femoral tunnel placement

A schematic drawing of the average femoral tunnel position measured by the modified quadrant method in every group is shown in Figure 1. The femoral tunnels of Groups 1 and 2 tended to be placed proximally, while those of Groups 3 and 4 were placed distally.

The height and depth of the femoral tunnel for the AM bundle and the PL bundle, calculated by the modified quadrant method, are shown in Table 2. Statistical analyses (Table 3) showed that the AM tunnel of Groups 1 and 2 (AM-OTT group) is placed in a significantly higher position than the other groups in flexed knee position. A statistically significant difference was not recognized in the femoral tunnel position of the PL bundle.

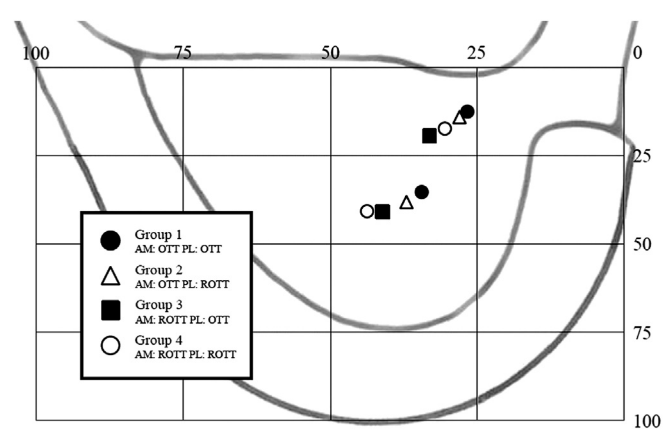

Figure 1. Schematic drawing of AM and PL femoral tunnel placement. Statistical analyses shows that the AM tunnel of Group 1 (●) and Group 2 (△) (AM-OTT group) is placed in a significantly higher position than in Group 3 (■) and Group 4 (○) in the flexion position. AM = anteromedial; OTT = over-the-top; PL = posterolateral; ROTT = reverse over-the-top.

Table 2
Measurements of height and depth of femoral tunnels by a modified quadrant method.[a]

	Group 1	Group 2	Group 3	Group 4
AM depth (%)*	26.8 ± 4.0	28.1 ± 3.0	33.2 ± 2.9	30.6 ± 3.0
AM height (%)*	12.6 ± 3.8	14.2 ± 4.4	19.5 ± 3.3	17.4 ± 3.7
PL depth (%)	34.5 ± 1.9	37.1 ± 1.6	41.2 ± 3.2	43.8 ± 1.9
PL height (%)*	35.4 ± 2.7	38.2 ± 2.8	41.0 ± 2.5	40.8 ± 2.8

* Analysis of variance was used to statistically analyse the differences among the four groups. The significance was determined at $p < 0.05$.
AM = anteromedial; PL = posterolateral.
[a] All parameters were calculated by the modified quadrant method. If the tunnel placement is higher or shallower in knee flexion position, the parameter will be smaller.

Table 3
Statistical analyses of the intergroup comparison of femoral tunnel placement.[a]

p		AM depth	AM height	PL depth	PL height
Group 1	vs. 2	0.582	0.187	0.336	0.128
	vs. 3	<0.05*	<0.01*	<0.01*	<0.01*
	vs. 4	0.094	<0.01*	<0.01*	<0.01*
Group 2	vs. 3	<0.05*	<0.01*	0.173	0.165
	vs. 4	0.245	<0.05*	<0.05*	0.192
Group 3	vs. 4	0.226	0.262	0.311	0.905

* $p < 0.05$.
AM = anteromedial; PL = posterolateral.
[a] Analysed using analysis of variance and Tukey test as *post hoc* test.

Relationships between graft tension change pattern and clinical results

There were no significant differences in patients' background among the four groups (Table 4). At the final follow-up, there were no significant differences in the maximum knee extension strength measurements (Figure 2A), the total Lysholm score (Figure 2B), and the change of Tegner score (Figure 2C). However, Group 2 showed a significant difference compared with Group 3 in KT measurements. Moreover, the positive rate of the pivot shift test was significantly more frequent in Group 2 than Group 4 (Table 5).

Discussion

The most important findings of the current cohort study were that the higher femoral tunnel placement of the AM bundle in knee flexion resulted in greater anterior and rotational instability, even though it was based on the anatomic tunnel creation concept in a DB ACLR. The other important finding was that poorer clinical outcome was predicted for the fixed graft tension change pattern reversed from the AM and PL bundles of the native ACL.[4]

The anatomic DB reconstruction is still vital as an attractive procedure for ACL injuries, and several methods and techniques have been reported. Nevertheless, the failure rate after ACLR has not been sufficiently improved. Postoperative failure could be due to technical errors, particularly inappropriate placement of femoral tunnels. In this study, the femoral tunnel placement was assessed by the modified quadrant method, which is simple and minimally invasive and has no inferiority to that of a three-dimensional computed tomography.[22] By matching the tension change pattern with the femoral tunnel position using the current method, a significant relationship was found between the tension change pattern combination at fixation and the postoperative outcome.

