Original Article

Autograft-Only and Allograft-Augmented Hamstring Autograft Have Similar Failure Rates After Anterior Cruciate Ligament Reconstruction

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Purpose: To compare failure rates and clinical outcomes after hamstring autograft anterior cruciate ligament (ACL) reconstruction with and without allograft augmentation by a single surgeon otherwise using the same surgical technique. **Methods:** This was a retrospective analysis with prospectively collected patient-reported outcomes of primary hamstring autograft ACL reconstruction with and without allograft augmentation performed in a military population by a single surgeon. The primary outcome measure was graft failure, defined as graft rupture confirmed by use of magnetic resonance imaging scans and/or revision ACL reconstruction. The secondary outcome measure was the postoperative Knee Injury and Osteoarthritis Outcome Score. **Results:** This study included 112 patients with a mean follow-up period of 65.3 months. In patients with a graft diameter of 8 mm or greater, there was no difference in failure rates (9.4% for autograft only vs 6.3% for hybrid, $P = .59$). There was a higher failure rate in patients in the autograft-only group with a graft diameter of less than 8 mm (29.4%) when compared with the hybrid graft group (6.3%, $P = .008$). There were no hybrid grafts less than 8 mm in diameter. There were no differences in the Knee Injury and Osteoarthritis Outcome Score between groups as long as the graft diameter was 8 mm or greater. **Conclusions:** In patients undergoing hamstring ACL reconstruction, there was no significant difference in graft failure rates or outcome scores between autograft only and autograft with allograft augmentation as long as grafts were 8 mm or greater. High failure rates were seen when the graft diameter was less than 8 mm. **Level of Evidence:** Level III, retrospective cohort study.

The anterior cruciate ligament (ACL) is one of the most commonly injured ligaments in the body, with an estimated 100,000 to 200,000 ACL reconstructions performed each year in the United States.[1,2] Revision for failed ACL reconstruction has a lower rate and increased time to return to sport compared with primary ACL reconstruction.[3] Consequently, it is important to maximize the potential for a full return to sport and minimize the risk of failure when performing ACL reconstruction.

Graft diameter is a modifiable variable the surgeon can control to lower the risk of graft failure in primary ACL reconstruction.[4] However, in hamstring ACL reconstruction, graft diameter can be unpredictable and small-diameter grafts are frequently encountered. Magnussen et al.[4] performed a retrospective analysis of 256 patients after primary ACL reconstruction with hamstring autograft and found revision rates of 1.7% for grafts greater than 8 mm, 6.5% for grafts of 7.5 to 8 mm, and 13.6% for grafts of 7 mm or less. Larger graft diameter has also been associated with improved patient-reported outcomes.[5] In a retrospective analysis of 263 patients in the Multicenter Orthopaedic Outcomes Network (MOON) cohort, the failure rate was 0% for grafts greater than 8 mm and 7% for grafts of 8 mm or less.[5] Additionally, the authors found a 3-point improvement in the International Knee Documentation Committee (IKDC) score and Knee Injury and Osteoarthritis Outcome Score (KOOS) for every millimeter increase in graft diameter.[5]

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To address small graft diameter, reduce the risk of graft failure, and improve patient outcomes, surgeons have attempted to augment small-diameter hamstring autograft with allograft. The safety and efficacy of allograft augmentation have previously been studied, with conflicting and heterogeneous results.[6,7] The purpose of this study was to compare failure rates and clinical outcomes after hamstring autograft ACL reconstruction with and without allograft augmentation by a single surgeon otherwise using the same surgical technique. We hypothesized that there would be no difference in failure rates between the 2 groups.

Methods

We performed a retrospective analysis of patients in a military population who underwent ACL reconstruction performed by a single surgeon (E.D.A.) from January 2007 through December 2017. A consort diagram is included in Figure 1. This period was selected because the surgeon began augmenting hamstring autografts less than 8 mm in diameter at the midpoint of the study period after the results of Magnussen et al.[4] were published in 2012. KOOS values were prospectively collected from these patients via telephone follow-up. Primary hamstring autografts with and without allograft augmentation were included in this study. Additional inclusion criteria were at least 12 months of follow-up and age of 18 years or greater. All other graft types were excluded. Patients were excluded from the study if they had inflammatory arthritis or underwent any of the following concomitant procedures: revision ACL reconstruction, tibial osteotomy, multiligamentous knee reconstruction, meniscal transplant, lateral extra-articular tenodesis, or cartilage restoration.

The primary outcome was ACL graft failure. Failure was defined as graft rupture confirmed on magnetic resonance imaging (MRI) and/or the need for revision ACL reconstruction. Secondary outcomes include the previously validated KOOS and return to the operating room (OR) for other procedures such as chondroplasty and meniscal procedures.[8,9] A retrospective analysis evaluating graft failure and return to the OR was performed via electronic chart review of patient clinical notes, as well as radiology reports, and review of advanced imaging. Data on surgical technique, graft type, implant, and graft diameter were collected from operative reports. Prospectively collected postoperative patient-reported outcome scores (ie, KOOS) were collected via telephone. Patients were also asked whether they had an MRI scan showing graft failure or underwent revision ACL reconstruction.

The KOOS includes 42 questions graded in 5 subscales: pain, symptoms, activities of daily living (ADL), function in sport, and quality of life (QoL).[8,9] The scores are graded from 0 to 100, with 0 being the worst and 100 being the best. Patient acceptable symptomatic state (PASS) thresholds for the KOOS were based on previously established values of 89 for the KOOS pain subscale, 57 for the KOOS symptoms subscale, 100 for the KOOS ADL subscale, 75 for the KOOS sport subscale, and 63 for the KOOS QoL subscale.[10] Minimal clinically important difference (MCID) thresholds for the KOOS were based on previously established values of 8 for the KOOS pain subscale, 1 for the KOOS symptoms subscale, 8 for the KOOS ADL subscale, 22 for the KOOS sport subscale, and 27 for the KOOS QoL subscale.[11,12] These results were compared via χ^2 analysis. The groups were then stratified by graft diameter into those measuring 8 mm or greater and those measuring less than 8 mm, and subgroup analysis was performed.

All patients were counseled preoperatively regarding graft options. Various graft options were discussed, and all patients in this study chose hamstring autograft with possible allograft augmentation offered if the procedure was performed after 2012 and the initial graft was smaller than 8 mm.

Surgical Technique

All procedures were performed with the patient positioned supine in the hemi-lithotomy position. The procedure began with an examination under anesthesia and diagnostic arthroscopy to confirm that the knee was ACL deficient. Dissection was carried down to the pes tendon insertion on the proximal medial tibia. The tendons were dissected from distal to proximal, with care taken to maintain the maximum length of the tendons. Once the distal insertions of the gracilis and semitendinosus were released, they were whipstitched and harvested. After harvesting of the semitendinosus and gracilis tendons, the hamstring autograft was doubled over a looped suspensory button (TightRope RT; Arthrex, Naples, FL) and measured with a sizing block. For grafts measuring less than 8 mm in diameter, the graft was augmented with non-irradiated, washed gracilis or semitendinosus allograft (BioCleanse; RTI Surgical, Alachua, FL) (Fig 2).

During graft augmentation, the allograft ends were whipstitched and the graft was looped over the TightRope RT button and sandwiched within the autograft tendons so that the autograft tendons would be in direct contact with the drilled tunnels, with a total of 6 strands exiting from the tibial tunnel (4 strands for an autograft only). Independent femoral and tibial tunnels were placed with a guide, initially with 2.4-mm guidewires, and tunnel location was assessed with intraoperative fluoroscopy. Once pins were in a satisfactory location, independent femoral and tibial tunnels were drilled. Grafts were fixed to the lateral femoral cortex using suspensory fixation and fixed to the tibia using a biocomposite sleeve with associated interference screw

(Bio-Intrafix; Mitek, Raynham, MA). A 6.5-mm backup screw and washer were used as a post distal to the tibial tunnel if adequate insertional torque was not obtained with the tibial interference screw.

Postoperatively, all patients followed the same institutional physical therapy protocol. Weight bearing as tolerated was allowed with a hinged knee brace for approximately 6 weeks. At 6 weeks, patients were transitioned to an ACL sport brace. They engaged in immediate physical therapy for range of motion with progressive strengthening beginning at 6 weeks. A full return to activity occurred at approximately 9 to 12 months and was individualized based on functional testing. At all time points in the study analysis, the patients were assessed by the primary surgeon.

Statistical Analysis

A power analysis was performed to detect a 20% difference in graft failure rates between groups. To achieve 80% power in this study, 62 subjects would be required in each group. Descriptive statistics were determined and compared between groups. The 2-tailed t test was used to compare continuous data, whereas χ^2 analysis was used to compared categorical data. Univariate analysis was performed for all variables. Groups were stratified by graft diameter, and graft failure rates and clinical outcomes were assessed.