The femoral tunnel placement of the current study was varied and higher than those of previous studies which reported on anatomic DB reconstruction according to the original concept of Yasuda et al.[1] Moreover, our femoral tunnel aperture position was slightly shallower than the anatomic centre of previous studies.[22–24] We concluded that the first reason for this was the variety of femoral footprint and the lateral intercondylar ridge in each individual. Also, there were many variations in the shape of the lateral wall of the lateral femoral condyle. The second reason was that we created the femoral tunnels using a transtibial approach in this case series, therefore the aperture position of the femoral tunnel was influenced by the angle and direction of the tibial tunnel. However, the gap from the anatomic centre was around 1–3 mm, and it could be considered that the femoral tunnel aperture position was almost anatomic on the footprint.

Table 4
Patients' background among the four groups.[a]

	Group 1	Group 2	Group 3	Group 4	*p*
Average age (y)	25.1 (14–46)	21.3 (15–51)	24.9 (14–48)	24.5 (15–41)	0.64
Male/Female	14/15	7/7	7/12	10/12	0.85
Body mass index (kg/m^2)	22.5 ± 2.6	21.2 ± 3.4	21.0 ± 2.5	22.8 ± 4.1	0.18
Preoperative months	8.6 (1–39)	13.7 (1–120)	22.5 (1–240)	7.8 (1–27)	0.39
Preoperative Lysholm score	77.5 ± 14.3	77.5 ± 16.8	85.7 ± 7.9	77.8 ± 14.5	0.17
KT side-to-side difference	7.7 (3.0–14.5)	6.8 (3.5–11.5)	6.2 (2.0–13.5)	6.4 (2.0–10.0)	0.23
Positive rate of pivot shift test	96.6	100.0	94.7	95.5	0.86
Graft diameter AMB (mm)	5.9 ± 0.5	5.9 ± 0.6	5.6 ± 0.5	5.8 ± 0.7	0.36
Graft diameter PLB (mm)	5.4 ± 0.5	5.3 ± 0.6	5.1 ± 0.6	5.3 ± 0.6	0.36
MM injury	85.7	93.3	84.2	68.2	0.23
LM injury	75.0	93.3	73.7	72.7	0.47

Data are presented as *n* (range), mean ± standard deviation, or %.
* $p < 0.05$.
AMB = anteromedial bundle; LM = lateral meniscus; MM = medial meniscus; PLB = posterolateral bundle.
[a] Analysed using analysis of variance excluding gender and meniscus injury rate. Gender and meniscus injury rate were statistically analysed by Chi-square test.