Results

We identified a total of 136 patients who underwent primary hamstring autograft ACL reconstruction performed by a single surgeon during the study period and met the inclusion criteria. Nine patients were excluded because they underwent revision ACL surgery. In addition, 15 patients were lost to follow-up (5 in autograft-only group [AOG] and 10 in hybrid graft group [HGG]), leaving 112 patients who comprised the study cohort (Fig 1). A total of 49 patients in the AOG and 63 patients in the HGG met the inclusion criteria. The characteristics of the 112 patients are shown in Table 1. This was predominantly a young male cohort, and the mean age was 29.0 years (range, 18-51 years), with no significant differences in age between groups ($P = .38$).

There was a statistically significant difference in graft diameter between the 2 groups (7.97 mm in AOG vs 8.66 mm in HGG, $P < .00001$) (Table 1). Graft failure was seen in 8 of 49 patients in the AOG (16.3%) versus 4 of 63 patients in the HGG (6.3%, $P = .09$) (Table 2).

The grafts in the AOG were then stratified into those measuring 8 mm or greater versus less than 8 mm in diameter. The average graft diameter in the AOG increased to 8.4 mm after stratification to only include grafts of 8 mm or greater in diameter. When comparing these 2 groups, we found that the AOG had a failure rate of 9.4% for grafts of 8 mm or greater. This failure rate was not significantly different from that in the HGG ($P = .59$) (Table 2). Grafts in the AOG measuring less than 8 mm had a significantly greater failure rate of 29.4% when compared with the HGG ($P = .008$). Table 1 provides data on the treatment of additional intra-articular pathology. In the AOG, 2 patients returned to the OR for recurrent meniscal tears. There were no infections in the AOG. In the HGG, 5 patients returned to the OR for recurrent meniscal tears; 3, for manipulation under anesthesia; and 1, for infection.

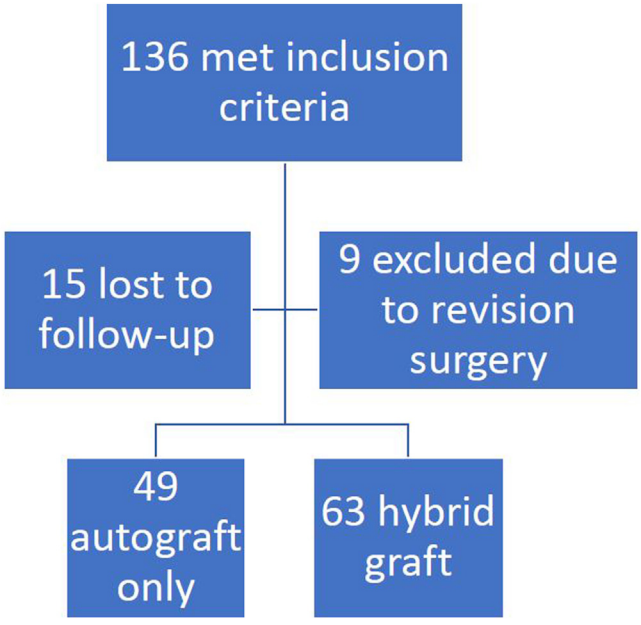

Fig 1. CONSORT (Consolidated Standards of Reporting Trials) diagram.

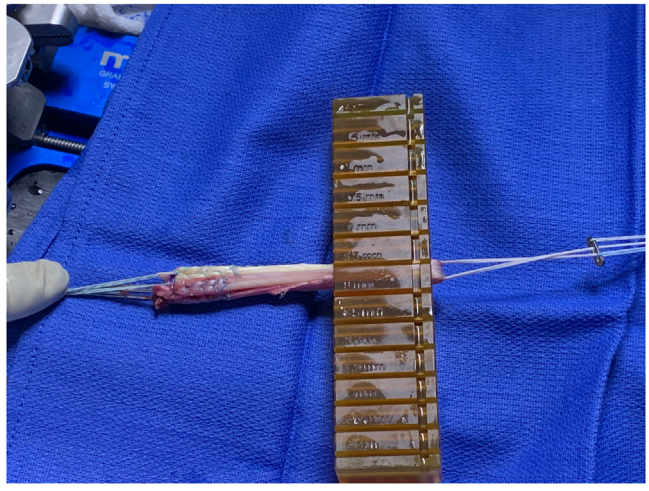

Fig 2. Sizing of hamstring autograft augmented with allograft.

Table 1. Patient Demographic Characteristics

	Autograft Only	Hybrid Graft	*P* Value
Mean age, yr	29.2 (range, 19-47; SD, 7.7)	28.8 (range, 19-51; SD, 7.7)	.38
Sex, n (%)			
Male	42 of 49 (86)	53 of 63 (84)	.52
Female	7 of 49 (14)	10 of 63 (16)	.52
Mean graft diameter, mm	7.97 (range, 6.5-10; SD, 0.8)	8.66 (range, 8-9.5; SD, 0.5)	<.00001*
Meniscal debridement, n (%)	15 of 49 (30.6)	25 of 63 (39.7)	.21
Meniscal repair, n (%)	13 of 49 (27)	18 of 63 (28.6)	.43
Chondroplasty, n (%)	3 of 49 (6.1)	4 of 63 (6.3)	.96

SD, standard deviation.
*Statistically significant.

There was 1 patient with deep venous thrombosis and pulmonary embolism in the AOG.

The mean length of follow-up was 73.7 months in the AOG and 58.8 months in the HGG ($P = .029$). Overall KOOS values and all KOOS subcategory scores were similar between groups, with no significant differences (Table 3). The overall response rate for prospectively collected outcome scores was 74%.

Discussion

The primary findings of this study are that in young patients undergoing hamstring ACL reconstruction with a graft diameter of 8 mm or greater, there was no significant difference in failure rates between autograft only and hybrid graft. There was a high failure rate (29.4%) in patients in the AOG with a graft diameter less than 8 mm, consistent with previously reported failure rates in patients with small-diameter hamstring autografts.[4] There were no differences in mean KOOS values between the groups among patients with a graft diameter of 8 mm or greater. This study is unique because the surgical procedures were performed by a single senior surgeon, in the final 10 years of practice, using the same surgical technique in both cohorts, with the exception of the use of allograft augmentation in the small-diameter hamstring group.

Previous studies have shown an increased risk of ACL graft failure when using allograft alone.[13] A prospective randomized controlled trial with 10-year follow-up showed a 26.5% graft failure rate with tibialis posterior allograft versus an 8.3% failure rate with hamstring autograft alone.[13] There is also concern for an increased risk of graft failure in adolescents with the use of allograft augmentation. A retrospective analysis showed a 30% ACL graft failure rate when irradiated allograft augmentation was used in adolescent hamstring ACL reconstruction (average diameter, 8.9 mm) versus 5% in the small-diameter autograft-only group (average diameter, 6.4 mm).[14] In this study, 3 surgeons performed the reconstructions, with a mix of transtibial drilling in some cases and independently drilled tunnels in others.[14] Transtibial drilling results in a more vertical femoral tunnel that may predispose the patient to early graft failure, confounding the results of the aforementioned study.[15] A retrospective analysis of 46 autograft versus 42 hybrid graft reconstructions in patients younger than 18 years showed a lower rate of graft failure in the large-diameter hybrid group (11.9%) versus the smaller-diameter autograft-only group (28.3%).[16] This study differs from the previous study because there was a single surgeon who used independently drilled femoral tunnels, which may have contributed to the different outcomes seen in its population.

The risk of graft failure is unclear when augmenting adult hamstring autograft with allograft. A systematic review of 6 studies and 544 patients found no significant difference in outcome scores, objective stability, failure rate, or reoperation rate.[17] Another systematic review of 12 studies and 471 patients with autograft only, irradiated hybrid graft, and non-irradiated hybrid graft showed inconsistent outcomes between the 3 groups, and the authors could not make any recommendations based on their review.[18] In a retrospective study of 29 hybrid grafts that matched these patients with patients who received autograft only, the authors noted a failure rate of 13.8% in the hybrid group versus 3.4% in the autograft-only group, with worse Lysholm and International Knee Documentation Committee (IKDC) scores in the hybrid group.[3] Limitations in their study include heterogeneity in femoral drilling technique (transtibial and anteromedial portal drilling), femoral graft fixation (interference screw in 50% and