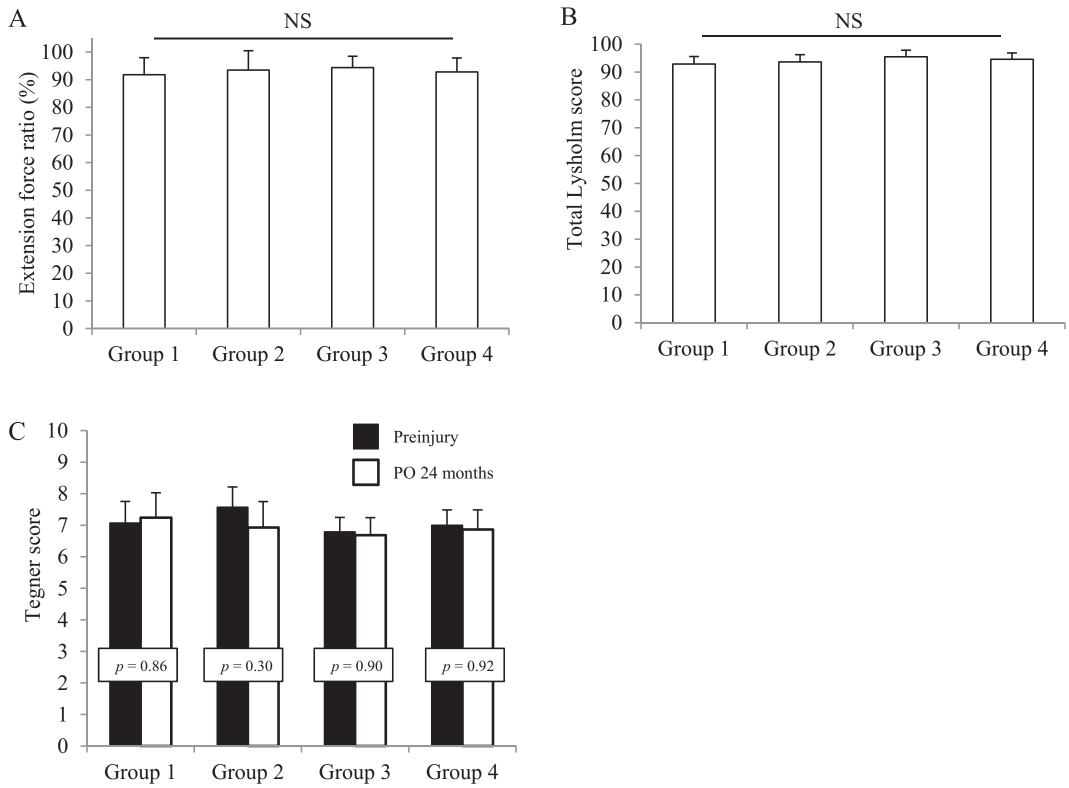

Figure 2. Comparison of clinical results at the final evaluation among the four groups. (A) The side-by-side comparison of maximum extension strength is measured by a Cybex machine (Lumex, Ronkonkoma, NY, USA); (B) Lysholm score; (C) Tegner activity score. The black bar indicates preinjury score and the white bar indicates the score at 24 months postoperative. NS = not significant; PO = postoperative.

Table 5
Statistical analyses of KT measurement and positive rate of pivot shift test at postoperative 24 months.[a]

	Group 1	Group 2	Group 3	Group 4	p
KT side-to-side difference (mm)	1.2 ± 0.3	2.1 ± 0.3	0.7 ± 0.3*	1.0 ± 0.3	0.022
Positive rate of pivot shift test	17.9	42.9	15.8	13.6*	0.063

Data are presented as mean ± standard deviation or %.
* $p < 0.05$; significant difference in comparison of Group 2.
[a] Analysed using analysis of variance and Tukey test as *post hoc* test.

In this study, comparison of the graft tension change pattern and the clinical results at the final clinical evaluation showed that Group 2 performed most poorly in KT measurements and the positive rate of pivot shift test. Groups 3 and 4 showed significantly better results among the four groups (Table 5). The results of the intergroup comparison of the femoral tunnel position showed that the femoral tunnels of the AM bundle in Groups 1 and 2 were significantly higher than in Groups 3 and 4 (Figure 1, Tables 2 and 3). Therefore, Group 3 or 4 show the recommended combination of graft tension change pattern. The results of the current study suggest that it is important to aim for the reproduction of the native physiological function of each AM bundle by ACLR. The remaining question is the relationship of physiological function and anatomic positioning of each AM graft and PL graft. Moreover, the current study was unable to indicate the appropriate femoral PL position that showed OTT graft tension change pattern constantly.

There were several limitations in this study. First, the data were analysed in a retrospective manner and the tension change pattern was evaluated by a standard probing technique without any objective method. However, all measurements were performed by the same surgeon and performed three times to minimize the intrarater variability. Analysis of the validity by comparing with the accurate graft tensioning system also yielded an intraclass correlation coefficient of 0.619 for the AM graft and 0.827 for the PL graft. Second, the graft was fixed with excessive tension as compared to the initial load. The graft loses its tension to some extent during the healing process after surgery. The changing tension during the process is important, but more detailed studies are necessary in the future to elucidate this important biologic process. Each position difference of the normal anatomy of the ACL has been poorly investigated based on the individual anatomic differences.

In conclusion, the current study suggests that reconstruction of the ACL with the reverse pattern of the natural AM bundles is least effective for knee stability recovery. In order to achieve better stability in DB ACLR, it is necessary to refrain from placing the femoral tunnel of the AM bundle high in knee flexion.

Conflicts of interest

The authors have no conflicts of interest relevant to this article.

Funding/support statement

No financial or material support of any kind was received for the work described in this article.

Acknowledgements

We would like to thank Ms Miyoko Ojima and Ms Aiko Yamada for the help of data collection.