Table 2. Graft Failure Rates Compared With Hybrid Graft Group

	Comparison of All Graft Sizes		
	Failure		
	n	%	*P* Value vs Hybrid Graft
All patients	12 of 112	10.7	
Hybrid graft	4 of 63	6.3	
Autograft only			
All sizes	8 of 49	16.3	.09
Diameter ≥ 8 mm	3 of 32	9.4	.59
Diameter < 8 mm	5 of 17	29.4	.008

Table 3. KOOS Comparison Between Patients Who Received Autograft Only With Graft Diameter of 8 mm or Greater and Patients Who Received Hybrid Grafts

	KOOS					
	Overall	Symptoms	Pain	ADL	Sport	QoL
Autograft only with diameter ≥ 8 mm	77.2	81	83.3	89.8	65	65.8
Hybrid	79.4	80	86.2	93.5	70.3	66.6
P value	.64	.84	.48	.30	.4	.91

ADL, activities of daily living; KOOS, Knee Injury and Osteoarthritis Outcome Score; QoL, quality of life.

suspensory button in 50%), and use of irradiated allograft. The higher risk of failure with irradiated allograft has been well described. In a retrospective analysis, 29 patients with autograft only were compared with 28 patients with irradiated hybrid graft and the failure rate was 3.4% in the autograft-only group versus 14.3% in the group with irradiated hybrid graft.[19] Additionally, the patients who received irradiated hybrid graft in this study had greater side-to-side differences on KT-1000 testing (MEDmetric, San Diego, CA), worse outcome scores, and a higher incidence of postoperative pivot shift than those who received autograft only.[19]

Once Magnussen et al.[4] established the risk of graft failure for grafts less than 8 mm in diameter, the senior surgeon changed his practice and began augmenting all hamstring grafts less than 8 mm in diameter. The only surgeon-controlled variable that differs between the groups in this study was the addition of allograft if the graft diameter was less than 8 mm.

Once this patient population was controlled for graft size, there was no difference in failure rates or patient-reported outcomes in either group. There was a much higher rate of failure for grafts measuring less than 8 mm in diameter. These findings are in concordance with a similar retrospective analysis that reviewed 59 hybrid ACL reconstructions and 80 autograft-only reconstructions, with no significant difference noted between groups (failure rate of 11.9% in hybrid group vs 18% in autograft-only group).[7] This study by Rao et al.[7] differs from our study because there were 31 different surgeons using various techniques for graft preparation and fixation in their study, introducing potential confounding variables.

The primary strength of this study is controlling for confounding variables such as varying surgical technique, allograft sterilization technique, and implants, as well as differences in surgeon experience. Analyzing results from an experienced single surgeon using a single technique provides valuable information given the conflicting results of previously published studies with more heterogeneous techniques.

Limitations

There are several limitations to this study, including its retrospective nature and military population, which may not be generalizable to the civilian population because of the physical demands required of these patients by their jobs. ACL injuries and reconstructions occur more frequently in female patients. Owing to the predominantly male population in the military, most of the patients in this study were men, and the results may not be completely generalizable to the standard population. This study had inadequate power because only 49 patients were included in the AOG when 62 were required for adequate power.

There was a significant difference in time to follow-up between groups. This is because of a change in practice by the surgeon in 2012, when Magnussen et al.[4] showed an increased risk of graft failure in small-diameter grafts. The surgeon began augmenting ACL grafts at that time, and consequently, the patients who received hybrid grafts likely underwent their surgical procedures more recently than those who underwent hamstring autograft—only reconstructions. With an average follow-up period of 4.9 years in the HGG and 6.1 years in the AOG, it is unlikely that this difference is clinically significant because most failures happen within the first 2 years after ACL reconstruction.[20] Finally, postoperative screening MRI scans were not completed, and we are unable to identify asymptomatic graft failures in this population.

Conclusions

In patients undergoing hamstring ACL reconstruction, there was no significant difference in graft failure rates or outcome scores between autograft only and autograft with allograft augmentation as long as grafts were 8 mm or greater. High failure rates were seen when the graft diameter was less than 8 mm.

References

1. Kaeding CC, Léger-St-Jean B, Magnussen RA. Epidemiology and diagnosis of anterior cruciate ligament injuries. *Clin Sports Med* 2017;36:1-8.
2. Mall NA, Chalmers PN, Moric M, et al. Incidence and trends of anterior cruciate ligament reconstruction in the United States. *Am J Sports Med* 2014;42:2363-2370.
3. Mohan R, Webster KE, Johnson NR, Stuart MJ, Hewett TE, Krych AJ. Clinical outcomes in revision anterior cruciate ligament reconstruction: A meta-analysis. *Arthroscopy* 2018;34:289-300.

4. Magnussen RA, Lawrence JTR, West RL, Toth AP, Taylor DC, Garrett WE. Graft size and patient age are predictors of early revision after anterior cruciate ligament reconstruction with hamstring autograft. *Arthroscopy* 2012;28:526-531.
5. Mariscalco MW, Flanigan DC, Mitchell J, et al. The influence of hamstring autograft size on patient-reported outcomes and risk of revision after anterior cruciate ligament reconstruction: A Multicenter Orthopaedic Outcomes Network (MOON) cohort study. *Arthroscopy* 2013;29:1948-1953.
6. Burrus MT, Werner BC, Crow AJ, et al. Increased failure rates after anterior cruciate ligament reconstruction with soft-tissue autograft-allograft hybrid grafts. *Arthroscopy* 2015;31:2342-2351.
7. Rao AJ, Macknet DM, Stuhlman CR, et al. Allograft augmentation of hamstring autograft in anterior cruciate ligament reconstruction results in equivalent outcomes to autograft alone. *Arthroscopy* 2021;37:173-182.e2.
8. Roos EM, Lohmander LS. The Knee injury and Osteoarthritis Outcome Score (KOOS): From joint injury to osteoarthritis. *Health Qual Life Outcomes* 2003;1:64.
9. Roos EM, Toksvig-Larsen S. Knee injury and Osteoarthritis Outcome Score (KOOS)—Validation and comparison to the WOMAC in total knee replacement. *Health Qual Life Outcomes* 2003;1:17.
10. Muller B, Yabroudi MA, Lynch A, et al. Defining thresholds for the patient acceptable symptom state for the IKDC subjective knee form and KOOS for patients who underwent ACL reconstruction. *Am J Sports Med* 2016;44:2820-2826.
11. Ingelsrud LH, Terwee CB, Terluin B, et al. Meaningful change scores in the Knee Injury and Osteoarthritis Outcome Score in patients undergoing anterior cruciate ligament reconstruction. *Am J Sports Med* 2018;46:1120-1128.
12. Harris JD, Brand JC, Cote MP, Faucett SC, Dhawan A. Research pearls: The significance of statistics and perils of pooling. Part 1: Clinical versus statistical significance. *Arthroscopy* 2017;33:1102-1112.
13. Bottoni CR, Smith EL, Shaha J, et al. Autograft versus 299 allograft anterior cruciate ligament reconstruction: A prospective, randomized clinical study with a minimum 10-year follow-up. *Am J Sports Med* 2015;43:2501-2509.
14. Pennock AT, Ho B, Parvanta K, et al. Does allograft augmentation of small-diameter hamstring autograft ACL grafts reduce the incidence of graft retear? *Am J Sports Med* 2017;45:334-338.
15. Abebe ES, Moorman CT III, Dziedzic TS, et al. Femoral tunnel placement during anterior cruciate ligament reconstruction: an in vivo imaging analysis comparing transtibial and 2-incision tibial tunnel-independent techniques. *Am J Sports Med* 2009;37:1904-1911.
16. Jacobs CA, Burnham JM, Makhni E, Malempati CS, Swart E, Johnson DL. Allograft augmentation of hamstring autograft for younger patients undergoing anterior cruciate ligament reconstruction. *Am J Sports Med* 2017;45:892-899.
17. Sochacki KR, McCulloch PC, Lintner DM, Harris JD. Hamstring autograft versus hybrid graft in anterior cruciate ligament reconstruction: A systematic review of comparative studies. *Arthroscopy* 2019;35:1905-1913.
18. Belk JW, Kraeutler MJ, Houck DA, Smith JR, McCarty EC. Comparing hamstring autograft with hybrid graft for anterior cruciate ligament reconstruction: A systematic review. *Arthroscopy* 2020;36:1189-1201.
19. Wang H-D, Gao S-J, Zhang Y-Z. Comparison of clinical outcomes after anterior cruciate ligament reconstruction using a hybrid graft versus a hamstring autograft. *Arthroscopy* 2018;34:1508-1516.
20. Sanders TL, Pareek A, Hewett TE, et al. Long-term rate of graft failure after ACL reconstruction: A geographic population cohort analysis. *Knee Surg Sports Traumatol Arthrosc* 2017;25:222-228.