References

1. Yasuda K, Kondo E, Ichiyama H, et al. Anatomic reconstruction of the anteromedial and posterolateral bundles of the anterior cruciate ligament using hamstring tendon grafts. *Arthroscopy*. 2004;20:1015−1025.
2. Desai N, Björnsson H, Musahl V, et al. Anatomic single- versus double-bundle ACL reconstruction: a meta-analysis. *Knee Surg Sports Traumatol Arthrosc*. 2014;22:1009−1023.
3. Xu M, Gao S, Zeng C, et al. Outcomes of anterior cruciate ligament reconstruction using single-bundle versus double-bundle technique: meta-analysis of 19 randomized controlled trials. *Arthroscopy*. 2013;29:357−365.
4. Amis AA, Dawkins GP. Functional anatomy of the anterior cruciate ligament. Fibre bundle actions related to ligament replacements and injuries. *J Bone Joint Surg Br*. 1991;73:260−267.
5. Yasuda K, Ichiyama H, Kondo E, Miyatake S, Inoue M, Tanabe Y. An in vivo biomechanical study on the tension-versus-knee flexion angle curves of 2 grafts in anatomic double-bundle anterior cruciate ligament reconstruction: effects of initial tension and internal tibial rotation. *Arthroscopy*. 2008;24:276−284.
6. Crawford SN, Waterman BR, Lubowitz JH. Long-term failure of anterior cruciate ligament reconstruction. *Arthroscopy*. 2013;29:1566−1571.
7. Kamien PM, Hydrick JM, Replogle WH, Go LT, Barrett GR. Age, graft size, and Tegner activity level as predictors of failure in anterior cruciate ligament reconstruction with hamstring autograft. *Am J Sports Med*. 2013;41:1808−1812.
8. Carson EW, Anisko EM, Restrepo C, Panariello RA, O'Brien SJ, Warren RF. Revision anterior cruciate ligament reconstruction: etiology of failures and clinical results. *J Knee Surg*. 2004;17:127−132.
9. Kamath GV, Redfern JC, Greis PE, Burks RT. Revision anterior cruciate ligament reconstruction. *Am J Sports Med*. 2011;39:199−217.
10. Sommer C, Friederich NF, Müller W. Improperly placed anterior cruciate ligament grafts: correlation between radiological parameters and clinical results. *Knee Surg Sports Traumatol Arthrosc*. 2000;8:207−213.
11. Muneta T, Yamamoto H, Sakai H, Ishibashi T, Furuya K. Relationship between changes in length and force in in vitro reconstructed anterior cruciate ligament. *Am J Sports Med*. 1993;21:299−304.
12. Zavras TD, Race A, Amis AA. The effect of femoral attachment location on anterior cruciate ligament reconstruction: graft tension patterns and restoration of normal anterior-posterior laxity patterns. *Knee Surg Sports Traumatol Arthrosc*. 2005;13:92−100.
13. Abebe ES, Kim JP, Utturkar GM, et al. The effect of femoral tunnel placement on ACL graft orientation and length during in vivo knee flexion. *J Biomech*. 2011;44:1914−1920.
14. Markolf KL, Hame S, Hunter DM, et al. Effects of femoral tunnel placement on knee laxity and forces in an anterior cruciate ligament graft. *J Orthop Res*. 2002;20:1016−1024.
15. Xu Y, Liu J, Kramer S, et al. Comparison of in situ forces and knee kinematics in anteromedial and high anteromedial bundle augmentation for partially ruptured anterior cruciate ligament. *Am J Sports Med*. 2011;39:272−278.
16. Muneta T, Koga H, Mochizuki T, et al. A prospective randomized study of 4-strand semitendinosus tendon anterior cruciate ligament reconstruction comparing single-bundle and double-bundle techniques. *Arthroscopy*. 2007;23:618−628.
17. Yamazaki J, Muneta T, Koga H, et al. Radiographic description of femoral tunnel placement expressed as intercondylar clock time in double-bundle anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2011;19:418−423.
18. Koga H, Muneta T, Yagishita K, et al. Effect of posterolateral bundle graft fixation angles on graft tension curves and load sharing in double-bundle anterior cruciate ligament reconstruction using a transtibial drilling technique. *Arthroscopy*. 2013;29:529−538.
19. Koga H, Muneta T, Yagishita K, Ju YJ, Sekiya I. The effect of graft fixation angles on anteroposterior and rotational knee laxity in double-bundle anterior cruciate ligament reconstruction: evaluation using computerized navigation. *Am J Sports Med*. 2012;40:615−623.
20. Koga H, Muneta T, Yagishita K, et al. Evaluation of a behind-remnant approach for femoral tunnel creation in remnant-preserving double-bundle anterior cruciate ligament reconstruction - comparison with a standard approach. *Knee*. 2015;22:249−255.
21. Koga H, Muneta T, Yagishita K, et al. Effect of femoral tunnel position on graft tension curves and knee stability in anatomic double-bundle anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2014;22:2811−2820.
22. Horie M, Muneta T, Yamazaki J, et al. A modified quadrant method for describing the femoral tunnel aperture positions in ACL reconstruction using two-view plain radiographs. *Knee Surg Sports Traumatol Arthrosc*. 2015;23:981−985.
23. Tsukada H, Ishibashi Y, Tsuda E, Fukuda A, Toh S. Anatomical analysis of the anterior cruciate ligament femoral and tibial footprints. *J Orthop Sci*. 2008;13:122−129.
24. Yamamoto Y, Hsu WH, Woo SL, Van Scyoc AH, Takakura Y, Debski RE. Knee stability and graft function after anterior cruciate ligament reconstruction: a comparison of a lateral and an anatomical femoral tunnel placement. *Am J Sports Med*. 2004;32:1825−1832.